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Increasing Capacity at Art Clinic by Reducing Variation

Master's thesis in Quality and Operations Management

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SUMMARY

This study investigates the current capacity and limiting factors at the knee and hip replacement surgery process at Art Clinic, with the aim of identifying bottlenecks and proposing improvements to increase surgical throughput. Using a mixed method approach, quantitative data analysis is combined with qualitative observations and interviews.

The clinic currently performs eight surgeries per day, with two primary bottlenecks identified: the operating room and the sterile processing room. Operating room inefficiencies stem from high variation in surgical duration, longer setup times for hip replacements and idle time caused by scheduling misalignment. The sterile processing room is limited by the capacity of the autoclaves, limiting the number of knee surgeries to six per day due to the number of instruments. In addition, the postoperative ward was identified as a potential limiting factor depending on daily demand and bed availability

To address these issues, the study recommends: (1) Reducing variation through subgroup analysis and improved planning, (2) Optimizing patient readiness to minimize idle time, (3) Enhancing learning and knowledge sharing, (4) Reducing the number of instruments and improving planning in the sterile processing room and (5) Reassessing the bed capacity in the PACU (post anesthesia care unit) due to an imbalance between the PACU and postoperative ward capacity.

Keywords: Capacity in Healthcare, Process Variation, Organizational Learning, DMAIC, Standardization, Bottleneck Analysis, Six Sigma

Table of Contents

Terms and Definitions

In this section, terms related to the hospital environment and the theoretical aspects of the thesis are explained.

Anesthesia Nurse – A nurse specialized in assisting with the administration of anesthesia and monitoring the patient's condition throughout the procedure.

Anesthesiologist – A doctor who administers anesthesia and monitors the patient's vital sign during surgery.

Assistant Nurse – A healthcare worker who supports nurses and helps with basic patient care.

Design Capacity – The maximum output a system is theoretically designed to achieve under ideal conditions, without accounting for variability or constraints.

Effective Capacity – The realistic capacity of a system, considering constraints such as staff availability, equipment, and scheduling insufficiencies.

Idle Time – Periods during which resources (e.g., operating rooms, staff) are not in use between scheduled surgeries, representing inefficiency and waste.

Intensive Care Unit Nurse (ICU Nurse) – A registered who provides specialized care for critically ill patients.

Joint Replacement Surgery – A procedure where a damaged joint (e.g. hip or knee) is replaced with an artificial implant.

Operating Room (OR) – A dedicated and sterile environment within a healthcare facility where surgical procedures are performed.

Postoperative Care Unit (PACU) – The recovery area where patients are monitored after surgery until the effects of anesthesia wears off and their vital signs stabilize.

Preoperative Unit – A room where patient is medically prepared for surgery before entering the operating room.

Scrub Nurse – A nurse who works directly with the surgeon in the sterile field, preparing instruments and assisting during surgical procedures.

Sterile Processing Room – The area where surgical instruments are cleaned, sterilized and prepared for reuse.

Sterile Processing Technician – A staff member responsible for cleaning, sterilizing, assembling and distributing surgical instruments and supplies.

Surgical Coordinator – A staff member who schedules surgeries and coordinates the use of operating rooms and personnel.

Surgical Duration – The total time from the initial incision to the final suture in a surgical procedure.

Turnover Time – The time between the end of one surgery and the start of the next, including cleaning and preparation.

1. Introduction

This section introduces the research topic by providing background information about the organization and relevance of the study. Furthermore, the purpose of the study is outlined, along with the research questions and delimitations.

1.1 Background

During the last 60 years, the total number of hip- and knee replacement surgeries has increased significantly, and the demand increases steadily, as illustrated in figure 1 (Rolfson et al., 2024).

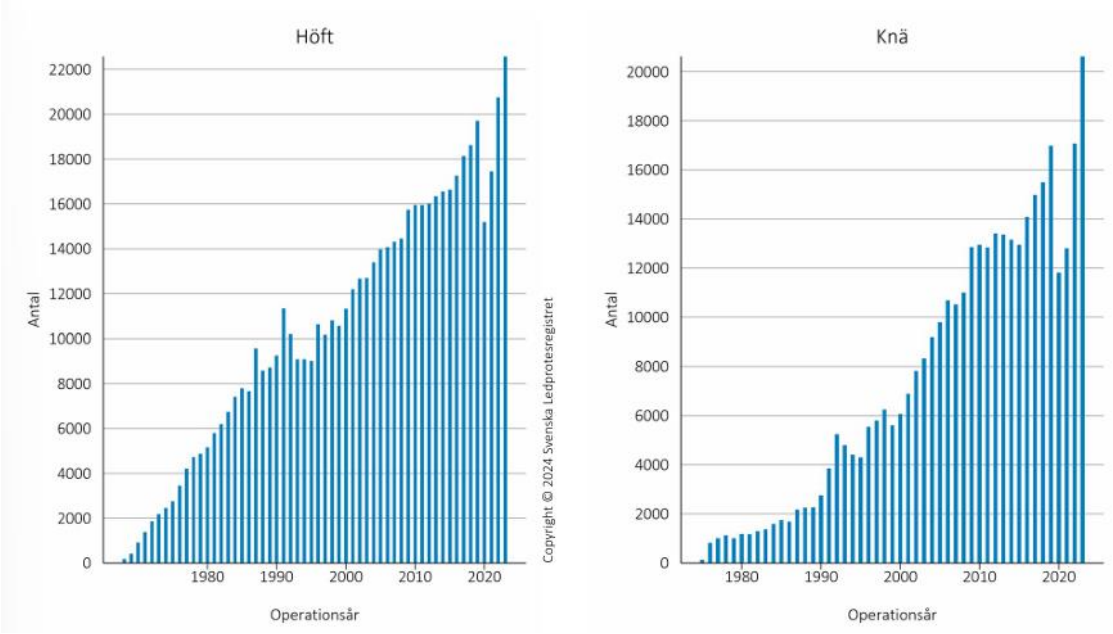


Figure 1: Number of hip (left) and knee (right) replacement surgeries performed in Sweden between 1968-2023. Y-axis: number of surgeries; X-axis: year. (Rolfson et al., 2024). Reprinted with permission.

The number of surgeries performed in 2023 increased by 20% compared to the benchmarking period during the pandemic, a time when all non-urgent procedures were temporarily put on hold (Rolfson et al., 2024). Despite the growing number of surgeries performed nationwide, demand remains high, leading to long waiting times for prosthesis procedures. In Sweden, there is a healthcare guarantee that grants patients the right to surgery or other medical intervention within 90 days of an established diagnosis (Sveriges Kommuner och Regioner [SKR], 2025). However, due to the demand the waiting times vary across regions, and some orthopedic surgeries exceed the healthcare guarantee (Vårdföretagarna, 2024).

In March 2024, 16% of all patients seeking orthopedic care waited longer than 90 days. The largest number of these patients were in the Västra Götaland Region, where 2600 people were on the waiting list for surgery. To manage the increasing demand, patients are distributed among various healthcare providers, with a large proportion now referred to private healthcare units (Rolfson et al., 2024). One of these units is Art Clinic (Aesthetic Reconstructive Treatments Clinic) in Gothenburg.

Art Clinic was founded in 1992 and opened its first clinic in Gothenburg in 1999, specializing in plastic surgery, ENT (ear, nose, and throat), vascular surgery, and general surgery (Art Clinic, 2025). The strategy to differentiate itself from other market players was to create a clinic where patient care and well-being were the primary focus and at the same time hire staff with a strong customer service mindset. In 2022, Art Clinic was acquired by the Aleris group, which also operates specialized healthcare clinics in Denmark, Norway, and various locations across Sweden. Today, Art Clinic operates four major surgical units in Sweden, performing approximately 6000 surgeries annually. The Gothenburg clinic nowadays specializes in plastic surgery, spinal surgery, and orthopedics, including hip and knee replacement surgeries.

According to The Swedish Arthroplasty Register, a total of 27 726 hip prosthesis surgeries (including total and partial prosthesis) and 20 624 knee prosthesis surgeries were performed at hospitals across Sweden in 2023 (Rolfson et al., 2024). Out of these, Art Clinic Gothenburg handled 467 hip prosthesis surgeries and 353 knee prosthesis surgeries, overview seen in table 1.

Table 1: Number of knee and hip replacement surgeries performed at Art Clinic compared to the national total. Data received from the Swedish Hip and Knee Arthroplasty Registers (Rolfson et al., 2024).

	Art Clinic	Total
Knee Replacement	535	20 624
Hip Replacement	467	27 726

Given that Art Clinic was originally founded as a facility primarily performing minor surgeries, and that its operations have now expanded to accommodate a large proportion of referred orthopedic patients, it has become relevant to assess the current situation. With the rapid scale-up, various concerns naturally arise, therefore Art Clinic seeks to map the current state and

evaluate its future potential in meeting increasing patient demand, while remaining the quality of their services.

1.1 Purpose

The number of patients requiring joint replacement surgeries continues to rise, therefore it becomes essential to assess the operational capacity of clinics performing these surgeries to identify areas of improvement. This study aims to determine the current capacity at Art Clinic and map the existing workflow to identify bottlenecks and obstacles for increasing capacity. Based on the analysis, the study will propose recommendations to reduce the capacity constraints.

1.2 Research Questions

To fulfill and investigate the purpose described, this study will seek to answer two research questions, which are as follows:

- What is the current capacity in the joint replacement surgery flow and what factors limit its potential increase?
- What practical changes can be introduced to increase capacity?

1.3 Delimitations

The study is limited to knee and hip replacement procedures at Art Clinic in Gothenburg. Consequently, other surgeries performed at the clinic, including revision surgeries, are not included in the scope. The capacity analysis is limited to the processes spanning from the moment the patient is checked in until the patient is in the postoperative ward. Activities that do not occur on the day of the surgery are thus excluded from the capacity analysis. Identified bottlenecks are examined in detail, while processes not constraining capacity will be analyzed at a general level. The case study is conducted between January and June 2025, with data collection restricted to this period. Additionally, company data from January 2023 to December 2024 will be utilized for analysis. To support the study, a site visit to Aleris Orthopedics Nacka was conducted to provide a comparative perspective used for recommendations. The study emphasizes the design of a solution, and the implementation of the recommended

improvements are therefore outside the scope. Lastly, no suggestions regarding medical procedures will be presented.

2 Theoretical framework

In this section, the theoretical framework is presented. It provides a factual basis for the subjects of interest for the study. It contains information regarding processes, lean principles, standardization, improvements, SMED, capacity and learning organizations.

2.1 Processes

According to Holweg et al. (2018), a process is defined as a sequence of activities where an input, such as raw materials, labor, or tools, is transformed through processing into an output, such as a product or a service, with added value. Processes vary across industries, but they all share a clear structure and purpose. Holweg et al. (2018) categorizes service-producing processes into four groups based on the level of customization and workload: *professional service, service shop, service factory,* and *mass service.*

Professional service involves the highest level of customization and workload, as they are tailored to individual needs and provided by experts in the field. Service shops also offer a high degree of customization, but the workload is somewhat lower since parts of the work follow standardized procedures Holweg et al. (2018). The author uses hospital as an example of describing a typical service shop, where patients move between specialized departments that combine routine-based work with meeting patient-specific needs.

2.1.1 Process Variation and Statistical Quality Control

In all processes, there exists some form of variability, either inherent or natural, regardless of how well maintained the system is (Montgomery, 2013). The presence of variability often results from numerous unavoidable and aggregated effects and is entirely normal. It is the amount of variation in a system that determines the actual capability of a process; hence it is essential to understand it (Muralidharan, 2016). However, most organizations fall into the mistake of basing decisions on averages, increasing the risk of variations getting hidden. Using averages only captures a single value, whereas using variation as a foundation for decisions captures a wider range of potential outcomes (Savage & Markowitz, 2012).

According to Deming (1982), there are two types of variation that may arise in a process: *common cause* and *special cause* variation. Common cause variation stems from factors within the system itself and is sometimes referred to as natural variation, as it cannot be fully

eliminated and remains consistent over time (Deming, 1982). Special cause variation, on the other hand, arises from specific, identifiable disturbances and should be detected and addressed when it occurs. Montgomery (2013) explains that processes affected by special causes are considered unpredictable and unstable, while a process with only common cause variation is regarded as statistically stable. A process is said to be out of control when a significant portion of measured values fall outside the upper or the lower control limits (the highest and lowest acceptable variations), which are typically set around ± 3 standard deviations from the mean.

According to Balestracci (2015) it is important to be aware of the difference between common- and special cause variation since trying to change one or the other without the knowledge will only cause further problems. The most typical approach to variation is to treat all as special causes, when in fact variations are estimated to be 15% special causes and 85% common causes, as stated by Gitlow and Gitlow (1987). When a system is affected by common cause, it becomes difficult for the staff to work as the variation depends on uncontrollable factors, hence the management should be responsible. On the same topic, Balestracci (2015) explains that a system in its current state is designed to deliver the results it is currently producing and expecting improvement without intentional changes is inaccurate. Balestracci (2015) further elaborates that the individuals in the system are already occupied to their maximum and implies that wasteful work might be concealed within routine work.

Regardless of what is causing the variation, it is recommended for organizations to understand the variation in the system in order to improve their processes and quality (Muralidharan, 2016). The ideal tool for this purpose is to use control charts (Montgomery, 2013; Muralidharan, 2016). Control charts allow for monitoring variation over time, and by analyzing the information it is possible to predict the process capability of the system. Once the deviations have been identified, they can be used to improve the process. Montgomery (2013) emphasizes that the most critical step in the improvement effort is to identify the root cause of the problem, so that the real problem gets solved, subsequently the variation eliminated. With a similar view, Muralidharan (2016) highlights three approaches on fixing variation. The first method is to only focus on fixing the incident by immediately trying to make things right, however this is not sustainable in the long perspective. The second method includes trying to understand the process and thereafter fixing it to avoid repeating it. Lastly, the managers can adapt to a holistic

view and instead look at the entire system and try to find a deeper systematic issue that causes the incidents.

When using the last-mentioned approach, Muralidharan (2016) underscores the importance for managers to ask the right questions when examining the root cause. It is advised not to compare two departments with the intent of identifying differences as it may lead to confirmation bias, potentially hiding the underlying root cause. Instead, it is recommended to examine what concrete improvements the benchmarking department has made to achieve their results.

To manage variation in healthcare, Rosenbäck (2017) recommend identifying and understanding the variation by evaluating its size, how it impacts process outputs and defining the variations which are possible to reduce. Incoming variation to the process can be influenced by patient mix, and as hospitals are characterized by complex and interdependent processes, variation in one step becomes input for the next process, causing system wide unpredictability. Reducing variation in hospitals is not only important due to operational efficiency as it also impacts patient safety, care quality and the work environment. Symptoms of high variation in hospitals include difficulty planning, failure to meet capacity targets, lower flow and resource efficiency and a reduced ability to respond to changes. To reduce variation, strategies such as standardizing procedures, evening out incoming flow, production planning with deviation management, routines for implementing process change, and creating a small queue prior to demanding resources are recommended. Additionally, a structured method for identifying and reducing variation through data driven subgroup analysis is proposed by Rosenbäck (2017), involving evaluating measurement quality, calculating the spread in variation, histogram comparisons and iterative testing of group divisions. By implementing planning routines based on reduced and better understood variation, predictability is improved.

2.1.2 Bottlenecks

A bottleneck is defined as the slowest processes, which, due to its pace, affects the throughput rate in a sequence of other processes (Holweg et al., 2018). Following the logic of this reasoning, the slowest process determines the rate and the theoretical maximum output of the entire system. When trying to exceed that capacity, only excess inventory will be created, and the throughput time will remain the same. Bottlenecks appear in different forms, as described by Holweg et al. (2018), either stationary or shifting, both of which occur over time. In addition,

there are also bottlenecks caused by temporary operating problems or other disturbances, referred to as one-time occurrences.

Stationary bottlenecks are often visible in a system since they are critical to how the system functions (Holweg et al., 2018). If everything runs smoothly in that process, the flow continues as normal. However, if that process suffers disruptions or errors, it causes critical and immediate consequences for other parts of the system. Given their fragile position in a system, these bottlenecks require careful attention to prevent system failure. This can be done, for example, by scheduling all other processes around the downtime of that specific process, or by applying additional maintenance to minimize the risks of failure.

Shifting bottlenecks, as described by Holweg et al. (2018), are more complex, as they are less easily identified or anticipated. These bottlenecks arise, for instance, due to quality issues in the system, or in manufacturing systems, as a result of frequent changeovers between different product batches. Although shifting bottlenecks are more irregular, they still need to be identified and addressed, since they cause scheduling problems. This can be managed by, among other things, understanding the issue and reviewing the product mix accordingly.

2.1.3 Process Mapping

Process mapping is a common tool used to visualize and create an understanding of the work processes and activities in the current state (Holweg et al., 2018). The map contains 15-40 boxes that represent each activity in the chosen process and is considered to be the most efficient in terms of detailed level of the process described. Similarly, Damelio (2011) highlights that process mapping is not only useful for visualizing the workflows but also for focusing on what creates value for the customer, as the approach helps to identify value-creating and non-value creating activities. By creating a representative visual map, relationships between different work tasks also become clear, illustrating how functions and activities directly influence each other. These insights can later serve as a foundation for future process improvements.

Holweg et al. (2018) outlines three key guidelines for process mapping, namely: *go to gemba, capture the vital few,* and *stick to the mapping methodology.* Firstly, to create the most accurate representation of the current state, it is essential to personally observe and analyze the entire process rather than relying on secondhand information. Additionally, it is helpful to focus on

identifying the main stages and activities to compare the difference between planned activities and those that are actually carried out. All this ensures that the mapping reflects the actual process and norms rather than the perceived one or anomalies.

To showcase the different activities, different standardized symbols are used (Holweg et al., 2018). These symbols are circles, diamonds, triangles, rectangles and arrows. Circles are used to showcase a start or end point, diamonds demonstrate that a decision is being made, and triangles represent inventory or a waiting point. Rectangles signify activities or process steps, showcasing a specific action or task that occurs within the process. An arrow visualizes the direction of the flow, from start to finish. For services, a distinction can be made by actions that are facing the customer and those that do not. The process mapping can also be used to show the division of responsibilities, by making a distinction of actions that can be done autonomously and actions that depend on other parts of the process to begin.

2.2 Lean Principles

Lean production originates from the 1950's when Eiji Toyoda visited Ford's production plant to learn how to mass produce cars (Pascal, 2016). However, during the visit, he realized that their needs were different, and together with production expert Taiichi Ohno the Toyota Production System was developed. The production system focused on efficiency, waste reduction, flexibility and continuous improvements, which became the foundation for Lean Production (Nicholas, 2018). Even though the production system initially was developed for the use of the automotive industry, it is now widely applied across various industries.

2.2.1 Value adding time and waste

An essential part of Lean Production is the definition of valuable and non-valuable activities (Pascal, 2015). The concept of value adding activities in Lean Production is that a system should be composed of activities that add value to the output of the system and necessary non-value adding activities (Nicholas, 2018). Other activities which do not add value are considered waste, and these activities should be reduced and not improved. Valuable activities can be defined in several ways, and when it comes to human motions (Pascal, 2015) categories them into three categories: work, auxiliary work and muda. Auxiliary work leads to value adding activities, and work is the value adding activity that increases the value of the product. Muda is described as motions which do not affect the product and therefore does not create value.

Reducing muda is described as one of the basic theories of Lean Production and by reducing it, efficiency can be increased (Liker, 2004). There are eight sources of Muda, often referred to as the 7+1 wastes (Nicholas, 2018). The eight sources of waste are as follows:

1. Defects
2. Overproduction
3. Waiting
4. Transportation
5. Inventory
6. Motion
7. Excess processing
8. Non-utilized human talent

Defects are defined as products with a flaw and if not noticed during production, it can become costly (Nicholas, 2018). On the other hand, time and resources spent during production to correct flaws on products is additionally considered a waste. The argument for categorizing all these activities as waste is that they would not be needed if the product was accurately produced, and therefore all efforts spent on rework, disassembling, extra material costs and labor is all considered a muda.

Overproduction is described as the act of producing when there is no need for the product, either by producing it prior to having a demand or in larger quantities than demanded (Hänggi et al., 2022). Additionally, overproduction means using more material, staff, machines, and energy which in turn creates costs for the organization (Pascal, 2016). Furthermore, it creates other waste in the shape of motion, waiting, transportation, defects, and inventory (Nicholas, 2018). Overproducing can be used to create inventory or increase resource utilization; however, it is still considered a waste. By comparing production vs sales, overproduction can be identified.

There are several different acts of waiting in a process, waiting can occur due to a prior process not being finished, an order not being placed, material not being at the right place at the right time or if repairs are needed on machines (Nicholas, 2018). Further forms of waiting are if an operator waits for a machine to finish processing. A common mistake is to replace waiting with overproduction, only shifting the waste from one form to another, more costly form.

Transportation is referred to as the act of moving the item or service which is being processed (Nicholas, 2018). The workflow sequence of a process, as well as the layout of the building determine the travel distance of the item or service. By minimizing transport distance: time, cost and space can be saved. Although not all transports are long-distance, they will still require resources and coordination which is costly while often not adding value to the processed item (Hänggi, et.al, 2022).

Non-utilized human talent is considered the eight types of waste, often referred to as the "+1" in the 7 +1 wastes as it originally was not a part of the Toyota Production System (Nicholas, 2018). It refers to a company's ability to recognize and make use of their employees. By involving, empowering, and creating ways for employees to develop their skills and responsibilities, organizations can utilize their talent.

2.2.2 Push and Pull

In production and operations management, two approaches for managing workflow are known as push system and pull system. A push system is based on anticipated demand rather than actual demand (Liker, 2004). In this approach, products are produced and pushed through the system without waiting for consumption signals. Each production process operates according to a predetermined plan, resulting in producing goods ahead of actual demand. Downsides of having a push system is increased risk of overproduction and excessive inventory. A pull system is initiated by actual customer demand and needs of the next process in the production line. Production activities are initiated by a signal, which indicates a need for production to start. Therefore, in a pull system, each process produces only what is needed for the next step, and thus overproduction is avoided, and production is aligned with the actual demand. Other positive aspects of employing a pull system are enhanced flexibility, less stock and inventory. For a pull system to succeed, having a standardized and reliable process is beneficial.

2.3 Standardization

According to Liker (2004), standardization is the fundamental foundation for working with continuous improvement. It is defined as the process of identifying the current best practice for a given process, which the entire organization is expected to follow, and then using it as a

baseline for further improvement efforts. Liker (2004) emphasizes the importance of finding a balance between designing a standard that is specific enough to serve as a practical guide, yet general enough to allow for individual freedom and flexibility in its application. This balance is particularly important because the standard should not be perceived as a rigid rulebook to be followed strictly, but rather as a guideline that provides users with the individual responsibility to develop and refine processes in pursuit of better practices, thereby facilitating organizational learning.

Furthermore, standardization is described as a prerequisite for stability. Liker (2004) highlights that organizations attempting to implement improvements in an unstable process will only encounter greater variations in the process, which in the long run will not contribute to the desired outcome. Standardizations can also be seen as a tool to support people in their work by making the processes more visible, and easier to spot errors in. This can be reinforced using visual tools, which in turn positively affect quality. For example, if an error occurs in a process, it should be easy for the employee to identify where the issue originated by reviewing the standard step by step. Once the problem is located, it should be addressed and documented, so that the learning can be shared throughout the organization.

2.3.1 Standardization in Healthcare

Healthcare settings naturally differ from manufacturing settings, as the input to the system, the patient, is inherently unpredictable (Lightner & Bagian, 2021). In today's healthcare contexts, there are standards that healthcare professionals relate to, such as evidence-based medicine, and standards in documentation systems (Zuiderent-Jerak, 2007). These are not used as fixed templates but are rather shaped through individual use. One problem described with existing standards is that healthcare professionals at times experience them as difficult to use, due to structural problems behind how they are designed. Usually, such standards are developed higher up in the organization, and when they are delivered to the staff who work with them daily, they are not fully applicable.

Zuiderent-Jarek (2007), argues that this had led to resistance to standards in healthcare, partly because there is great variation in the patient inflow and it is difficult to have a one-standard-fits-all practice, but also due to the lack of insight into how work is carried out in the operational part of the organization. To address this resistance, it is instead proposed that standards should

not be implemented as a strict guide, but rather as a concept that should be developed in consultation between different healthcare professions and then further developed in practice. The same principle is highlighted by Lightner and Bagian (2021), when they explain that standards in healthcare should be designed as a guideline for procedures that can then be adapted to each patient's unique needs. This flexibility not only fosters a sense of involvement for the practitioners but also enables situational adaptation, aligning with Weick and Sutcliffe's (2007) statement that standardization should not come at the expense of professional opinions, but it also ensures patient safety (Lightner & Bagian, 2021).

2.4 Continuous Improvements: Kaizen

Kaizen is the Japanese term for continuous improvement but has a deeper meaning and symbolizes the mindset of constantly feeling the urge to never settle and always seek for an ideal state even though it is not achievable (Medinilla, 2014). In organizations, Kaizen represents a commitment to never-ending improvement and there comes no point in declaring that the work is finished.

The philosophy is a part of a culture where everyone should be involved in the improvements and continuously identify new opportunities, not only in response to obvious defects or failures (Medinilla, 2014). Because it should be seen as a part of the culture, Balestracci, (2015) underscores two vital principles: *non-tolernace for blame* and *if blame: it is alwyas the systems fault, never the people in it.* Kaizen has historically led to significant gains in productivity and quality organization that have taken on philosophy, however some individuals may initially find the approach overwhelming or in conflict with the ways of working, as it may differ from what organizations are used to.

Medinilla (2014) highlights that Kaizen, most importantly, is not about short-term fixes but rather a long-lasting commitment for the entire organization to work with improvements. Culture plays a critical role in sustaining Kaizen efforts, ensuring that continuous improvement becomes an integrated part of everyday work.

2.5 Single Minute Exchange of Die

The Single Minute Exchange of Die (SMED) was invented in the 1950s by the industrial engineer Shigeo Shingo in Japan because of manufacturing companies suffering significant losses in availability during machine changeover times (Che Ani & Shafei, 2013). The method aims to reduce the changeover time between different operations to less than a single-digit value, namely below ten minutes.

According to Shingo and Dillon (1985) SMED is defined as the minimum possible time required to switch production activity, measured from the moment the last step of the previous process is completed until the first step of the new process begins. Che Ani and Shafei (2013) further explains that SMED has several objectives, but the primary ones are to increase productivity and capacity by reducing the downtime, in other words, the time the process is idle due to the machine being unavailable. By improving this, it is consequently expected that economic losses will also decrease, as the method contributes to reduced unnecessary inventory and better accuracy in customer deliveries.

Godina et al. (2018) explains that the method consists of five different phases necessary to create a structured workflow. The first phase involves a systematic analysis in which the current process should be observed to enable the identification of where in the process time losses and non-value adding time occur. Next, activities with *internal* and *external setup times*, which both exist in SMED, should be separated from each other. Internal setup time refers to activities that can only be performed while the machine is not in operation (Che Ani & Shafei, 2013). These activities are crucial to define because they determine how long the machine will remain idle, thus directly influencing downtime. External setup time, on the other hand, includes activities that can be performed while the machine is still running. By strategically executing these activities while the machine is operating, the total idle time for the operation can be minimized.

Further, Godina et al. (2018) explain that step 3 in the SMED method aims to convert as much of the internal setup time into external setup time as possible, which in turn contributes to faster changeover times. The final two steps focus on optimizing the remaining steps in the process and, finally, standardizing and documenting the change to ensure further applications and continuous improvement.

2.5.1 Single Minute Exchange of Die in Healthcare

SMED is not only applicable in industrial production environments but can also be effectively implemented within hospital settings. By systematically reducing changeover times between surgical procedures, improvements can be achieved in workplace safety, quality of care, and overall productivity (Amati, et al., 2022). Within the surgical contexts, changeover time is defined by Mizumoto et al. (2016) as the time between when the first patient in the flow exits the operating room until the subsequent patient enters and can begin preparation for anesthesia. In other words, it is the non-operative time during the patient turnover between procedures, which represents time that can be optimized through the application of SMED principles.

The objective, in this context as well, is to minimize non-value-adding time and activities, thus reallocating that time to value-adding activities (Amati, et al., 2022), such as patient care or the initiation of the next surgical procedure. By employing parallel processes, that is, converting internal activities to external ones, it becomes possible to maximize utilization rates Mizumoto et al. (2016). However, it is equally important to consider the challenge of balancing flexibility in changeovers with the clinical requirements and the standardized work procedures that exist to ensure patient safety and surgical outcome quality (Amati, et al., 2022).

While natural variation associated with patients and surgical procedures is inevitable and cannot be controlled, standardization through SMED can assist in reducing incoming variation that is unrelated to these inherent factors (Amati, et al., 2022). Such variation frequently results in process inefficiencies and time losses, by mitigating it, workflow efficiency can be significantly improved.

2.6 Capacity

According to Slack and Brandon-Jones (2019), capacity is defined as the highest amount of value-adding work a process can perform within a given time frame under normal operating conditions. The capacity of an organization should reflect its available resources in relation to demand. Therefore, effective capacity planning involves selecting a strategy for how quickly and in what way capacity should be adjusted.

Measuring capacity is not always straightforward, as it depends on whether the process is standardized and repetitive (Slack & Brandon-Jones, 2019). In processes where the outputs vary

a lot, capacity is often measured using input-based metrics, for instance available beds. On the other hand, in more consistent and predictable system, output-based metrics, for instance number of treated patients, may be more appropriate. When neither input nor output metrics provide a complete calculation, particularly in complex service operations such as hospitals, an aggregated capacity measure can be useful. These metrics combine various inputs and outputs to give an overall understanding of the capacity in relation to a diverse mix of services.

Hospitals are a typical example of systems where capacity management can be particularly challenging. As Slack and Brandon-Jones (2019) states, healthcare services vary greatly, and the output (a treated patient) cannot be stored as a resource and is not entirely predictable due to the unique and fluctuating needs of each patient. In such contexts, it is essential to determine whether input or output measures offer the most meaningful insight.

In general, the ideal situation occurs when demand equals capacity (McLaughlin & Hays, 2008). If demand exceeds capacity, not all customers (or in this case patients) can be served, leading to longer lead times (Heizer et al., 2023). Whereas if capacity exceeds demand, resources are underutilized which results in unnecessary cost. The authors discusses that in healthcare, it is more often more economical to underutilize less costly resources, such as administrative or service personnel, in order to maximize the utilization of the more expensive resources, such as doctors (McLaughlin & Hays, 2008).

To accurately assess capacity, Slack and Brandon-Jones (2019), identify three key capacity measures. The first one is *design capacity* which refers to the theoretical maximum capacity of an operation. Secondly, there is *effective capacity*, referring to the achievable capacity after planned losses are accounted for. Lastly, *actual output* can also be considered as it represents the capacity after both planned and unplanned losses are accounted for. According to (Heizer et al., 2023), the measures mentioned can be calculated through equations 1, 2 and 3.

Equation 1:

$$\text{Design Capacity} = \text{Produced products per hour} \times \text{Operating hours}$$

Equation 2:

$$\text{Effective Capacity} = \text{Design Capacity} - \text{Lost output due to planned resource unavailability}$$

Equation 3:

$$\text{Actual Output} = \text{Design Capacity} - \text{Lost output due to planned and unplanned resource unavailability}$$

Further, Slack and Brandon-Jones (2019), discuss that capacity management also has implications for organizational performance in terms of cost, quality, and flexibility, among others. Different strategies will influence these factors in different ways and should therefore be selected carefully based on operational contest. Two commonly discussed capacity strategies are the *level capacity plan* and the *chase (demand) capacity plan*. The level capacity plan maintains a constant capacity level throughout the planned period, regardless of fluctuations in demand. To avoid having to make adjustments, the base capacity must be rather high to cover for the fluctuations. In contrast, the chase strategy aims to align capacity closely with the forecasted demand and stay flexible to make quick changes. This approach is particularly suitable when output is high in variation.

In summary, capacity planning must consider multiple dimensions when decisions are made. It is not only important to maximize capacity usage, but also to ensure that the output effectively meets the actual demand.

2.6.1 Capacity Measurements in Healthcare

As described in chapter 2.6 calculating capacity requires a nuanced approach that reflects the characteristics of the process in question. In a hospital environment, it is crucial to consider these factors, despite the complexity of processes that often involve shared resources. As previously outlined in the bottleneck section, the slowest process acts as the limiting factor, determining both the throughout rate and the number of patients that can be accounted for in the flow. According to Rosenbäck (2017), it is essential to acknowledge this constraint and base planning on the bottleneck capacities, as it ultimately defines the system's overall throughput per unit of time.

Rosenbäck (2017) also emphasizes the importance of accounting for available capacity, that is, *the total output due to planned unavailability of resources*, as defined in the previously introduced equations. To provide a realistic estimation, available capacity, and correspondingly available time, must reflect the actual time that personnel can devote to the task in question.

Time allocated for other activities must be included as limiting factors to avoid producing overly optimistic outcomes. For instance, time spent on breaks and administrative tasks should be taken into account and therefore lower the available time for the task in question.

2.6.2 Productivity in Relation to Capacity

According to Almström (2024), certain forms of capacity measurements, such as output capacity, defined as the number of units produced per time unit, closely resemble productivity in both definition and method of calculation. In such cases, capacity and productivity are measured in the same way and then the productivity factors can also be examined for capacity. The productivity factors are divided into three factors: *method (m), performance (p)* and *utilization (u)* and these factors aim to explain why an activity takes the time it does.

The method is related to *how* the work is performed, taking into account movements, usage of tools and what the working environment looks like (Almström, 2024). The factor also determines what the ideal duration of a specific activity is, and by improving the method, hence making the duration shorter, productivity can increase. Moving on, performance explains how fast the work is carried out compared to the standard method used and is often affected by the human factor. The performance factor measures the deviations in the carried-out work. Lastly, the utilization indicates the proportion of available working time that is spent on value-adding and necessary support activities. Productivity depends directly on the utilization rate, where a low utilization rate also means unutilized capacity which causes lower productivity.

2.7 Learning Organizations

As organizational environments become increasingly dynamic, unpredictable and competitive, an increase in the importance of organizational learning has been observed (Jacobsen and Thorsvik, 2021). Increasing organizational learning is motivated by either a need for adaptation, innovation, efficiency or to gain a competitive advantage. Learning is defined not only as the process of acquiring knowledge, but also a change of behavior. According to Jacobsen and Thorsvik (2021), a learning organization requires individual reflection, knowledge sharing between individuals and collective application of the knowledge into practice. Two main types of learning are distinguished: single-loop learning and double-loop learning. Single-loop learning is defined as improving actions withing existing goals and values, while double-loop learning involves questioning the underlying assumptions and values guiding a behavior. It

includes open discussion, factual evaluation, and reflection on outcomes. To be able to utilize double-loop learning, organizations need to be able to de-learn by refining, revising and improving current operational practices.

In addition to these two learning types, Jacobsen and Thorsvik (2021) emphasize managing both tacit and explicit knowledge. Tacit knowledge refers to experience-based knowledge, including skills and insights developed over time which often are difficult to articulate. Explicit knowledge is easily explained, written down and shared with others. To create a learning spiral in an organization, where tacit knowledge and explicit knowledge reinforce each other, systems must be created where knowledge is articulated and integrated into shared routines and practices. Jacobsen and Thorsvik (2021) explain four shapes of learning, needed to create a knowledge spiral in an organization.

1. Socialization: This describes the transformation from tacit knowledge to tacit knowledge, which is when knowledge is unintentionally and informally shared, through for example observations without being explicitly communicated.

2. Externalization: From tacit knowledge to explicit knowledge, where tacit knowledge is articulated to explicit knowledge and thus is made available to others through formulating and sharing a best practice method.

3. Combination: When explicit knowledge is combined with other explicit knowledge to form new insights, by for example combining and analyzing data points.

4. Internalization: Explicit knowledge to tacit knowledge. When individuals apply the explicit knowledge and integrate it to their own personal skillset, for instance when applying new methods in practice.

3 Method

This chapter presents the methods conducted in this study. Firstly, the research strategy, research design and quality criteria are explained. Following this, the methodology for the literature review, interviews, observations and scope- and estimation methods are described in more detail.

3.1 Research Strategy

This study is combining quantitative and qualitative research and data, referred to as a mixed methods approach (Bryman et al., 2022). The choice of using several methods is based on the fact that the hospital environment in this specific case was relatively unknown to the researchers at the start of the study and the desire to increase the understanding of the current situation of the environment. Dalen (2015) emphasizes that employing multiple methods and gathering various types of data contributes to forming a broader and in-depth understanding of the topic under investigation. An additional argument for using a mixed methods approach is when using solely a quantitative or qualitative method is not enough to describe the studied area (Creswell & Plano Clark, 2017). In a hospital setting, while quantitative metrics such as cost, and efficiency are critical, qualitative factors such as patient care and safety hold equal significance. Consequently, the use of a mixed method is essential to capture the complexity of a health care unit. Qualitative data aids in understanding different perspectives while quantitative data is valuable for investigating measurable issues (Bryman et al., 2022) since both are of importance for this study, both methods are used. The research strategy used in the study is predominantly inductive, as it seeks to develop an understanding based on data collected through mixed methods. According to Bryman et al., (2022) an inductive approach involves generating theory from data.

There are several ways to conduct a mixed methods approach, and this case study conducted a mixed methods convergent parallel design. When analyzing using a convergent parallel design, the quantitative and qualitative data is combined (Creswell & Plano Clark, 2017). The quantitative and qualitative data is not collected sequentially, but rather simultaneously. When presenting the results, all sets of data are considered and integrated into the final conclusions. The quantitative and qualitative data is treated as equal in a convergent parallel design with the purpose of comparing the results derived from the combination of methods (Bryman et al.,

2022). The qualitative methods used in this study consist of semi-structured and unstructured interviews, effective scoping, observations during a study visit and the affinity-interrelationship method which will be further explained in section 3.5. The quantitative methods used are three-point estimate and data analysis of historical data as well as structured observations, further explained in section 3.5.

3.1.1 Limitations of the Research Strategy

Two main arguments against mixed methods research are that quantitative and qualitative methods are separate and thus cannot be combined and secondly that quantitative and qualitative methods are grounded in distinct epistemological assumptions (Bryman, 2016). Therefore, combining methods might indicate that the researcher has conflicting views of the world and how it can be studied. The authors of this study share a pragmatic worldview, which is a common world view for researchers performing a mixed method and especially for convergent parallel research (Creswell & Plano Clark, 2017). With a pragmatist worldview, the problem itself is the central focus, thus the selection of methods may be quantitative or qualitative or a combination of both. The chosen method is determined by the effectiveness in addressing the problem.

3.2 Research Design

The research design used in the study is a case study, which involves an in-depth and focused examination of a specific case (Bryman et al., 2022). It is different from other research designs due to its focus on one specific situation or system with clear boundaries that work towards a specific purpose. A case may be an organization, a location, an individual, or a particular event. For this thesis, the case studied is a single location, Art Clinic's Gothenburg unit for hip- and knee replacement surgeries. It is common for case studies to combine quantitative and qualitative methods through a mixed methods approach (Bryman et al., 2022) which is the method used in this case study. Incorporating a mixed method approach within a case study enhances the ability to provide a detailed and realistic description of the case, making it useful to understand the complex characteristics of a case (Creswell & Plano Clark, 2017). The purpose of a case study is to be able to explore the specific and unique characteristics of a case (Bryman et al., 2022). Since this study aims to evaluate the capacity and improvements related to a specific unit, it is aligned with the aim of a case study.

To structure the thesis, the Six Sigma approach Define-Measure-Analyze-Improve-Control (DMAIC) was employed. As can be viewed in table 2, effective scoping and AIM was used to define the problem. Measurements were collected during the observations, interviews and three-point estimation. The data given by the organization was then analyzed using JMP. As the process was iterative, the results from the analysis and measurements were used to redefine the problem as well. These methods aided in finding the bottlenecks for the capacity, scoping the problem and aligning the project goals with the different stakeholders. In the improve phase, an integrative approach was used by combining the results from the quantitative and qualitative methods and literature study.

Method	D	M	A	I	C
AIM	X				
Effective Scoping	X				
Process Map	X				
Three-Point Estimate		X	X		
Observations		X	X	X	
Interviews		X	X	X	
JMP			X	X	
Study Visit			X	X	

Table 2: The methods used, connected to each of the DMAIC phases.

3.3 Literature Review

A literature study was conducted prior to and during the data collection phase as well as throughout the study. Literature has been used to develop both research methodology and theoretical framework. Primarily, the literature consists of academic books, which have been sourced and selected through Chalmers Library's online service, Google Scholar and physical books borrowed from Chalmers Library. Relevant search terms include "Process Mapping", "Process Flow", "Process Theory", "SMED", "Capacity", "Standardization", "Continuous Improvement", "Learning Organizations", "Changeover time AND operating room", "Lean", "Lean Healthcare". Additionally, company specific data was gathered through the clinic's website and through interviews with the CEO. Due to the inductive nature of the research, the

literature review followed a narrative approach, enabling the incorporation of emerging themes throughout the research process (Bryman et.al, 2022).

3.4 Quality criteria

To evaluate business research, the quality criteria for reliability, replicability, and validity are used (Bryman et al., 2022). The first criterion, reliability, refers to the consistency of measurements in a study and if they are reproduceable over time. To strengthen reliability of the quantitative data, observations during the study were performed on random days and times, following different surgical teams. The results showed that the data recording process remained consistent regardless of which team member added the data, strengthening the reliability. Additionally, the data was analyzed across a two-year period, and similar trends were identified across different months and years, indicating a consistent pattern in the process, and supporting the reliability of the results.

In qualitative research, reliability is often more challenging to achieve compared to quantitative research (Creswell & Plano Clark, 2017). In qualitative studies, greater emphasis is often placed on validity rather than reliability. Interviews are mentioned by Trost, (2010) as having low reliability due to the psychological conditions of the interviewees such as mood and stress levels influencing an interview and thereby reducing reliability. To mitigate these effects, efforts were made to create a comfortable interview environment where open communication was encouraged. Additionally, follow-up questions were asked to ensure that the information received was correctly interpreted.

Validity is an important quality criterion focusing on the accuracy and trustworthiness of the conclusions from research studies (Bryman et al., 2022). The validity of the research will be explained through an examination of both measurement validity and external validity. The concept of measurement validity refers to the ability of the measurement system to accurately measure what it intended to (Bryman et al., 2022). It assesses whether the collected data reflects the specific construct being studied. The quantitative data analysis for the study was based on data provided by the company Art Clinic. To ensure measurement validity the accuracy of the data entry process was studied through observations to observe any differences in the added data and the actual event. For example, the time registered as incision was compared to the actual incision time during the procedures. The results showed that the greatest difference

between the added data and the real scenario was five minutes, which was considered sufficiently small to not significantly impact on the validity of the measurement system.

In addition to measurement validity, aspects of external validity were considered. External reliability is defined as the generalizability of the research (Bryman et al., 2022). For quantitative studies, external validity is often connected to sampling and the selected group accurately representing the population. Since a case study was performed, the general idea was not to be able to generalize the findings to all hospitals in the world, but rather to be able to generalize the collected data and apply it to Art Clinic. For the quantitative data analysis, the sample of data consisted of joint replacement surgeries performed by all different doctors and surgical staff at the hospital. Therefore, the quantitative data can be generalized to Art Clinic. However, the measurements are highly individual to the case and thus cannot be generalized to other hospitals. For the three-point estimate, snowball sampling was used which has a lower probability of creating a representative sample (Bryman et al., 2022), thus lowering the external validity. Efforts to increase the external validity were made by comparing parts of the three-point estimate with measurements from the data analysis as well as interviewing different personnel at the same unit to confirm the collected data.

Validity in qualitative data collection refers to the process of evaluating the obtained information to determine its accuracy and authenticity (Creswell & Plano Clark, 2017). There are several strategies to use to increase qualitative validity, and a minimum of using three strategies is recommended. For this research, three strategies were used. Member checking, which involves returning to participants to confirm that the conclusions drawn from the data collection accurately reflect their perspectives, was employed. For example, the finished process descriptions were validated by sending them to the interviewees to make sure that every process step was correctly portrayed. The second strategy used was a combination of observations and quantitative data to verify the three-point estimate created through interviews. The third strategy employed is being transparent regarding conflicting information.

The third quality criterion, replicability, refers to the repeatability of the study (Bryman et al., 2022). To increase replicability, a detailed description of how the study was conducted is needed. Following this section, an in-depth explanation to the different methods used will be

presented to strengthen the replicability of the study. Further measures taken are a detailed description of the data analysis.

3.5 Scope and Estimation Techniques

In this section, an explanation is given of the methods used in the initial stage of the study, in order to gain an understanding of the current practices and problems.

3.5.1 Three-Point Estimate

Three-point estimate is a commonly used method in project management used to improve accuracy of estimates by considering uncertainties (Kerzner, 2017). In the Six Sigma methodology, three-point estimates are particularly useful in the define-phase and in contexts where data is lacking, and the confidence is low (Hammersberg, 2025). The purpose is to create an understanding of data with simple estimations of variability to gain better insight of uncertain aspects.

The model consists of three estimates: *most likely (m), optimistic (a)* and *pessimistic (P)* (Project Management Institute, 2021). Using these estimates, it is possible to calculate an expected value (e), the standard deviation (σ), and the variance (v). To calculate these values, equations 4, 5, and 6 are used.

Equation 4: Expected value (e)

$$e = \frac{a + 4m + P}{6}$$

Equation 5: Standard Deviation (σ)

$$\sigma = \frac{P - a}{6}$$

Equation 6: Variance (v)

$$v = \sigma^2$$

In this study, the three-point estimate method was used during the define phase, at a time when it was still unclear which part of the process should be examined. To identify where the staff

perceived the greatest variation in the patient flow, three investigations were conducted: one focusing on planning, one on the preoperative phase, and one on time spent in the operating room, see table 3 and 4.

Table 3: The three-point estimate question asked regarding the preoperative unit.

	Process Step	Unit	Most Likely (m)	Optimistic (a)	Pessimistic (P)
1	Time from when a doctor submits a surgery request to the surgical coordinator until the patient is scheduled for surgery	*Days*			
2	Waiting time for surgery	*Days*			
3	Time from patient check-in to seeing the surgeon	*Minutes*			
4	Surgeon's preoperative visit	*Minutes*			
5	Preoperative preparations by the nurse	*Minutes*			
6	Transport from the preoperative unit to the operating room	*Minutes*			

Table 4: The three-point estimate question asked regarding the activities in the operating room.

	Process Step	Unit	Most Likely (m)	Optimistic (a)	Pessimistic (P)
1	Time to loss of consciousness	*Minutes*			
2	Intubation, positioning and sterilization	*Minutes*			
3a	Surgical duration: Knee Replacement	*Minutes*			
3b	Surgical duration: Hip Replacement	*Minutes*			
4	Transport from the preoperative unit to the operating room	*Minutes*			
5	Emergence from anesthesia and extubation	*Minutes*			
6	Cleaning of the operating room	*Minutes*			
7	Idle time between patients	*Minutes*			

The results of the three-point estimate were also intended to be used in the results and discussion sections of the report, to compare perceived time estimates with actual durations obtained through quantitative data analysis.

The sampling method used for the three-point estimate has been snowball sampling, meaning that participants referred to other participants with the knowledge sought after by the interviewee (Bryman et al., 2022). A negative aspect of snowball sampling is the low probability of gaining a representative sample. This approach was used due to the low availability of staff due to operations being performed simultaneously as the interviews were held. Arguments for using snowball sampling are when the studied population is difficult to reach as in this study (Bryman et al., 2022).

3.5.2 Affinity-Interrelationship Method (AIM)

As a part of the early problem identification phase, an Affinity-Interrelationship Method Workshop, hereby referred to as AIM, was utilized to gain a comprehensive understanding of what the staff at Art Clinic perceive as the department's most significant challenges. AIM is a structured problem-solving tool inspired by Professor Shoji Shiba's 19 step by step approach and the KJ-method by Professor Kawakita Jiro (Alänge, 2009). Further inspiration for the method is the usage of affinity diagrams and the interrelationship graph. The method is used as a tool to create a shared understanding between participants and is structured as a workshop. It can be used to identify cause-and-effect relationships, aid in prioritizing problem areas and analyze complex qualitative data. In this study, the purpose of the workshop was to explore the initial perspective on the problem formulation, thereby reducing the risk of overlooking other critical issues. Additionally, it was essential to consider and listen to the opinions of those working in the daily operations.

The number of participants is between 4-8, with a preferred number of 6 participants (Alänge, 2009). It consists of 10 main steps as listed below:

1. Developing the question to be analyzed in the workshop
2. The warmup phase
3. Gathering information
4. Clarifying the information
5. Organizing the information by creating groups
6. Higher level organization through titles and creating additional groups
7. Identifying relationships between groups
8. Final layout - arranging the final structure

9. Prioritization through voting
10. Conclusion: answering the question

The sampling for the aim-workshop was done through purposive sampling, meaning that participants were chosen with intention due to their experiences and knowledge regarding the subject (Creswell, 2017). The workshop participants included: one surgeon, one anesthesia nurse, one scrub nurse, one assistant nurse, one ward manager, and one surgical coordinator. Purposive sampling was chosen to gain access to participants with the right knowledge to answer the questions addressed in the workshop related to capacity. Therefore, personnel within the operations and planning departments were considered most relevant, as they are directly involved in creating and managing capacity. The specific type of purposive sampling used for the workshop was maximal variation sampling. This sampling method aims to sample individuals who represent a wide range of perspectives, with the intent of gaining knowledge of their different views to understand the problem from multiple views (Creswell, 2017). This approach was chosen as the goal of the aim-workshop was to gain an understanding of the issue of increasing capacity from various perspectives.

3.6 Interviews

As a part of the qualitative research in this study, various forms of interviews have been conducted. According to Denscombe (2018), interviews are well suited for capturing personal perspectives, particularly when the aim is to achieve a deeper understanding rather than gathering objective facts. Similarly, interviews can serve as a tool for exploring complex issues to gain insight into broader systems and the interaction of contributing factors. One of the advantages of interviews as a method, as noted by Bell and Waters (2018), is their adaptability, which allows for in-depth exploration. Denscombe (2018) further emphasizes that interviews can be used to obtain *privileged* information, which are insights that may not be accessible through other methods but contribute significant value to the study. However, as Bell and Waters (2018) emphasize, despite interviews being a powerful research tool, they carry an inherent risk of bias. This risk may stem from both the interviewer who designs the interviews, and the interviewee, who coveys their own subjective reality and opinions. Denscombe (2018) also shares this concern, noting that one of the limitations of the interview method lies in the difficulty of validating the information obtained. To mitigate these risks, the interviewer has a

significant responsibility to design suitable interview structures and remains aware of the potential for bias when analyzing the results.

3.6.1 Types of Interviews

Interviews are usually divided into the following three categories: *structured, semi-structured* and *unstructured* (Bell & Waters, 2018; Denscombe, 2018), which all are commonly used in qualitative research. The primary distinction between them, as noted by Denscombe (2018), lies in the degree of flexibility granted to both the interviewer and the respondent. Structured interviews follow a pre-design schedule where both the questions and response options have been formulated in advance. The format closely resembles a questionnaire, and respondents are usually asked to make judgements based on pre-defined alternatives, leaving no room for elaboration or personal reflection. Flick (2022) points out that a major challenge of this format is that all questions must be predetermined. This places considerable responsibility on the interviewer to ensure that the questions are well-though trough to capture relevant insights, without introducing their own bias to the subject.

Semi-structured interviews, on the other hand, resemble structure interviews in that the interviewer follows a predefined interview guide (Denscombe, 2018). However, according to Flick (2022), a semi-structured interview should resemble a dialogue between interviewer and respondent. The interviewer is free to adapt the structure during the conversation by asking follow-up questions, reordering the topics, or remove or add questions between interviews. This flexibility is also given to the interviewee as they can respond in an open and detailed manner. It is further emphasized that open-ended questions allow for genuine answers (Denscombe, 2018), and Flick (2022) warns that close-ended questions is a common mistake that can limit the information.

Unstructured interviews are described by Denscombe (2018) as entirely open-ended conversations in which the interviewer's role is to introduce a broad topic or a general question, which the interviewee is then free to explore without interruption or constraints. The aim is to allow the interviewee to shape the direction of the conversation and share in-depth reflections.

Another format of interview, explained by Atkinson and Hammersley (2007) is ethnography. Data collection in ethnographic research typically takes place through multiple methods, one

of which is interviewing. This approach involves the researcher participating in the daily activities of the interviewees where the aim is to develop an understanding of different perspectives within the natural context of the interviewee, rather than having predetermined occasions. These interviews are usually conducted within a selected group of people to gain a deep insight and in an unstructured manner as the need to ask questions arises. The selection of the interviewees is rarely known at the beginning, instead it develops over time as it becomes clearer to the researcher who can provide relevant and valuable insight in the selected topic examined.

3.6.2 Ensuring Ethics and Openness in Interviews

When conducting interviews in a research project, it is essential to consider the ethical aspects of the process (Bell & Waters, 2018; Denscombe, 2018; Flick, 2022). According to the authors, this can be ensured by always informing the interviewee about the purpose and structure of the interview, to obtain their outspoken consent before starting the interview. In addition, Bryman et al. (2022) highlight three core ethical issues that must be considered before initiating an interview: *potential harm to participants, invasion of privacy* and *deception.* Harm can be prevented through anonymization of the interview persons, and invasion of privacy can be avoided by handling each interview with confidentiality. To avoid deception, the interviewer should inform the interviewee about the purpose of the research and transparency.

To optimize the outcomes of the interviews, Denscombe (2018) argues that it is equally important to create a safe and open atmosphere that encourages the interviewees to speak freely. This can be achieved in various ways, such as beginning the interview with an introduction to the topic and study purpose, followed by a few light introductory questions that allow the interviewee to present themselves. Creating a sense of trust and openness can be further supported by clarifying that the interview will be anonymized and that all data will be treated confidentially.

3.6.3 Interviews in this study

In this study, interviews were used as a qualitative research tool to obtain a comprehensive understanding of the subject. The interviews were conducted in two separate rounds, each serving different purposes. Initially, semi-structured interviews were carried out with three different surgeons to explore surgical procedures, operating instrument usage and learning

processes within the medical field. These interviews were personal, meaning that each session involved only the interviewer and the interviewee (Denscombe, 2018). The interviews followed a pre-designed guide (see Appendix A), which was adapted and modified as needed throughout the process. The first interview served as a foundation for the subsequent ones, and in line with the semi-structured nature of the method, the interviewer was free to ask relevant follow-up questions to gain deeper insight into the previously mentioned topics. To ensure compliance with ethical research principles, all participants were informed about the purpose of the interviews, how the data would be used, and were made aware that all information would be treated confidentially and anonymized in the final report. Before the report was published, all interviewees were also given the opportunity to review the quotations attributed to them, in order to validate their responses and comment on any statements that might have been misrepresented and misunderstood. The data generated from these interviews will be compiled and presented as a part of the qualitative results section and will be further discussed in the discussion chapter.

The second type of interview conducted in this study were ethnographic and took place sporadically throughout the research process. These informal interviews were primarily conducted with surgical nurses working in the operating room, namely scrub nurses, anesthesia nurses and assistant nurses, and took place at the same time as they performed their daily work. However, conversations were also held with sterilization technicians and surgical coordinators on various occasions. The aim of these interviews was to gain a more comprehensive understanding of how the organization functions in practice, and to hear the opinion of the staff at Art Clinic and not necessarily search for objective data. Topics included how surgeries are scheduled, questions about specific medical procedures within the operating room, and general logistical questions related to the sterile processing room, among others. As with the previously described interviews, the data from these ethnographic conversations will be presented in the qualitative result chapter. The content will be thematically compiled and anonymized, without reference to individual participants and will be revisited in the discussion to provide the reader with more depth of the current operational context.

3.7 Observational Studies

To develop an understanding of the daily operations at Art Clinic, this study has employed various forms of observations. Bell and Waters (2016) describe observation as a method aimed at examining how processes are structured, how tasks are performed, and how information flows through different interactions between individuals. The collected data can subsequently be utilized to enhance the understanding and explanation of how individuals act or relate to others within a specific group in the observed environment.

When conducting observational studies, Bell and Waters (2016) emphasize the importance of defining what is to be observed and questioning why a particular aspect is relevant to the study before selecting the method. This approach ensures the best possible outcome. Prior to the observation, the researcher should also recognize that his method does not capture all potentially relevant factors, such as individuals' emotions or informal power dynamics. Consequently, combining multiple methods can be advantageous. Furthermore, the authors highlight the risk that observed individuals may develop a sense of suspicion towards the observer and may not share the same perspective on the outcome of the observation. Depending on the purpose of the observation, it is, where feasible, recommended, to involve two participating observers, as perceptions may differ due to human subjectivity. Bell and Waters (2015) also stress the importance of informing those being observed about the study's purpose and their role in advance. This ensures that they have the opportunity to provide informed consent, thereby addressing ethical considerations.

In this study, a combination of participant and structured observations was conducted, as it was deemed necessary both to create an accurate representation of Art Clinic's current state and to validate their data. A total of 36 observations were carried out, with 17 being participant observations and 19 being structured observations. The guidelines and execution of these observations will be further described in chapter 3.7.1 and 3.7.2.

3.7.1 Participant Observations

Bell and Waters (2018) describe participant observation as a method in which the observer actively engages in the daily activities of those being observed. During the observation period, the observer asks questions, listens actively, and seeks to develop an objective understanding of the observed process. This format is advantageous for gaining a comprehensive perspective

and identifying implicit information that may only emerge once the observed individuals no longer feel scrutinized. However, this approach presents difficulties, as there is a risk that the observer may develop bias and lose objectivity in their assessment. Such bias may arise if the observer becomes integrated into the group and struggles to maintain the perspective of an external third party.

All participant observations served as a foundation for understanding the clinic's operations, as there was no prior experience regarding how all elements within a surgical department interact. This form of observation was primarily employed at the beginning of the study, as it was the areas of use that were considered most relevant for mapping the processes at that stage. During these observations, the observer had the opportunity to freely ask questions about work procedures, organizational structures, and other aspects, thereby gaining deeper insights into the dynamics of the department. This form of close interaction may also have helped mitigate the Hawthorne effect, as staff members gradually became more comfortable with the observer's presence and were less likely to adjust their behavior.

The Hawthorne Effect, as described by McCambridge et al. (2013), refers to the phenomenon in which individuals change their behavior or work practices when they are aware that they are being observed. This is often connected to trying to perform better and align with what they believe are the desired outcomes of the study. For example, it is common for observed individuals to become more productive during the observation period, which may result in findings that are less representative of typical conditions and thus biased. To prevent this, it can sometimes be beneficial for the observer to interact with participants in a natural and informal way to create a more comfortable environment in which behaviors are more likely to reflect the norm. However, in such cases the observer must be particularly mindful of their own potential biases, which, as previously mentioned, is a known risk in participant observations. In the context of this study, the individuals being observed were aware that the observations aimed to validate data and to gain an understanding of their daily routines. It may also be argued that the results remained objective, as the observers had no prior knowledge of medical procedures or workflows and therefore held no preconceived opinions about how the tasks should be carried out. Additionally, an observation schedule was utilized to document the surgical procedures observed and to serve as a reference for potential modifications and improvements in future observations, visualized in table 5.

Table 5: The observational schedule utilized during the first observations.

	1	2	3	4	5
Observer ID					
Type of observation					
If surgery: What type of surgery?					
Noticable deviations or disturbances					

3.7.2 Structured Observations

A structured observational study is considered the most accessible format for inexperienced observers, as it follows a predefined, objective structure that is documented systematically (Bell & Waters, 2015). Prior to conducting a structured observation, it is essential to establish what will be observed and which behaviors or events should be recorded. Additionally, the frequency of observations must be determined, ideally at set time intervals or based on event triggers. During the observation, Bell and Waters (2018) stated that the observer should observe without interfering with the observed individuals to ensure objective data collection. At the same time, the authors acknowledge that an observer can never remain entirely unnoticed. However, they should strive to act in a manner that captures a natural state of behavior. Upon completion of the observations, the collected data should be compiled and analyzed, preferably through quantitative analysis.

In this study, structured observations were utilized to validate the existing measurement system used in the operating rooms. To ensure the reliability of the data provided by Art Clinic, it was necessary to observe how this data was collected. These observations met the criteria for being classified as structured since they followed a predetermined observation schedule, which reduces biases, and the observer did not participate or interrupt in any of the processes being examined. However, it should be noted that during the observation sessions, the observer was allowed to ask relevant follow-up questions to the surgical staff if clarification regarding specific procedures was required.

3.7.3 Observation Schedules

According to Bell and Waters (2018) observation schedules can take various formats depending on the aspect being examined. The authors emphasize that there is no universally correct or incorrect structure, instead observation schedules should be adapted to the specific context to

ensure that they effectively capture the necessary data. Furthermore, the authors highlight that iteration and refinement of the schedules may be required throughout the study to enhance their effectiveness.

In this study, the observation schedules were designed based on the existing measurement parameters currently utilized by Art Clinic, as the primary aim was to validate this data. A summary of the observation structure is presented in table 6 below.

Table 6: The observation schedule used for this study.

	1	2	3	4	5
Date					
Type of surgery					
Observer ID					
Operating room					
Surgeon					
Scrub nurse					
Anesthesia nurse					
Assistant nurse					
Instrument setup start time					
Patient in					
Anesthesia start					
Ready for surgery					
Incision start					
Incision end					
Patient out					
Operating room cleaning start					
Operating room cleaning end					
Noticable deviations or disturbances					

To validate the data, as external observers, definitions for each measurement parameter were required. For example, what aspects of the process determine when each measurement point should be recorded in the system. To establish these definitions, two randomly selected employees were interviewed: one anesthetic nurse and one operating room assistant, both of whom work in the operating room and are directly involved in data collection for surgical procedures.

Each measurement parameter was presented in chronological order, and the interviewees were asked to provide their definitions freely, explaining how they determined when the corresponding data entry should be made. After both interviewees had provided their independent definitions, their responses were compared and subsequently used as a guideline for determining the exact time points to be observed. The complete definitions and methodology are presented in Appendix D.

3.8 Use of Artificial Intelligence

In this thesis, artificial intelligence (AI) has primarily been used as a tool for language refinement, assistance with grammar and report structure. AI was also used to efficiently understand medical terms and concepts throughout this study. All AI-assisted help was carefully reviewed and approved by the authors to ensure accuracy.

4 The case

The following chapter presents the current state of Art Clinic, explaining the layout of the facilities, the staffing arrangements, the surgical pathway described from a patient's perspective and activities performed in the sterile processing room.

4.1 The Layout

The preoperative care pathway within the operating department at Art Clinic has been carefully designed to ensure that incoming and outgoing patients never cross paths. This separation helps reduce patient anxiety by avoiding exposure to others who may appear in pain or distress after surgery, thereby contributing to a calmer and more reassuring experience. The operating department consists of the following units: a desk for check-in, preoperative unit, sterile preparation room, sterile supply, sterile processing room, operating room, post anesthesia care unit (PACU) and the postoperative ward, all seen in figure 2.

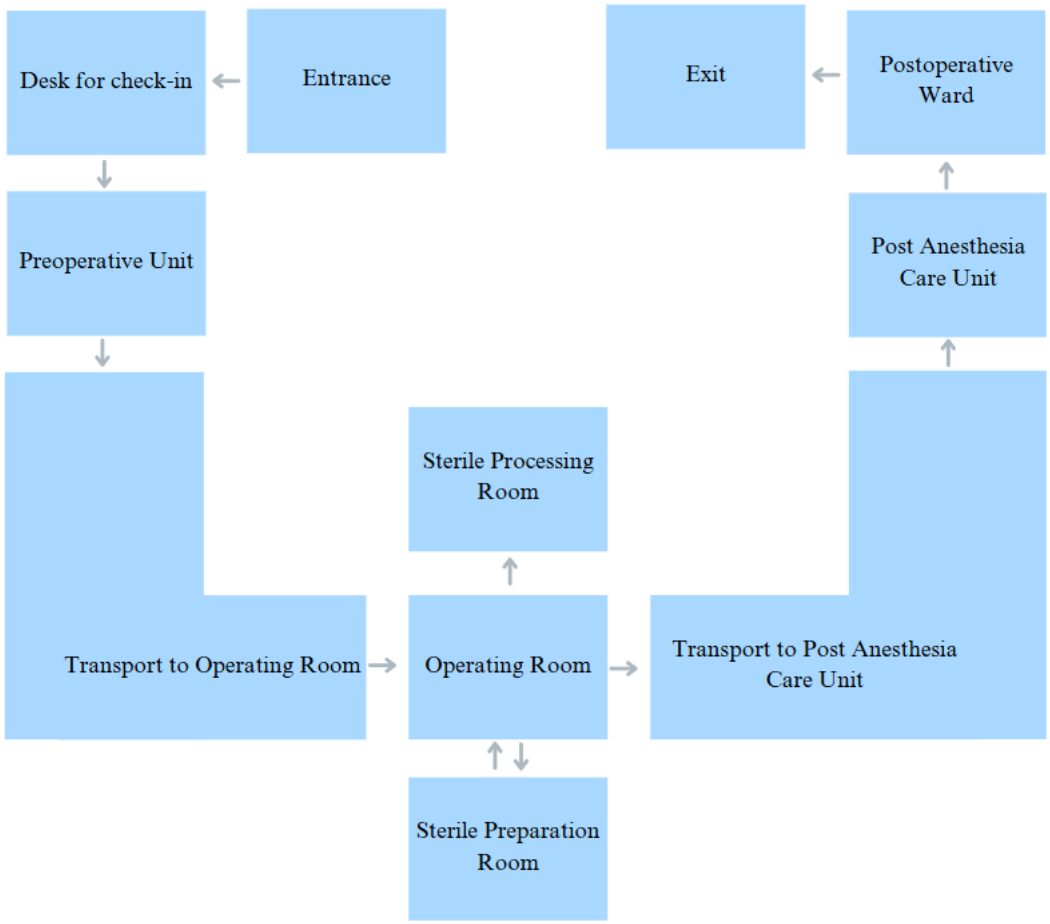


Figure 2: The processes at Art Clinic involved in the knee and hip replacement surgeries.

4.2 Personnel and Staffing Arrangements

The following chapter provides an overview of the personnel and staffing arrangements within the operating department at Art Clinic. It includes only staff working in this specific department and does not cover personnel from other parts of the organization, nor teams involved in other types of surgical procedures performed at the clinic. In short, only staff directly engaged in knee- and hip replacements are included. At the department, the distribution is as follows in table 7.

Table 7: The staffing arrangement at Art Clinic.

Role	Number of staff	Notes
Surgeon	2	Full-time permanent employees
Consultant Surgeon	8	Rotates on a 5-week schedule
Anesthesiologist	2	
Scrub Nurse	11	Shared across operating rooms
Anesthesia Nurse	9	Shared across operating rooms
Assistant Nurse	9	1-2 takes turn helping the sterile processing room
Registered Nurse	1	Assigned to the preoperative unit
ICU Nurse	3	Assigned to PACU
Sterile Processing Technician	2	

During a typical week, the goal is to perform scheduled surgeries in 5 out of 5 operating rooms from Monday through Wednesday, with 2 operating rooms allocated specifically for knee and hip replacements. On Thursdays, only 4 of the operating rooms are typically in use and on Fridays the clinic does not conduct knee and hip replacements as an overnight stay is required. In each operating room where joint replacements are performed, the surgical team consists of the following staff, see table 8.

Table 8: The staffing arrangement in the OR during surgery at Art Clinic.

Role	Number of staff
Surgeon	1
Scrub Nurse	2
Anesthesia Nurse	1
Assistant Nurse	1

To ensure smooth workflow there is a corridor team working to support the operating rooms throughout the day. This team plays a key role in maintaining efficiency by managing operating room cleaning, logistical tasks, and assisting where needed, allowing the operating room staff to focus on surgery without unnecessary interruptions. Furthermore, they take over the responsibilities of the operating room team during lunch to ensure that the flow is not stopped during lunch hours. The corridor team consists of staff members who are not assigned to work inside an operating room on that day, and its composition varies from day to day. Typically, the team includes two scrub nurses, two anesthesia nurses and two assistant nurses.

4.3 The Surgical Care Pathway

On the day of the surgery, the patient first arrives at the reception desk on the fifth floor to check in. They then proceed to the sixth floor, where the operating department is located. Upon entering the department, the patient is welcomed at a secondary reception area by the ward hostess, who provides additional information and guidance. The patient is then guided to the preoperative unit, where they change into a hospital gown and are met by a nurse. The nurse prepares the patient with preparatory tasks such as shaving the surgical site, inserting intravenous lines, and administering preoperative medications. Once these preparations are complete, the patient meets the surgeon for a brief consultation. Finally, the anesthesia nurse assigned to surgery arrives to escort the patient to the operating room.

Inside the operating room, the patient is positioned on the surgical table, and anesthesia is administered shortly thereafter. The introduction of anesthesia always involves two professionals, either two anesthesia nurses, or one anesthesia nurse in collaboration with an anesthesiologist. Once the patient is fully anesthetized and intubated, the surgical team proceeds to position the body, disinfect the surgical site, and apply sterile draping. When all the preparations are complete, the surgeon enters the room for a final preoperative check-in with the team, after which the surgical procedure begins.

When the procedure is complete, the patient is carefully awakened and extubated with the assistance of two trained anesthesia professionals. The patient is then transferred to the PACU where they remain under close monitoring for several hours before being moved to the postoperative ward. Most patients stay overnight in this unit; however, postoperative admission is not always required and depends on the type of surgery performed. For implant and prosthetic

procedures, an overnight stay is mandatory, whereas patients undergoing less extensive surgeries may be discharged the same day. The entire patient journey, as outlined above, is illustrated in figure 3.

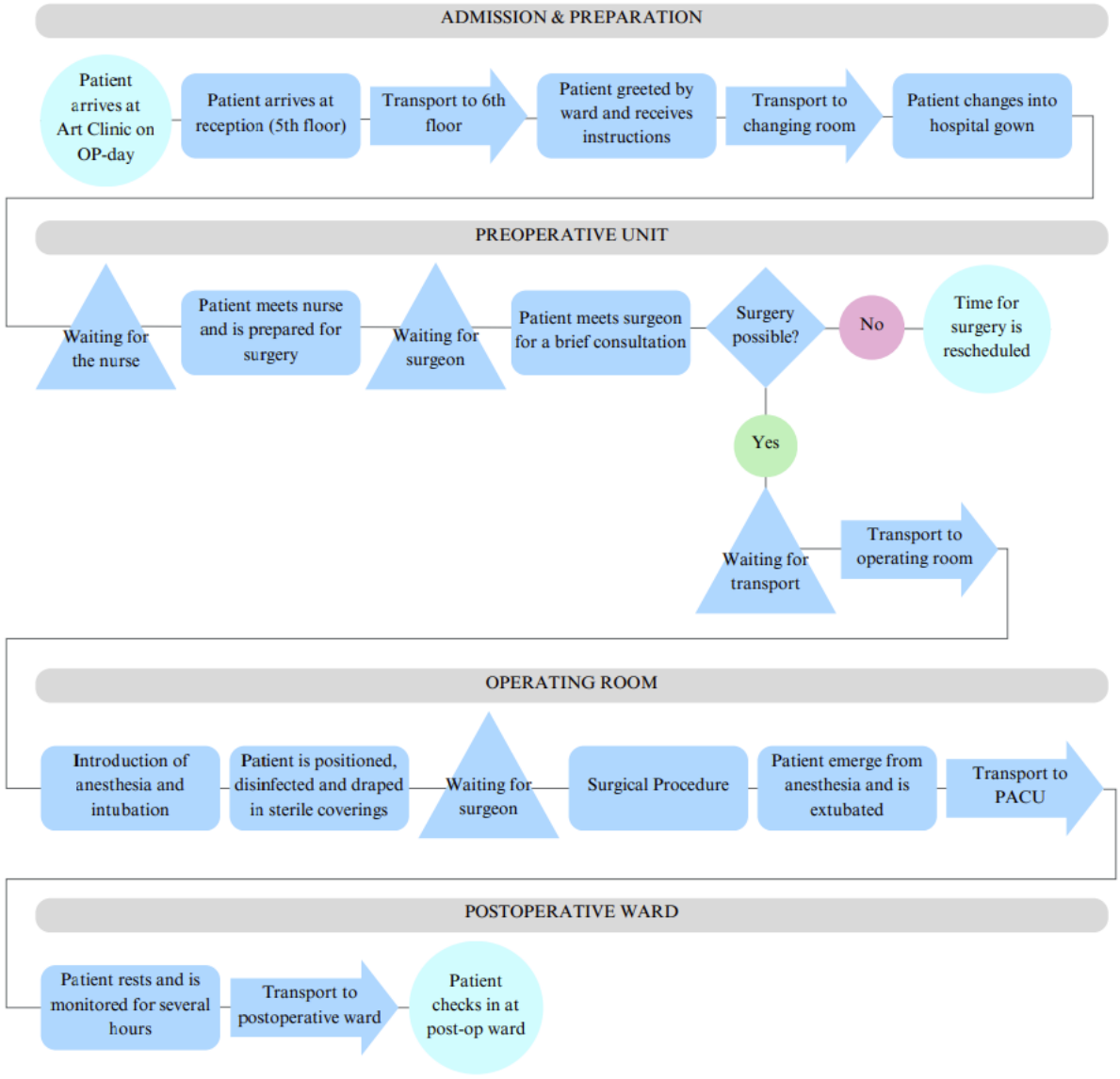


Figure 3: Illustrates the patient's journey and all processes on the day of surgery.

4.4 The Activities in the Operating Room

The first step in the operating room is the surgical setup, which includes the time between the patient entering the operating room until the patient is prepared and ready for surgery. The initial step is to anesthetize the patient which is done with the patient laying on its back. Thereafter, the patient is positioned correctly using a hip or knee positioning device.

Subsequently, the patient is cleaned, prepared and sterilized for the surgery, which is initiated once the surgeon has entered the room and is ready. The surgical duration is defined as the time interval between the initial incision and the completion of wound closure. Extubating and patient awakening are defined as the time interval between wound closure and the patient's transfer out of the operating room, which subsequently initiates the cleaning process. At Art Clinic, the surgeon often aids in transferring the patient from the surgery bed to the aftercare bed, leaving the operating room at the same time as the patient.

4.5 The Activities in the Sterile Processing Room

The sterile processing room is responsible for cleaning, packaging, and sterilizing surgical instruments to ensure they are safe and ready for use in upcoming procedures. It is staffed between 07:00-18:00 with two available shifts (07:00-16:00 or 09:00-18:00) with two sterile processing technicians and one assistant nurse. The sterile processing room contains one pre-cleaning area, two smaller washes and one bigger washer, a packaging area, two autoclaves and area for storage. The following chapter describes the flow of the sterile processing room, as illustrated in figure 4.

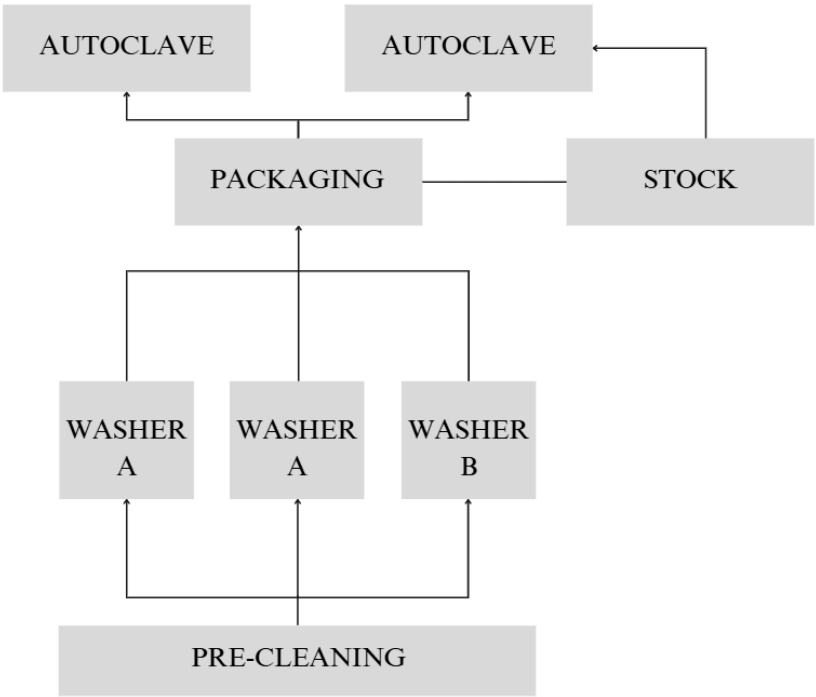


Figure 4: The steps performed in the sterile department visualized.

The instruments arriving from surgery are first manually pre-cleaned to remove debris in hard-to-reach areas that may not be reached in the washing machine. After this step, the instruments are placed in a washer that thoroughly cleans the equipment. When the washers are finished, the next step is to inspect, sort, reassemble, label, and pack the instruments. If any items are found to be insufficiently cleaned, they and other instruments next to it are required to go through the washer once more. Following the packaging, the surgical instruments are placed in the autoclave to be sterilized for 75 minutes. If the autoclaves are already running or the packaged instruments do not fit, it is instead placed in a storage area awaiting the autoclaves. The storage is limited to 20 containers at a time. Once out of the autoclave, the packages are inspected to make sure that they are intact and that the sterile indicators show successful sterilization through a color change of the labeling. The packaged instruments cool down for 15 minutes and are then placed in stock or taken directly to the next surgery depending on demand. The process with the longest duration is the autoclaves with a cycle time of 75 minutes per machine. Given the 11-hours of available time, the autoclaves can complete 16 cycles each day in total.

Various types of instruments are used in different surgeries, meaning that depending on the type of surgeries performed each day, the instruments take up more or less space in the washing machines and autoclaves. The total number of instruments required for knee replacements is 157 items, and for hip replacement surgery 119. In the current planning at Art Clinic, two joint replacement surgeries are usually performed simultaneously in two operating rooms. This creates the possibility of three different scenarios where instruments arrive at the sterile processing room: two knee replacements, two hip replacements or one knee- and one hip replacement surgery.

4.5.1 Two Knee Replacement Surgeries

The surgical instruments for knee replacement surgery consist of 6 containers and 2-3 cages in total. In figure 5 the containers are illustrated as a blue circle and the cages as half circles. During two knee surgeries, all three washers are used, leaving no washers free for other surgeries performed at the clinic. After the packing, the instruments are placed in the two autoclaves. However, as visualized in figure 5, the instrument for the surgeries will not fit in the autoclaves. Therefore, a stock is created, waiting for the autoclaves to finish their ongoing sterilization. The stock will contain either 6 containers or 6 cages, depending on what went into

the autoclaves. If there are additional knee surgeries performed during the day, the stock will increase in increments of 6, progressing to 12, 18 and so forth.

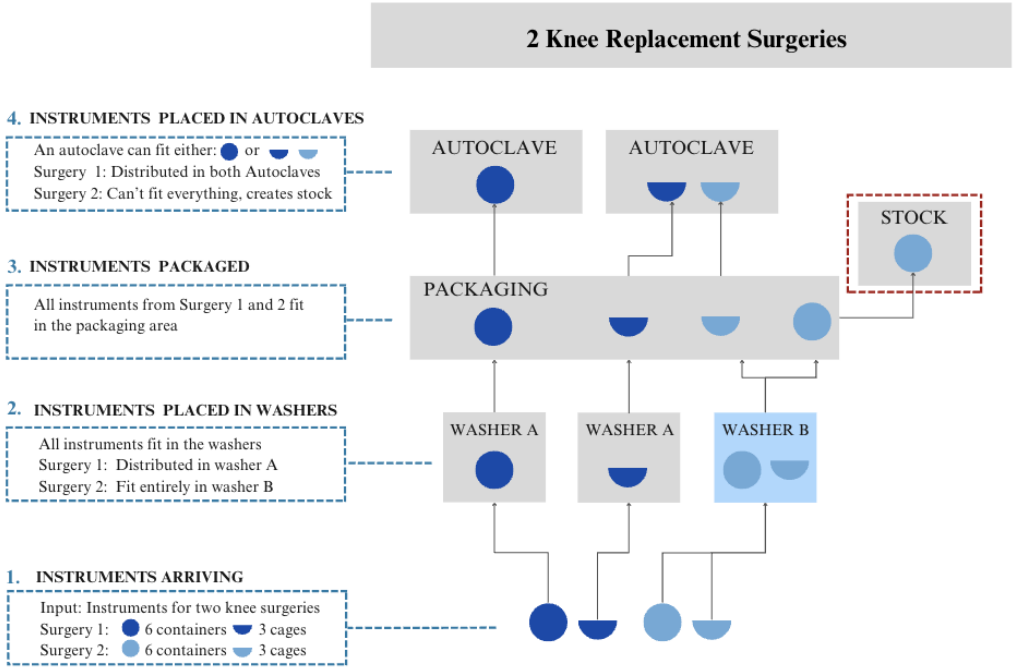


Figure 5: Describes how incoming instruments from two knee replacement surgeries travel through the processes of the sterile processing room, from step 1-4.

4.5.2 Two Hip Replacement Surgeries

The material used for two hip surgeries consists of 3 containers and 3 cages, represented as one figure, a blue dot in figure 6. During two hip surgeries, only two washers are needed, leaving the third washer free for other surgeries to use. One hip surgery can fit in one autoclave, thus both autoclaves are needed for two hip surgeries. There is no storage of items as both surgeries can fit in both the washers and autoclaves. On the other hand, if other surgeries need an autoclave, storage will be needed for those items.

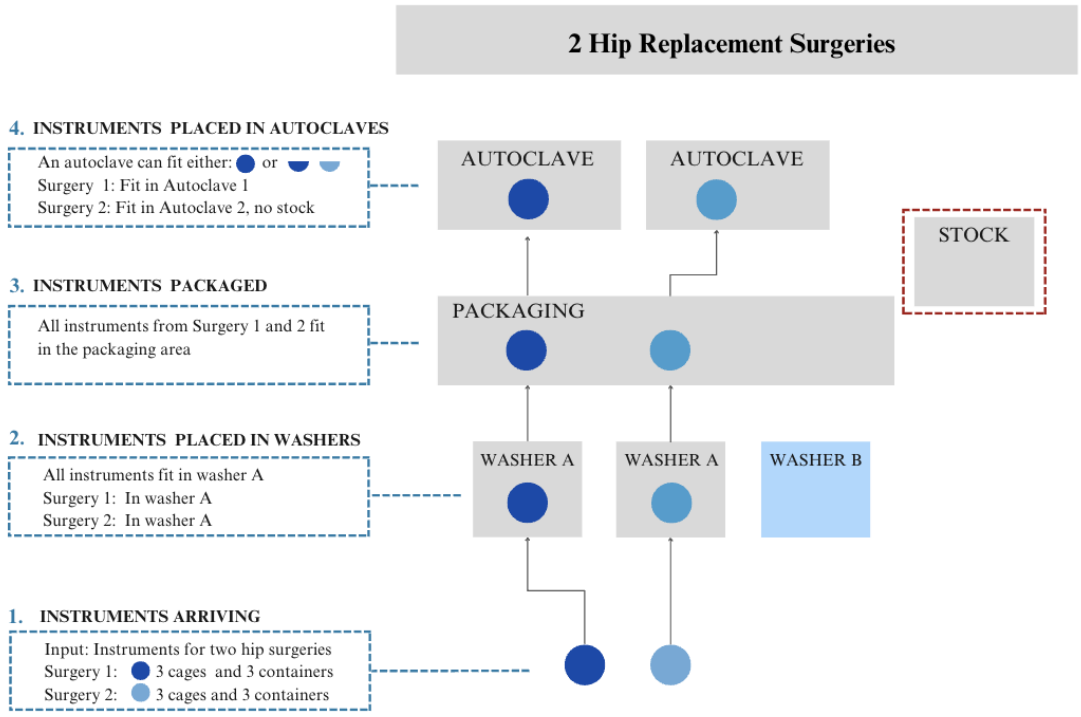


Figure 6: Describes how incoming instruments for two hip replacements travel through the processes in the sterile processing room, from step 1-4.

4.5.3 One Hip Replacement Surgery and One Knee Replacement Surgery

The scenario of instruments from one hip surgery and one knee surgery arriving at the sterile processing room is visualized in figure 7. The instruments from the knee surgery are placed in washer B, and the material from the hip surgery is placed in one of the other two washers. As only two out of the three washers are used, one will be available for other surgeries. The instruments from the hip surgery is placed in one of the autoclaves, and as there is not enough space for one knee replacement surgery in the second autoclave, storage is created for the items that cannot fit in the autoclave. If additional knee and hip surgeries are performed, the maximum amount of stock created is six containers.

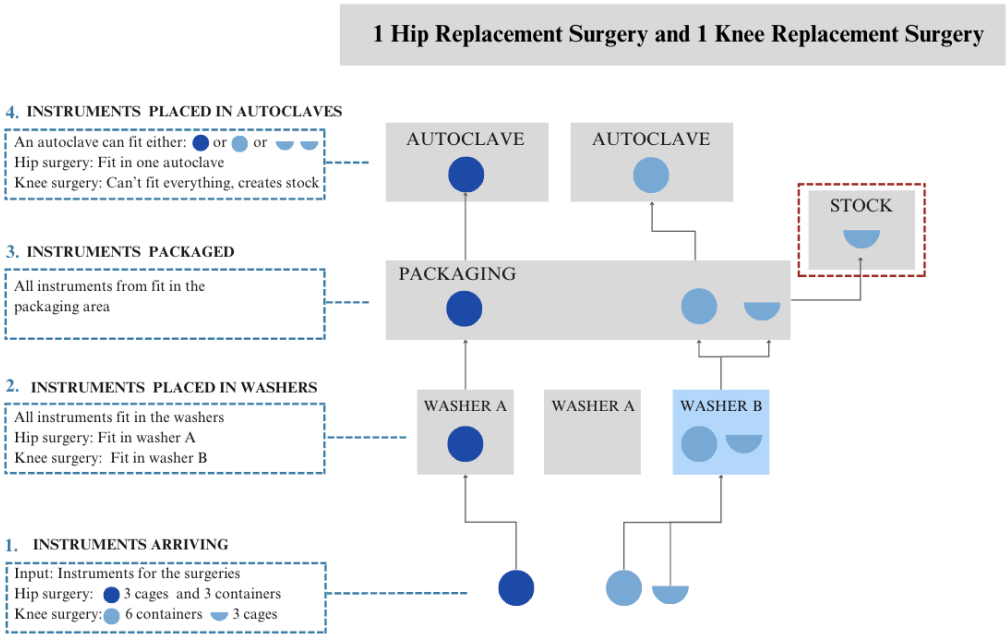


Figure 7: Describes how incoming instruments from 1 hip surgery and 1 knee surgery fit in the different processes of the sterile processing room, from step 1-4.

5 Quantitative results

For the quantitative analysis, historical data between January 2023 – December 2024 and data from the three-point estimate method are used to calculate the current capacity and variation in capacity for Art Clinic. The calculations are carried out individually for each unit to highlight their specific capacities and are based on the theoretical framework from chapter 2.6. For the best- and worst-case calculations, the numbers used are based on the 10^{th}-90^{th} percentile in order to capture the variation but exclude extreme outliers.

5.1 Preoperative Unit

In the preoperative unit the patient is prepared for surgery by a nurse and at Art Clinic there are two pre-operative preparation rooms, each holding two beds. The opening hours are 06:45-15:30, however after 14:00 the nurses usually do not have any patients and instead work with other tasks, for instance preparing for the upcoming day. Usually, there is only one nurse working in the unit at time, meaning that the nurse is responsible for maximum four patients at the same time.

The capacity of the preoperative unit refers to the number of patients that can be prepared for surgery based on the number of patients treated per hour and the available time. Following the equations in chapter 2.6, the results are as follows:

Design Capacity

Average preparation time per patient: 20 minutes

Total time during the shift: 8.5 hours

$$Design\ Capacity = \frac{60}{20} \times 8.5 \approx 26.25 = 26$$

Effective Capacity

Average preparation time per patient: 20 minutes

Available time during the shift: 7 hours

$$Effective\ Capacity = \frac{60}{20} \times 7 = 21$$

Best Case Capacity

Shortest preparation time per patient: 12 minutes

Available time during the shift: 7 hours

$$Best\ Case = \frac{60}{12} \times 7 = 35$$

Worst Case Capacity

Shortest preparation time per patient: 30 minutes

Available time during the shift: 7 hours

$$Worst\ Case = \frac{60}{30} \times 7 = 14$$

The design capacity for the preoperative unit is calculated to accommodate 26 patients per day, while the effective capacity is 21 patients. In best case they can prepare 35 patients per day if needed, and in worst case only 14, see figure 8 for an overview.

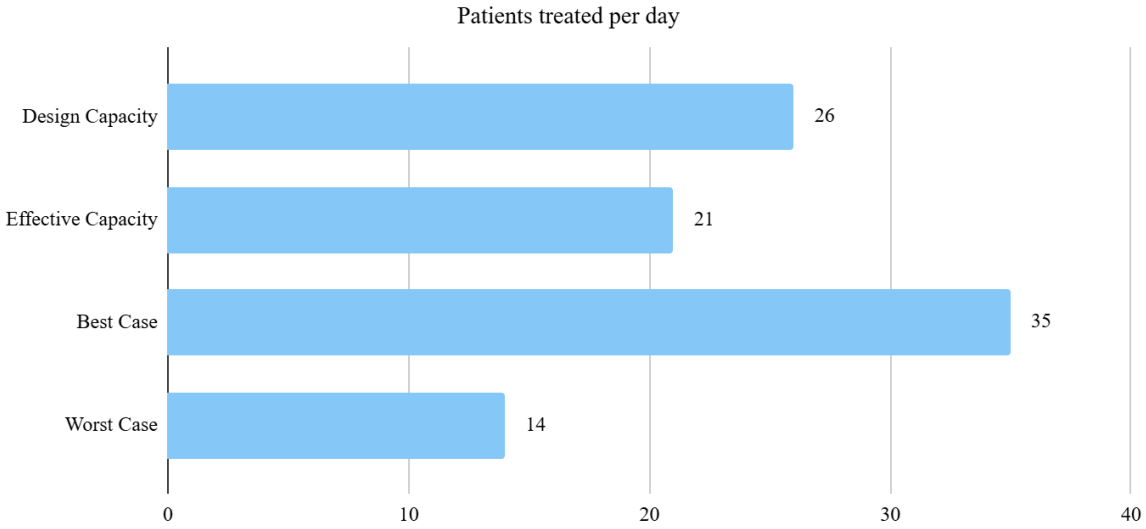


Figure 8: The design capacity, effective capacity, best case and worst case for the preoperative unit, expressed in number of patients treated per day.

5.2 Operating Room

There are three operating rooms in total where joint replacement surgeries can be performed, however the number of surgeons available seldom surpasses two, limiting the daily use to only two of them. The opening hours are between 07:00-16:00, but the first patient normally does not enter until 07:30 as preparations take place beforehand. The time in the operating room includes all the activities such as surgical setup, surgical duration, and turnover time. The capacity of the operating room is the number of patients that can undergo surgery per day. Following the equations in chapter 2.6, the results are as follows:

Design Capacity

Average time in the operating room, without idle time: 114 minutes

Total opening time: 9 hours

Operating rooms available: 3

$$Design\ Capacity\ per\ OR = \frac{60}{114} \times 9 \approx 5{,}04 = 5$$

$$Total\ Design\ Capacity = 5 \times 3 = 15$$

Effective Capacity

Average time in the operating room, with idle time: 123 minutes

Planned operating room time: 8.5 hours

Operating rooms available: 2

$$Effective\ Capacity\ per\ OR = \frac{60}{123} \times 8.5 \approx 4.14 = 4$$

$$Total\ Effective\ Capacity = 4.25 \times 2 \approx 8.5 = 8$$

Best Case Capacity

Shortest time in the operating room, without idle time: 92 minutes

Planned operating room time: 8.5 hours

Operating rooms available: 2

$$Best\ Case\ per\ OR = \frac{60}{92} \times 8.5 \approx 5.5 = 5$$

$$Total\ Best\ Case = 5.5 \times 2 \approx 11.1 = 11$$

Worst Case Capacity

Longest time in the operating room, including idle time: 140 minutes

Planned operating room time: 8.5 hours

Operating rooms available: 2

$$Worst\ Case\ per\ OR = \frac{60}{140} \times 8.5 \approx 3.64 = 3$$

$$Total\ Worst\ Case = 3.64 \times 2 = 7.28 = 7$$

The design capacity for the operating room is calculated to accommodate 15 patients per day, while the effective capacity is 8 patients. In best case they can accommodate 11 patients per day if needed, and in worst case only 7, see figure 9 for an overview.

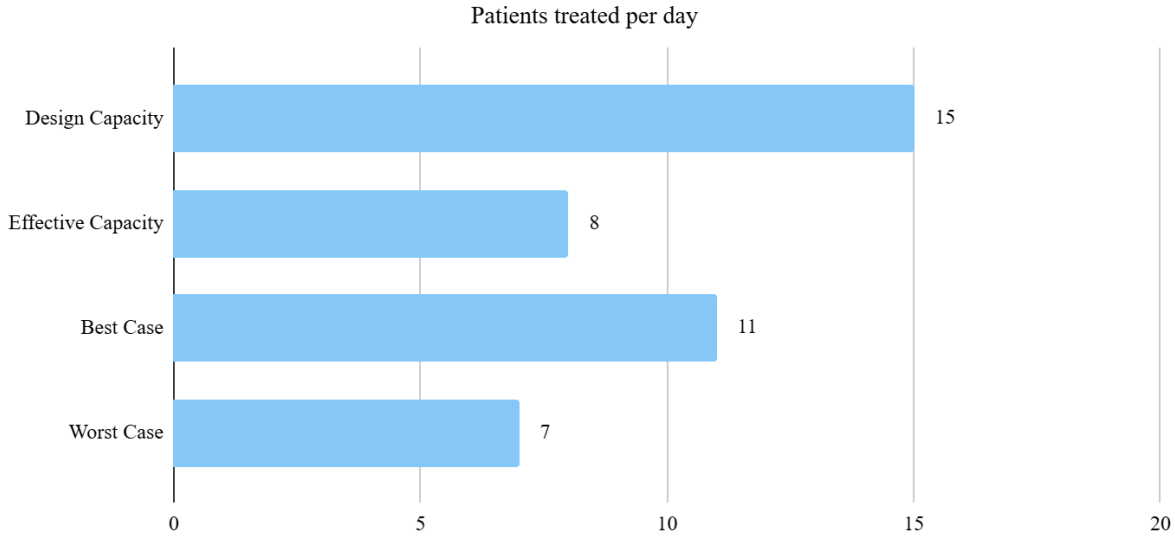


Figure 9: The design capacity, effective capacity, best case and worst case for the operating room, expressed in number of patients treated per day.

To gain a clearer understanding of how capacity is distributed across each operating room, rather than solely per day, the results were consequently broken down. As illustrated in figure 10, it is evident that, given current resources and scheduling, the available capacity is 4.5 patients per room per day. However, it is not possible to perform partial surgeries and therefore

the results can be explained by the following scenarios: One of the operating rooms completes 4 procedures and the other 5. This can for instance be explained by the surgical team's efficiency or the overall flow of their work during the day. It could also indicate that neither room completes its procedures within scheduled hours, resulting in working beyond regular working hours.

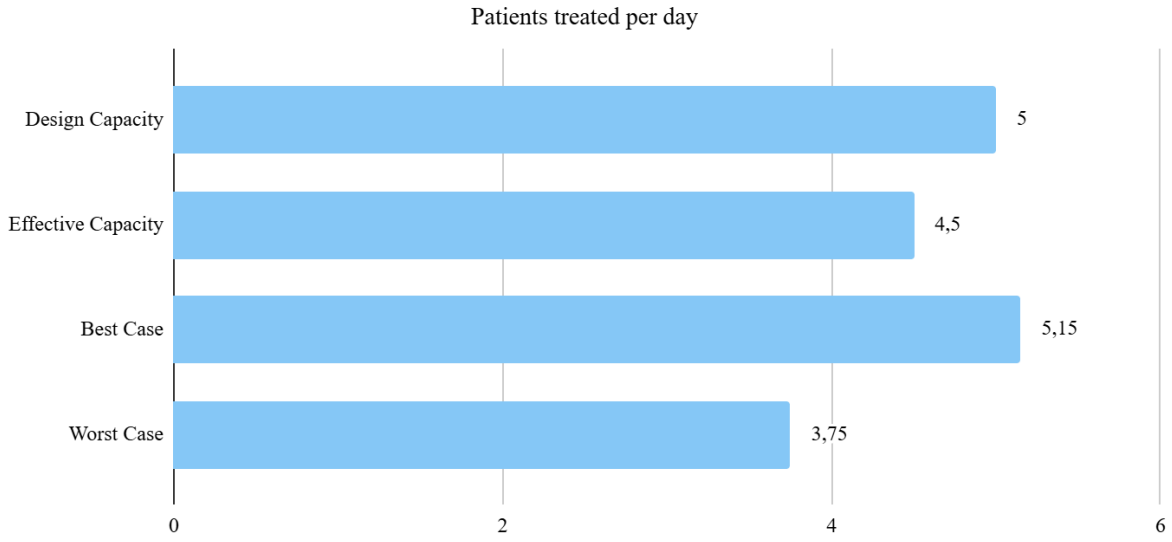


Figure 10: The design capacity, effective capacity, best case and worst case for the operating room, expressed in patients treated per operating room.

5.3 Post Anesthesia Care Unit & Postoperative Ward

The post anesthesia care unit is where patients are transferred to after their surgical procedure for monitoring and recovery. The unit is open between 08:00-20:00 and consequently staffed in two different shifts, the first one being 08:00-16:00 and the second one being 11:00-20:00. The patients arrive at the unit between 09:00-16:00. At Art Clinic the department consists of 14 beds and although the number of beds is limited, the unit can accommodate more patients throughout the day, as some patients only stay for a short period (usually between 2.5-3.5 hours), before being discharged. The capacity in the PACU refers to the maximum number of patients that can be safely monitored and cared for within a given period, considering the number of recovery beds, available staff, and average patient recovery time.

Design Capacity

Average recovery time: 180 minutes

Total time available: 12h

Number of beds: 14

$$Design\ Capacity = \frac{60}{180} \times 12 \times 14 = 56$$

Effective Capacity

Average recovery time: 180 minutes

Patient arrival hours: 7h

Number of beds: 14

$$Effective\ Capacity = \frac{60}{180} \times 7 \times 14 \approx 32.6 = 32$$

Best Case

Shortest recovery time: 150 minutes

Patient arrival hours: 7h

Available beds: 14

$$Best\ Case = \frac{60}{150} \times 7 \times 14 \approx 39.2 = 39$$

Worst Case

Longest recovery time: 210 minutes

Patient arrival hours: 7h

Available beds: 14

$$Best\ Case = \frac{60}{210} \times 7 \times 14 = 28$$

Patients who have undergone surgeries involving implants, including joint replacement procedures, or need extra monitoring are admitted to the postoperative ward where they have a mandatory overnight stay. In total there are 13 beds available and thus the capacity of the unit is 13 patients per day. As a result of the postoperative ward being shared between all implant procedures, the number of available beds, and the capacity for knee and hip replacement patients may be lower, depending on the other planned surgeries. See table 11, for an overview.

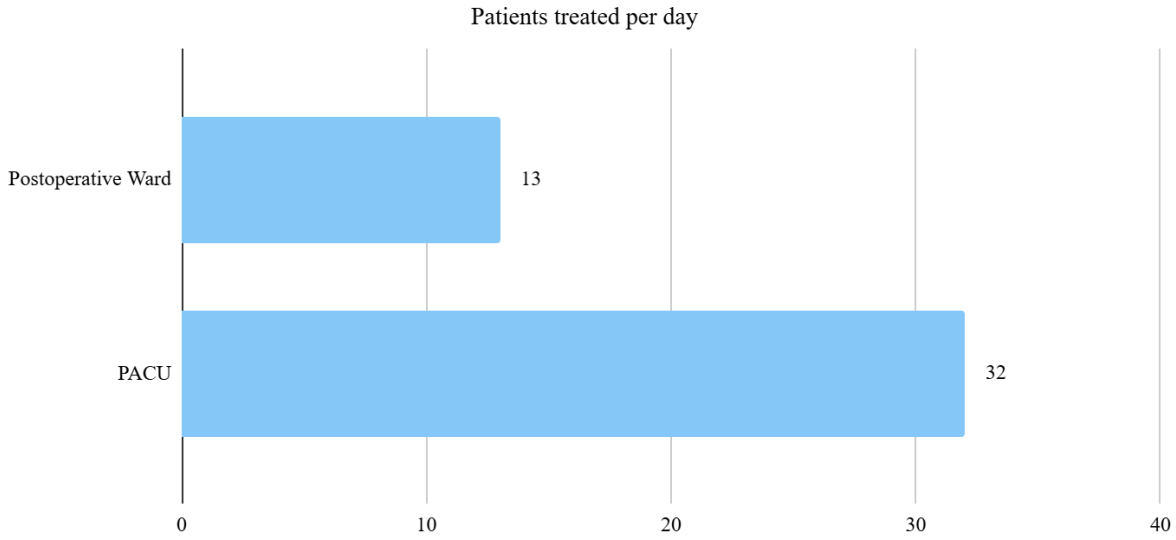


Figure 11: The capacity in the Postoperative Ward and PACU expressed in available beds.

5.4 Sterile Processing Room

The sterile processing room is a resource shared between all the different surgical procedures performed at Art Clinic. In the capacity calculation, the autoclave is identified as the bottleneck, as it represents the process step with the longest cycle time and therefore determines the overall throughput. Thus, the capacity is limited to the available time for autoclave cycles, and additionally, depend on what instruments are entering the sterile processing room.

Design Capacity

The design capacity for the sterile processing room is the theoretical maximum numbers of autoclave cycles per day, based on resources not being shared, which according to the previous equation is 16.

Effective Capacity

The sterile processing room is a shared resource, and in addition to the 8-9 joint replacement surgeries performed daily, between 6-13 other planned surgeries are conducted per day. The number of instruments used during these surgeries vary, and only few surgeries require one autoclave cycle. Six autoclave cycles are therefore allocated to non-joint replacement surgeries in the calculations. Consequently, the effective capacity equals the design capacity subtracted by 6, resulting in 10.

Best Case

The best case is described as receiving material from two hip replacement surgeries, as this requires the least amount of space in the autoclaves.

Number of possible autoclaves per day: 10

Number of autoclaves needed to complete one full setup: 1

$$Best\ Case = \frac{10}{1} = 10$$

Worst Case

The worst case is based on receiving material from two knee replacement surgeries, as it requires the most amount of space.

Number of possible autoclaves per day: 10

Number of autoclaves needed to complete one full setup: 1.5

$$Worst\ Case = \frac{10}{1.5} \approx 6.67 = 6$$

Overview

To summarize the capacity calculations for the sterile processing room, the effective capacity is calculated to 10 joint replacement surgeries, the worst case is described as receiving instruments from two knee replacement surgeries, resulting in a capacity of 6 surgeries (figure 12).

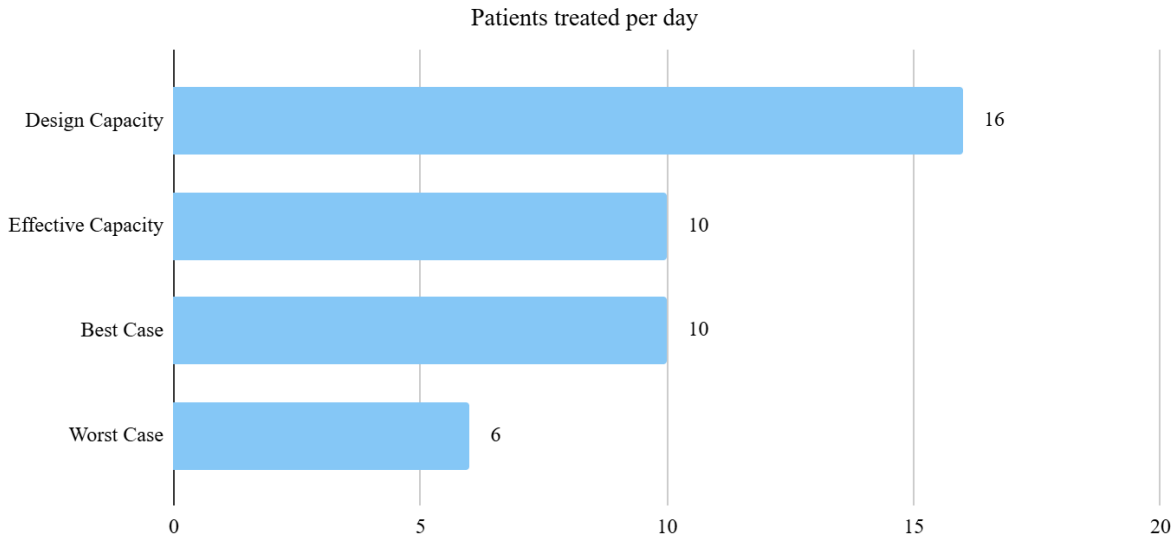


Figure 12: The number of complete instruments sets the sterile processing department can process per day.

5.5 Sterile Preparation Room

The sterile preparation room is located between operating room 2 and 3 and is used to prepare sterile equipment for all surgeries conducted each day. It is staffed based on demand by two members from the corridor team, typically a scrub nurse and an assistant nurse. The setup process begins at 07:00, during which the instruments and materials for the first two joint replacement surgeries for the day are prepared. Once those two procedures are in progress, the setup for the next two surgeries begin, and this cycle continues throughout the day. The goal is to always stay one step ahead with the surgical setups, ensuring that no upcoming procedure is delayed due to unprepared materials.

In this process step, it is particularly difficult to map out the exact capacity or timing, as the workflow is parallelized with the surgeries and carried out routinely by staff who are familiar with the schedule. According to conversations with scrub nurses and assistant nurses in the unit, the sterile set up process itself is never perceived as a problem, nor does it cause delays in surgery. However, what may occasionally occur is something referred to as an *instrument conflict*, meaning what essential instruments or equipment have not yet been processed in the preceding step – the sterile processing room. In such cases, problems can arise in the sterile preparation room as well since it is directly dependent on the previous process to function

effectively. Aside from these exceptions, the setup process is considered reliable and efficient, therefore, capacity will not be calculated for this room in this study.

5.6 Analysis of capacity and variations

To summarize the findings in regards of capacity, it can be stated that there are two primary bottlenecks limiting the capacity at Art Clinic: the sterile processing room, and the operating room, as visible in figure 13. Following this finding, further investigations were made to analyze the processes.

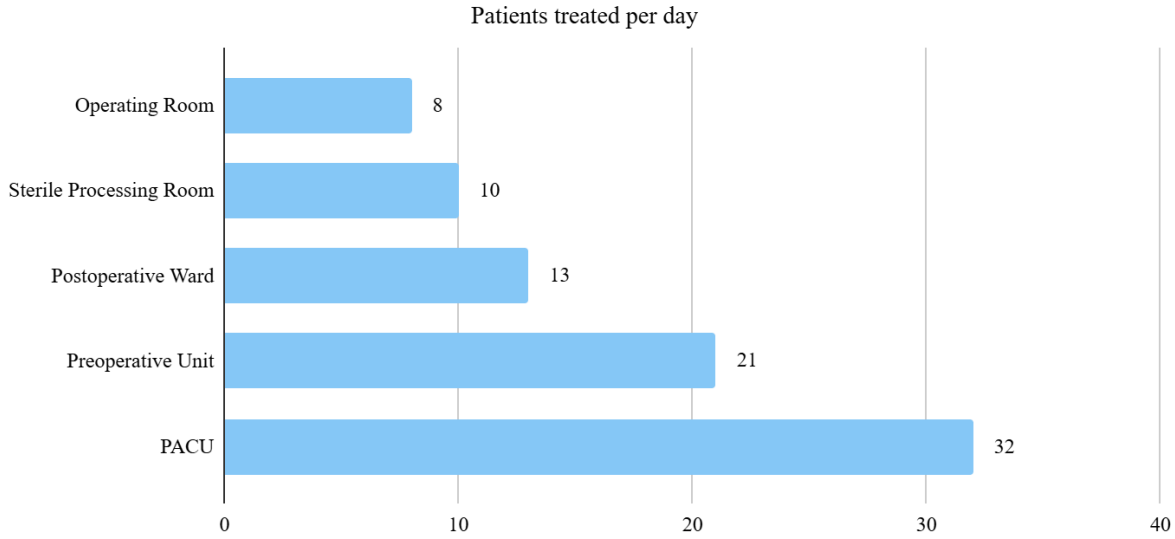


Figure 13: Summary of the effective capacity for all activities analyzed.

The operating room workflow consists of several activities, and these will be divided into two categories for the purpose of analyzing: *main activities* and *support activities.* The main activities are defined as the activities performed during the surgery, including all the steps between incision and completion of surgery. The support activities are activities that also utilize the time in the operating room, which are not directly linked to the procedure but are necessary to perform the surgery. These include time required for surgical setup, the time between completion of surgery to patient exit, cleaning of the operating room and idle time between patients. Examining the main- and support activities, it is evident that each represents 50% of the total allocated operating room time, as visualized in figure 14.

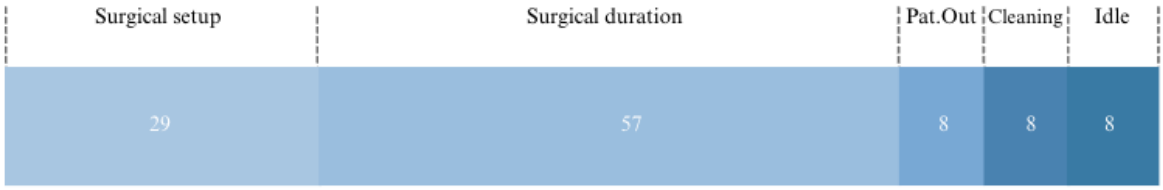


Figure 14: The main- and support activities in the operating room with their average duration expressed in minutes.

To examine if the different activities in the operating room have any relationship, a multivariate correlation matrix and color map of correlation (figure 15) was used. A strong positive relationship between two variables is represented with 1.0 in the matrix, and a bright red in the color map. If a strong negative relationship between two variables is found, it is represented with -1.0 in the matrix, and a dark blue color in the color map. The result shows a weak-to no correlation between the activities, with values close to 0 in the matrix, and no strong colors depicted in the color map. This shows that the duration of one activity, does not affect the duration of another. The strongest correlation, shown in a darker blue in the color map of correlation and -0,2011 in the matrix is between the time to patient exit and the cleaning duration. Although this is a weak relationship, a possible explanation was given during the observations in the operating room. If a patient required extra time to regain consciousness and exit the operating room, the cleaning process began during the waiting period, thereby reducing the overall cleaning time.

	Surgical setup	Surgical Duration	Time to patient exit	Cleaning duration	Idle time
Surgical setup	1,0000	0,1118	0,0575	-0,0084	-0,0703
Surgical Duration	0,1118	1,0000	-0,0331	0,0411	-0,1007
Time to patient exit	0,0575	-0,0331	1,0000	-0,2011	-0,1350
Cleaning duration	-0,0084	0,0411	-0,2011	1,0000	-0,0077
Idle time	-0,0703	-0,1007	-0,1350	-0,0077	1,0000

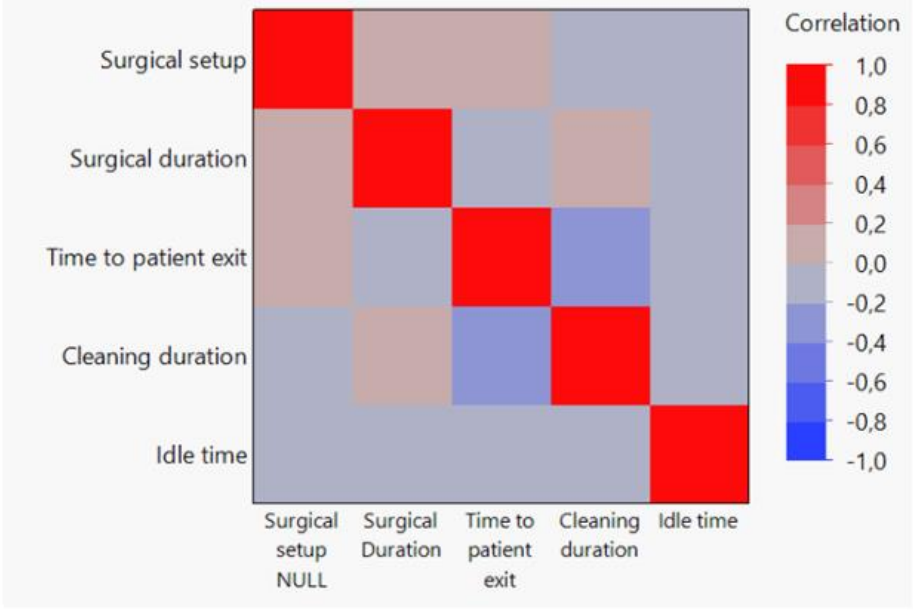
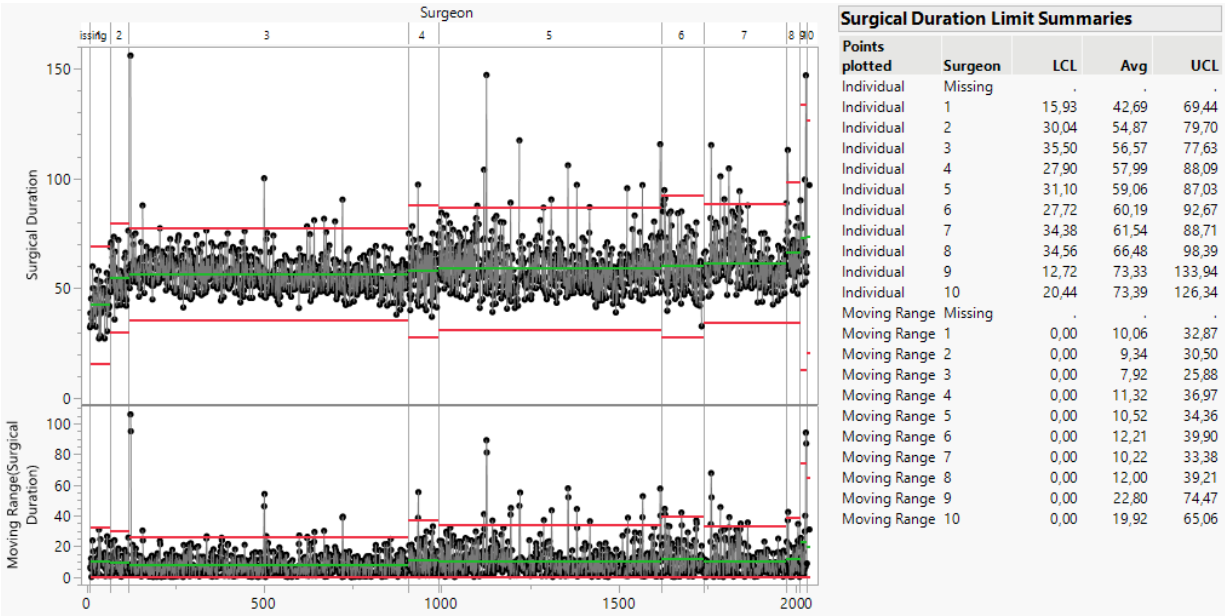


Figure 15: A multivariate correlation matrix for the activities in the OR and a color map of the correlations.

5.6.1 Main Activities in the Operating Room

Analyzing the surgical duration across all joint replacement procedures indicated that the average duration differed between surgeons. However, the control chart stratified by surgeon (figure 16), revealed that the majority of variations in surgical duration occur within each surgeon's own set of procedures, rather than between different surgeons. The average surgical duration ranged from 43 minutes (surgeon 1) to 73 minutes (surgeon 10). Further, most of the data points fall within the control limits, suggesting that the observed variation is largely due to common causes, inherent to the process. However, some individual observations, especially among surgeons with lower or higher averages, exceed the control limits. These may represent special cause variation.



Surgical Duration Limit Summaries

Points plotted	Surgeon	LCL	Avg	UCL
Individual	Missing	.	.	.
Individual	1	15,93	42,69	69,44
Individual	2	30,04	54,87	79,70
Individual	3	35,50	56,57	77,63
Individual	4	27,90	57,99	88,09
Individual	5	31,10	59,06	87,03
Individual	6	27,72	60,19	92,67
Individual	7	34,38	61,54	88,71
Individual	8	34,56	66,48	98,39
Individual	9	12,72	73,33	133,94
Individual	10	20,44	73,39	126,34
Moving Range	Missing	.	.	.
Moving Range	1	0,00	10,06	32,87
Moving Range	2	0,00	9,34	30,50
Moving Range	3	0,00	7,92	25,88
Moving Range	4	0,00	11,32	36,97
Moving Range	5	0,00	10,52	34,36
Moving Range	6	0,00	12,21	39,90
Moving Range	7	0,00	10,22	33,38
Moving Range	8	0,00	12,00	39,21
Moving Range	9	0,00	22,80	74,47
Moving Range	10	0,00	19,92	65,06

Figure 16: Control chart representing the variation in surgical duration by surgeon (top), as well as the moving range (bottom).

A one-way analysis of variation, ANOVA, was conducted to assess whether the surgical duration differed between surgeons. The analysis showed a statistically significant effect of the individual surgeon on surgical duration, with $p<0.0001$, see table 9. Despite this statistical significance, the variance between surgeons accounted for a relatively small proportion of the overall total variance, compared to the within-surgeon variance. This suggests that although the difference between the surgical duration was statistically significant, it accounted only for 12% of the total variance, while the remaining 88% is due to within-surgeon variation. The findings suggest that surgeon identity plays a minor role in explaining the variation.

Table 9: The results from the ANOVA for the surgical duration amidst surgeons.

ANOVA					
Source	**DF**	**Sum of Squares**	**Explained Variance**	**Mean Square**	**F Ratio**
Surgeron (between)	9	26615.83	0.1195 ≈ 12%	2957.31	29.1903
Error (within)	1936	196139.17	0.8805 ≈ 88%	101.31	Prob > F
C. Total	1945	222.755			< 0.0001

To examine the utilization of the operating room, an analysis of the planned time and actual surgical duration was conducted. Using a scatter plot, with defined mean and range was used to visualize the outcome, see figure 17. The black line indicates the mean surgical duration for each planned time category. The comparison between planned- and actual surgical duration

demonstrates weak correspondence across all categories. Moreover, a high degree of variation is also evident within each planned duration group (60, 70, etc.), especially in the 70 minute-group, where both the spread of data and the number of outliers were high. This supports the conclusion that planned time alone is a poor predictor of actual surgical duration and that the current planning intervals do not adequately account for the observed variability.

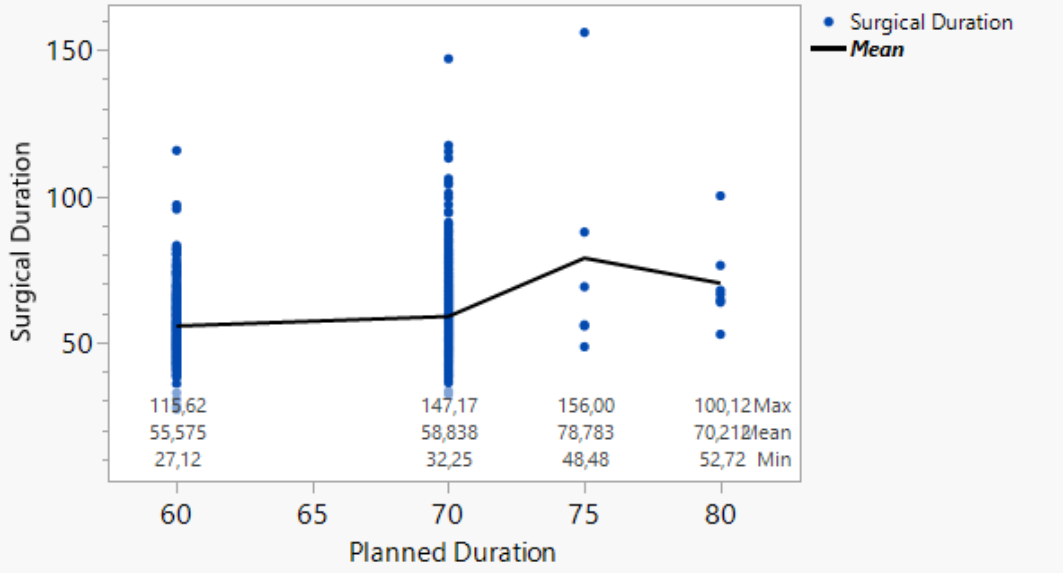


Figure 17: Scatterplot showcasing the planned surgical duration (x-axis) versus the actual surgical duration (y-axis). In the bottom of the figure, the mean as well as the maximum- and minimum value is presented.

Diving deeper into this and investigating the control chart, see figure 18, it can be stated that there is a consistent overestimation of surgical duration in the planning process. On average, the surgeries are completed approximately 9.5 minutes faster than scheduled. However, the process exhibits variation with several instances of large deviations both above and below the control limits, indicating the presence of special cause variation.

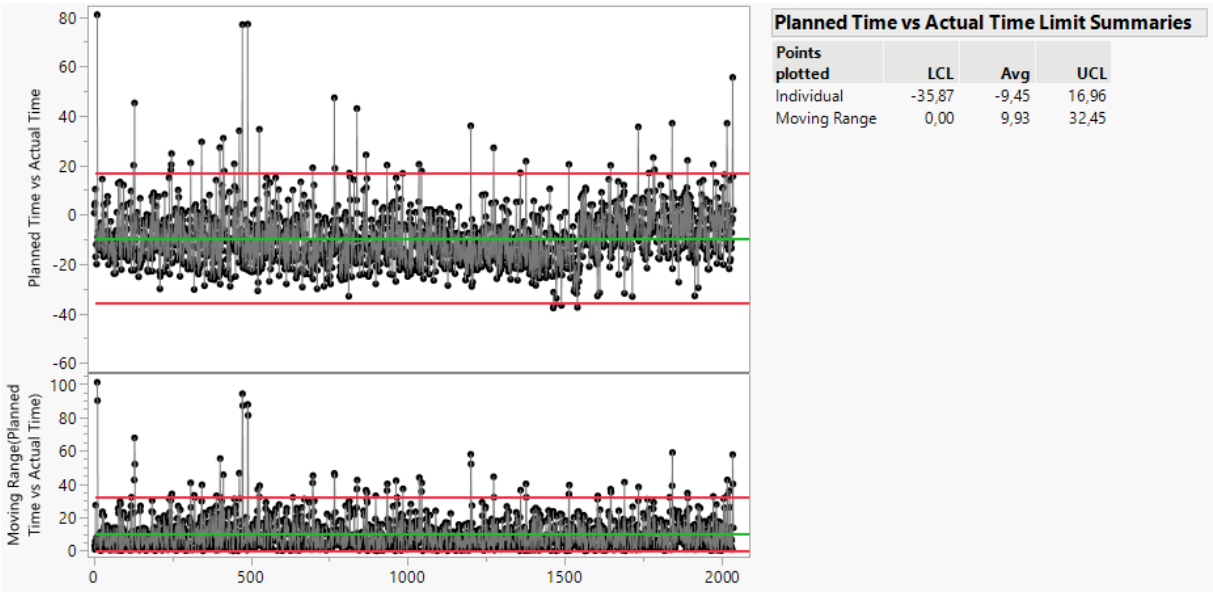
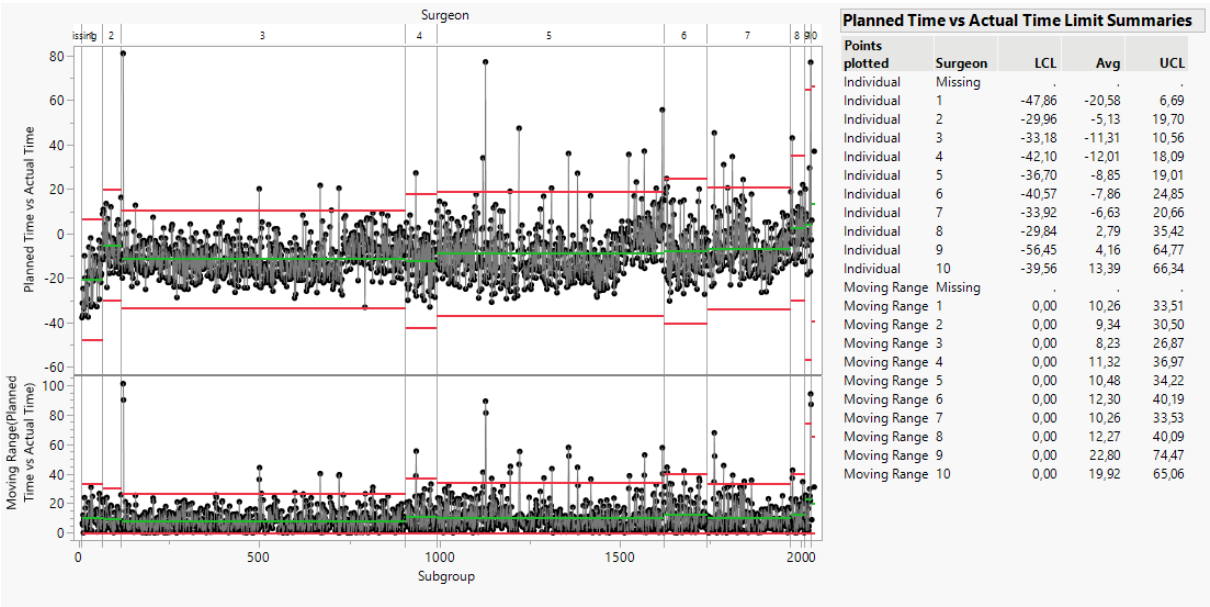


Figure 18: Control chart visualizing the planned time vs actual surgical duration (top) and the moving range (bottom) between the planned time and actual surgical duration.

An additional analysis was also conducted to explore potential influencing factors, specifically whether differences in surgeon or type of surgical procedure affected the inconsistency between planned and actual surgical duration. Regarding the surgical procedure, the control chart analysis for knee and hip procedures also reveals a consistent overestimation in planning. Similar to previous analysis, surgeries are approximately 9-10 minutes faster than scheduling, regardless of what procedure, suggesting a systematic buffer in the planning process where it is planned for 10 minutes of "waste" each procedure. The control chart stratified by surgeon also points toward variation in the accuracy of planned surgical duration (figure 19). For instance, surgeon 1 stands out with an average deviation of -20.6 minutes, while surgeon 10 exhibits a positive deviation of +13.4 minutes, meaning their procedures are typically not aligned with the planned duration.



Planned Time vs Actual Time Limit Summaries

Points plotted	Surgeon	LCL	Avg	UCL
Individual	Missing	.	.	.
Individual	1	-47,86	-20,58	6,69
Individual	2	-29,96	-5,13	19,70
Individual	3	-33,18	-11,31	10,56
Individual	4	-42,10	-12,01	18,09
Individual	5	-36,70	-8,85	19,01
Individual	6	-40,57	-7,86	24,85
Individual	7	-33,92	-6,63	20,66
Individual	8	-29,84	2,79	35,42
Individual	9	-56,45	4,16	64,77
Individual	10	-39,56	13,39	66,34
Moving Range	Missing	.	.	.
Moving Range	1	0,00	10,26	33,51
Moving Range	2	0,00	9,34	30,50
Moving Range	3	0,00	8,23	26,87
Moving Range	4	0,00	11,32	36,97
Moving Range	5	0,00	10,48	34,22
Moving Range	6	0,00	12,30	40,19
Moving Range	7	0,00	10,26	33,53
Moving Range	8	0,00	12,27	40,09
Moving Range	9	0,00	22,80	74,47
Moving Range	10	0,00	19,92	65,06

Figure 19: Control chart visualizing the planned time vs actual surgical stratified by surgeon.

5.6.2 Support Activities in the Operating Room

The average time spent on the support activities in the operating room is 57 minutes, varying between 47 minutes (10^{th} percentile) to 76 minutes (90^{th} percentile), indicating that 80% of support activities fall within this interval. A further examination was conducted with a control chart analysis, see figure 19, revealing that the process is stable over time, with very few datapoints falling outside the upper and lower control limits. The average time spent on support activities during each surgical procedure is almost 60 minutes. The variation ranges between 24 minutes, being the lowest amount spent, and 96 minutes on those activities. Overall, the most variation is due to common causes, however there are a limited amount of special cause factors.

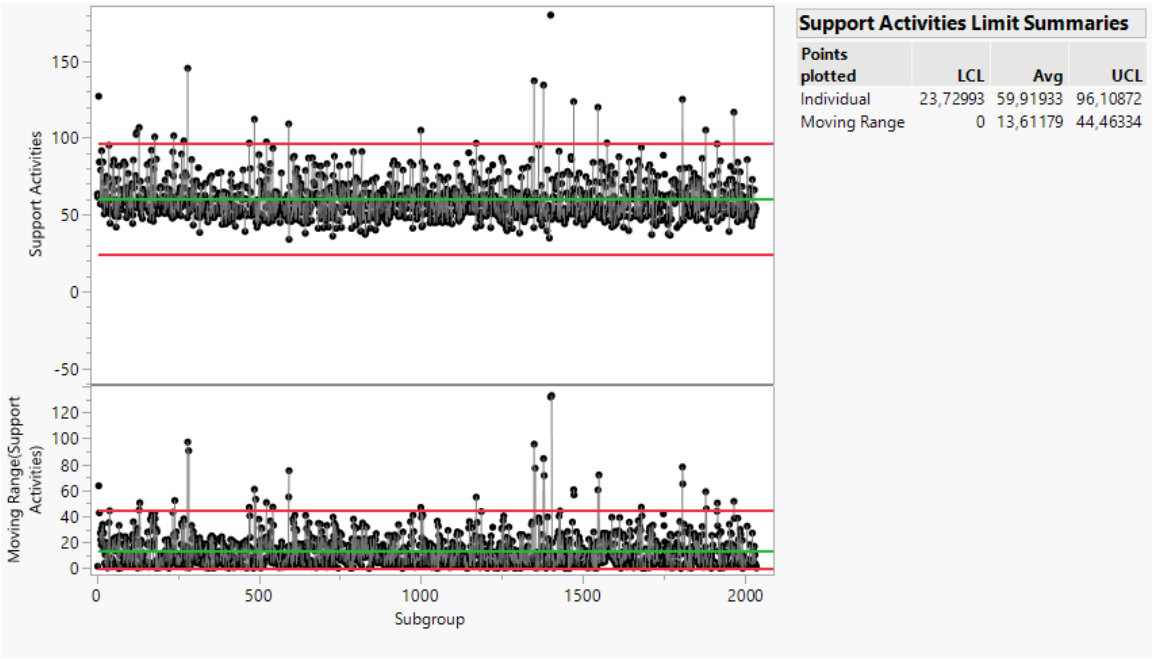


Figure 20: Control chart showcasing the variation in the duration of the support activities (top) as well as the moving range (bottom).

To further investigate, their distribution was depicted in a scatterplot (figure 20). Notably, the two processes with the widest spread in duration are the surgical setup and the idle time between patients exit until the next patient arrives, suggesting higher unpredictability. In contrast, the time to patient exiting and the cleaning duration display a narrower spread, indicating a more consistent execution.

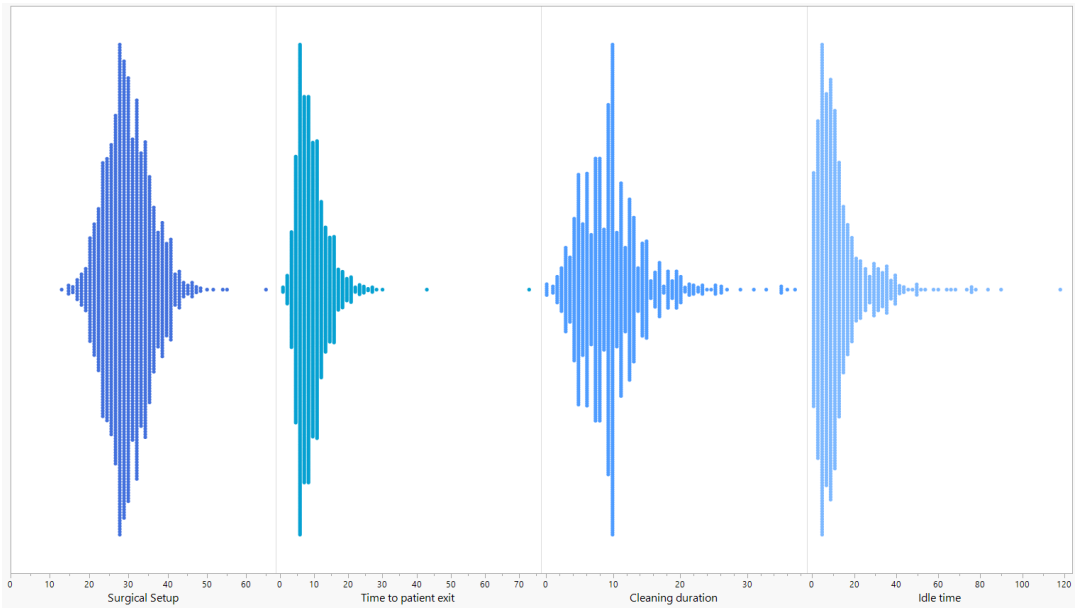


Figure 21: Illustrates the distribution of each support activity using a scatterplot.

Additionally, the variation in duration for the process steps were analyzed in comparison with the type of surgery. Notably, for hip replacement surgeries, the surgical setup is slightly longer (figure 20). The control chart shows a relatively stable process with most values within the control limits. However, a consistent difference is observed between procedure types. Hip replacements require a longer average setup time of 32.8 minutes (ranging from 20-46 minutes), compared to 26.6 minutes (ranging from 14-40 minutes) for knee replacements. The low number of outliers and narrow moving range value suggest that the setup process is primarily influenced by common cause variation.

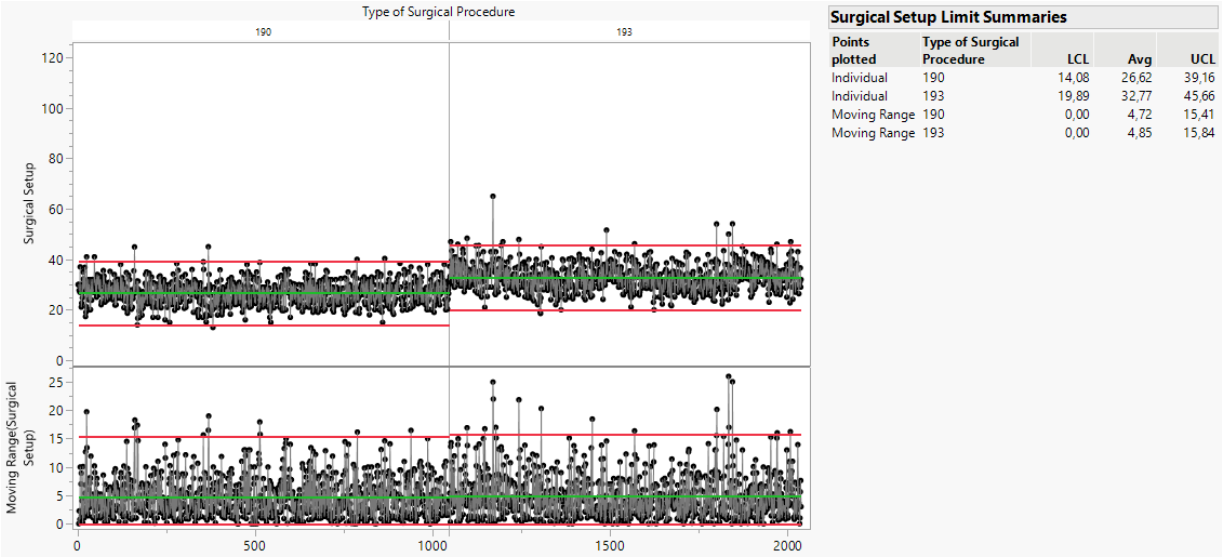


Figure 22: Control chart depicting the variation in surgical setup depending on type of surgery where 190= knee replacement surgery and 193=hip replacement surgery.

To determine if the observed differences in the support activities between surgical procedure types were statistically significant, a one-way ANOVA was conducted for each process step. Beginning with the surgical setup time, there is a statistically significant difference between knee and hip procedures, see table 13 for an overview. Hip replacements have a longer average setup duration, and the procedure type explains 28.6% of the variation in this step. This suggests that hip replacement surgeries require more time or more complex preparation in the operating room compared to knee replacement surgeries. For both time to patient exit after complete procedure and duration of cleaning the operating room, there was no statistical significance. Lastly, the ANOVA test revealed that there is a statistically significant difference (p=0.0428) in the idle time between knee and hip procedures. Inspecting all parameters in the ANOVA test,

the difference in the mean value between the procedure types is limited and have an overlapping confidence interval, implying that it will not have a meaningful effect.

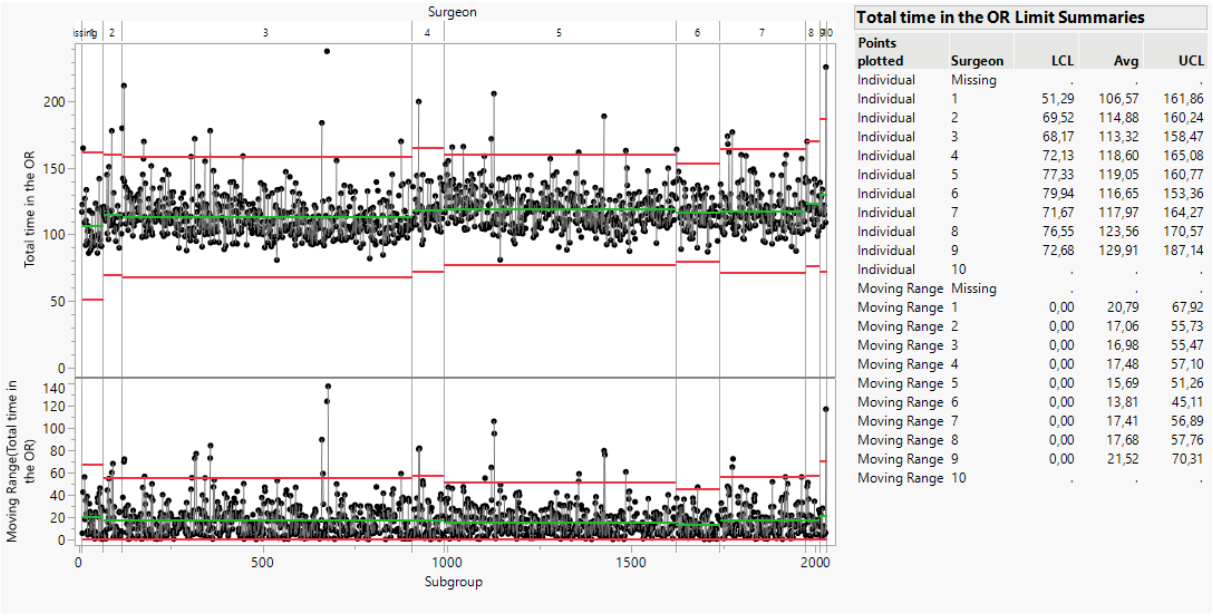
Table 10: The results of the ANOVA for the surgical setup time, time to patient exit, cleaning of the operating room and idle time awaiting the next patient.

ANOVA				
Surgical Setup Time				
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	5176.53	5176.53	46.2507
Error	1944	217578.48	111.92	Prob > F
C. Total	1945	222755.00		< 0.0001
Time to patient exit				
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	42.667	42.6668	2.0930
Error	1914	39018.7	20.3859	Prob > F
C. Total	1915	39061.367		< 0.1481
Cleaning of the operating room				
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	7.792	5.7922	0.2731
Error	1840	39023.355	21.2083	Prob > F
C. Total	1841	39029.148		< 0.6013
Idle Time (waiting for next patient)				
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	555.65	555.647	4.1118
Error	1321	178514.13	135.136	Prob > F
C. Total	1322	179069.78		< 0.0428

5.6.3 The Effects on the Total Time in the Operating Room

As previously mentioned, the main activities and the support activities each account for an equal share of the total time spent in the operating room. It has also been shown that the duration of each of the activities in the operating room varies. However, in the analysis it was concluded that one surgeon has a shorter average surgical duration, and that knee surgeries often have a shorter setup time. To evaluate if the shorter time spent on surgery and surgical setup influences the total time spent in the operating room, two control charts were created, depicting the total time in the operating room stratified on surgeon and type of surgery.

The control chart stratified by surgeon (figure 23) indicates only minor differences in total time spent in the operating room across surgeons. The time saved by operating at a faster pace is reduced due to the variation in the other activities. While surgeon 1 on average performs surgeries 14 minutes quicker than surgeon 3, the difference in average total time in the operating room is 7 minutes. The large variation within the processes for each surgeon is greater than the variation between the total time spent in the operating room per surgeon. Meaning that even though it earlier was presented that surgeon 1 has short surgical duration, they still utilize the same amount of time in the operating room.

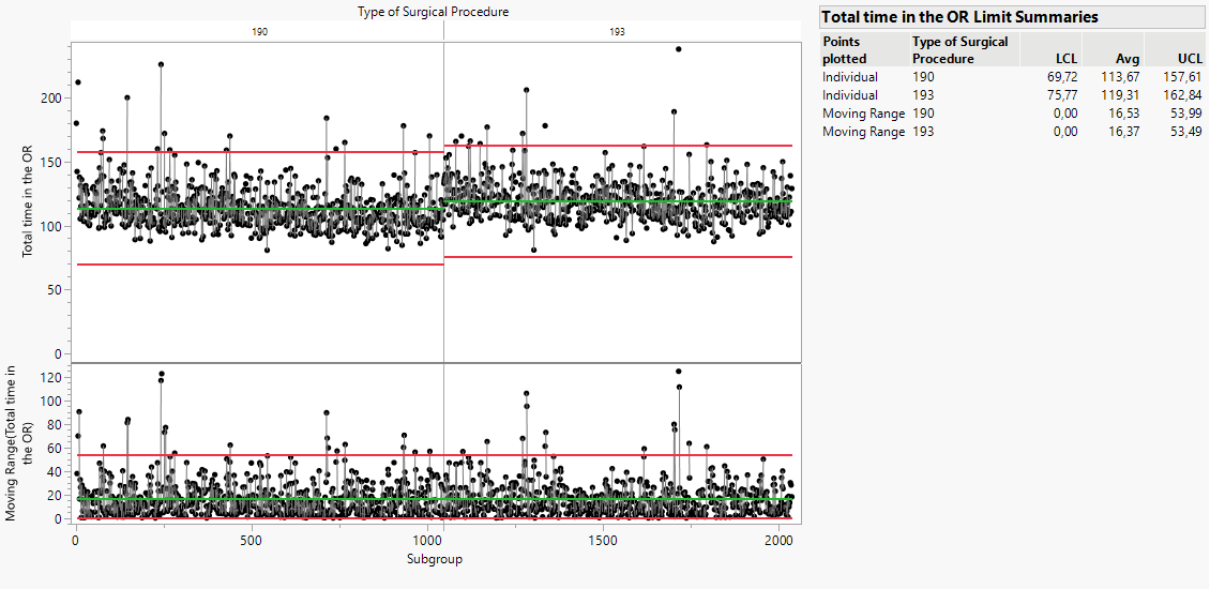


Total time in the OR Limit Summaries

Points plotted	Surgeon	LCL	Avg	UCL
Individual	Missing	.	.	.
Individual	1	51,29	106,57	161,86
Individual	2	69,52	114,88	160,24
Individual	3	68,17	113,32	158,47
Individual	4	72,13	118,60	165,08
Individual	5	77,33	119,05	160,77
Individual	6	79,94	116,65	153,36
Individual	7	71,67	117,97	164,27
Individual	8	76,55	123,56	170,57
Individual	9	72,68	129,91	187,14
Individual	10	.	.	.
Moving Range	Missing	.	.	.
Moving Range	1	0,00	20,79	67,92
Moving Range	2	0,00	17,06	55,73
Moving Range	3	0,00	16,98	55,47
Moving Range	4	0,00	17,48	57,10
Moving Range	5	0,00	15,69	51,26
Moving Range	6	0,00	13,81	45,11
Moving Range	7	0,00	17,41	56,89
Moving Range	8	0,00	17,68	57,76
Moving Range	9	0,00	21,52	70,31
Moving Range	10	.	.	.

Figure 23: Control chart depicting the total time in the operating room by surgeon.

The control chart stratified by type of surgery (figure 24) indicates a minor difference in average time spent in the operating room, where hip replacement surgeries on average take 6 minutes longer than knee replacement surgeries. When comparing it to the average difference in surgical setup duration for the type of surgeries, hip surgeries also took 6 minutes longer on average. Thus, the average longer variation in surgical setup times is not reduced by the variation in the other processes.



Total time in the OR Limit Summaries

Points plotted	Type of Surgical Procedure	LCL	Avg	UCL
Individual	190	69,72	113,67	157,61
Individual	193	75,77	119,31	162,84
Moving Range	190	0,00	16,53	53,99
Moving Range	193	0,00	16,37	53,49

Figure 24: Control chart depicting the total time in the operating room by type of surgery, 193 = hip surgery, 190 = knee surgery.

5.6.4 Sterile processing room

The sterile processing room effective capacity was calculated to receive instruments from 10 surgeries. On the other hand, the worst-case capacity was calculated to be six knee surgeries, as these surgeries instruments require more space in the autoclave. For six knee surgeries, the autoclaves will run nine times to process all the materials. With a running time of 75 minutes, this will take approximately 6.4 hours for the staff to complete. As there are other surgeries which also require autoclaves, it leaves 4.6 hours for autoclaving instruments from other surgeries which is enough time to run three cycles per autoclave. The stock will reach 18 containers or cages, which is visualized in table 11 as the space in the storage is limited to 20 containers, it will fit. If materials are received from eight surgeries, the storage will increase above the limit of 20 containers.

Table 11: A simulation of the flow of instruments when six knee replacement surgeries are performed, showing the created stock and their placement in the autoclaves.

Surgical Procedure	Instruments	Autoclave A	Autoclave B	Stock
#1 #2				
#3 #4				
#5 #6				
Stock Clerance				
Stock Clerance				

6 Qualitative results

In this segment, the results from the qualitative methods used during the study are presented, namely from the effective scoping, AIM-workshop, interviews, observations and study visit.

6.1 Effective scoping

In line with the Six Sigma methodology, effective scoping was conducted to gain a comprehensive view of the process and aid in defining the problem accurately. It was conducted with a key stakeholder at Art Clinic, namely the unit manager. The result of the effective scoping is presented in Appendix C.

At the initial stage of the project, the main area of concern was the operating room. However, through observations and the results presented in the AIM-workshop, it became evident that limiting the analysis to one single process would not sufficiently address the root cause of the capacity limitations. Instead, a more holistic approach was needed where upstream activities such as patient preparations, scheduling and material inflow were analyzed. This change in the scope of the project reflects a shift from “push thinking” to “pull thinking”, rather than focusing on one process, it was necessary to view the system as an interconnected whole, where actions upstream influence downstream outputs. Therefore, the measure chosen to investigate was redefined to include the entire process, starting from when the patient is checked in until the patient is in the postoperative ward, to identify the bottlenecks limiting the capacity.

While the bottlenecks are the focus of investigation, it became evident that the service quality, patient safety and not disturbing the flow for other surgical procedures are important aspects not to be compromised. Another significant insight from the effective scoping was the identification of missing data points in the processes outside of the operating room, as existing measures did not cover all activities in need of analysis. To address this gap, three-point estimate was used to collect approximate data on the unmeasured processes.

6.2 AIM-workshop

The key question guiding the workshop was: *What are the major challenges in managing a higher number of patients in the flow?* For this study, *patients* were exclusively defined as individuals in need of hip and knee replacements. The results from the workshop revealed that

all expressed concerns and challenges fundamentally stemmed from the risk of compromising quality when managing a higher volume of patients in the flow, and the formulated problem-statement ended up being:

Equipment and staffing are insufficient. This leads to an increased workload for the staff, which in turn may pose a risk of reduced quality.

In addition to the major problem formulation and overarching concern, the following five issues were also highlighted by the staff:

1. The surgical department is too small, with insufficient resources in terms of equipment, supplies, and staff, to perform a higher number of surgeries.

2. Increased workload may lead to employee dissatisfaction, which in turn could affect the reputation of Art Clinic and lead to declining attractiveness as a workplace. Consequently, making future recruitment more challenging.

3. An increase in the number of patients per day could make staff feel unheard regarding their workload and unable to guarantee the quality of care they take pride in delivering. Furthermore, there are already instances of the "wrong" person in the wrong role within the organization, leading to the underutilization of employees' full competencies which can cause an unsatisfying work environment.

4. Lack of space for patients affects the number of incoming patients possible, as there is currently no room for postoperative care for additional patients.

5. Increased material costs will also arise in connection with a potential expansion and to accommodate a future increase in capacity.

In conclusion, the AIM-workshop identified several additional factors that could influence the current state, hence broadened the perspective of the problem formulation. The results also acted as a guide for examining other parts of the process that might be impacted by these factors.

6.3 Interviews and observations

The following sections will elaborate on the findings from the observations and interviews conducted at Art Clinic.

6.3.1 Observations

Most of the observations in this study were conducted in the operating room during ongoing surgeries. During the participant observations, issues related to positioning the patient emerged during the surgical setup. In several cases, and particularly during hip replacement surgeries, the nursing team encountered difficulties in securing the hip support in a stable and anatomically correct position for the patient. First and foremost, during hip procedures, it was challenging to attach the support to the operating table, as the existing rail system did not always align well with patients of different heights. Furthermore, nurses occasionally struggle to achieve the correct positioning of the patients, as the patient is under anesthesia and therefore becomes difficult to maneuver. On two occasions, there was a staff shortage, which resulted in a single scrub nurse having to position, disinfect, and drape the patient alone (instead of two and two, as per standard protocol). This extended the preparation time and consistently delayed the starting time. The support used during knee procedures was not always without challenges either as it was sometimes difficult to know the patient's full range of motion beforehand, resulting in the positioning occasionally having to be repeated several times.

Further, it was noted that there is no clear system in place for informing the surgeon when to enter the room after the patient has been prepared for surgery. When a surgical procedure is completed, the surgeon leaves the operating room and goes to see the next patient to brief them about the upcoming surgery and to mark the surgical site. Thereafter the surgeon has a short break and then returns to the scrub area and then enters the operating room again for the next surgery. Since there is no clear notification when the next patient has been prepared by the nursing team, it happened during several occasions that the patient and the staff in the operating room had to wait for minutes until the surgeon entered. When this occurred, the staff called the surgeon and told them that the operating room was ready to start. On the other hand, an opposite issue was also observed. That is, during several observations the operating room remained unoccupied while nurses waited for the next patient to be ready for entry. This was found to be due to two main reasons. The first was related to scheduling as patients were sometimes called for a specific time that did not align with the actual pace of the earlier surgeries. In other words,

if previous surgeries were completed faster than anticipated, a gap of idle time emerged in between. The second reason was that the patient had been called slightly too late to the preoperative unit. This was particularly problematic for mobility-impaired patients, for whom preparation naturally took longer. In some cases, delays could be also attributed to normal variation due to the human factor, such as difficulty inserting an IV line or repeated trips to the restroom to fully empty the bladder.

An additional observation was the well-coordinated and experienced collaboration between the surgical team and the corridor team at Art Clinic. The corridor team were always vigilant about the completion of the surgery, and within a few minutes, they entered the operating room to initiate the cleaning process, thereby enhancing efficiency. It was also observed that many of the activities in the operating room are performed simultaneously. For instance, medication and anesthesia equipment for the next patient is prepared during the previous ongoing surgery. Further, many of the internal cleaning activities have been converted into external activities, when safe to do so according to patient safety. By carrying out steps while the patient is still waking up from anesthesia in the operating room, the clinic can save time and at the same time decrease the non-value adding time, such as waiting, which subsequently affects the turnover time.

On specific observational days, five surgeries were performed by a single surgeon, which deviates from the normally performed four surgeries per surgeon. This primarily occurred when a version of staggering was used, where the surgeon conducted four surgeries in one operating room and then immediately exited to a second operating room to perform a fifth surgery. In this setup, the surgical setup for the fifth procedure was carried out concurrently with the fourth surgery. On these occasions, the surgeon performing five surgeries was allocated additional support, including prioritization by the corridor team for cleaning and staffing. In one observed instance, all five surgeries were completed in the same operating room, which was facilitated by processes being at the lower end of their observed variation ranges, and only in some instances slightly above the average, as visualized in table 12.

Table 12: Presents the deviation from the average time for each process step in five surgeries performed in a single operating room, in minutes. Values above the average are highlighted in red.

Surgical Setup	Surgical Duration	Patient Out	Cleaning	Time to next patient	Total time in the OR
00:01	00:20	00:03	00:01	00:05	84
00:09	00:17	00:00	00:02	00:01	88
00:07	00:18	00:02	00:00	00:01	85
00:02	00:18	00:03	00:01	00:10	86
00:06	00:29	00:00	00:00	-	78

6.3.2 Interviews

To begin with, during the semi-structured interviews, each interviewee was asked to describe step by step how they carried out the surgical procedures. The following results section is based on the similarities and differences identified across the interviews. In total, three interviews were held with surgeon 1, surgeon 2 and surgeon 3, the interview guide and duration can be found in Appendix A and B.

The surgeons each have their own approach to performing respective procedures, although the overall process is relatively similar. The first difference identified was the time it took to reach the hip joint. For interviewee 3, it usually takes around one minute, while for interviewee 1, it takes approximately 10 minutes. This variation could partly be due to the patient's anatomy, as some areas are more difficult to access. Another difference noted was how and when the diathermy was performed. Interviewee 1 used it throughout the entire incision to manage bleeding, whereas interviewee 3 only applied diathermy once reaching the joint capsule, avoiding its use in the tissue layers above.

Another difference that emerged was the use of the X-rays taken prior to the surgery. The patient undergoes an X-ray of the pelvic area, which the surgeon reviews before the surgery, using a digital measuring tool to get a preliminary sense of the patient's anatomy and to estimate an initial size for the prothesis. Interviewee 1 explained that they cannot rely on the X-rays, as their perception is that the images only accurately reflect the real anatomy in about 50% cases:

The problem with the X-rays is that you need to have the correct hip rotation (when the patient is positioned for the scan), which you rarely get. For example, the radiologist may not know exactly how to do it, and sometimes the patient cannot turn their legs like that due to limited mobility.

Interviewee 1 instead utilizes alternative instruments, for instance calipers and other measuring tools to determine sizes during the surgery. Interviewee 3, on the other hand, mostly relies on the X-rays, as they believe it provides an accurate representation of the patient's anatomy. In a follow-up question concerning the hip-rotation problem, as described earlier, interviewee 3 said:

Yes, you can sometimes see that the calibration is not correct, but there is almost never a big difference. Then it's about the fact that the sizes may not be quite what you thought and then it may differ one size up or down. /.../. It's based on your template, so the proportions are still there. /.../ But if the calibration is wrong, you have to adapt your surgery to the reality, it's not a big problem.

Later in the interview, the surgeons were asked which steps they considered important to ensure that they perform a well-executed job that they can stand by. Interviewee 1 responded as follows:

I use as many control methods as possible and templates everywhere. I want to compare and make sure I end up roughly where I planned to and try to recreate the anatomy as much as possible. Then I test to ensure that the hip is stable.

Interviewee 3 responded:

I want to know if the cup angle and offset are right, then I also want to make sure that they get good cementation. I also want to make sure that there is a good tension in the hip.

Both interviewees are precise and keen about the results, however the biggest difference is the safety measures they use. Where interviewee 1 applies a lot of control-steps, while interviewee 3 has a few that they deem necessary.

The general similarities and differences identified during the interviews can be categorized under the following subheadings: use of instruments, learning within organizations, and quality.

The interviewees were asked how many of the prepared surgical instruments were actually used during the procedure. Two interviewees responded that they did not use all the instruments laid out in the operating room, while one said that all instruments were used. The interviews also revealed that the surgeons have access to different instruments depending on their respective clinics.

One area where all interviewees shared the same view was learning and approaches to surgery. The question *How do you learn to perform surgery? Is there a right or wrong way in terms of which steps should be included?* The following were their responses:

Interviewee 1:

Partly your education, you operate with several different surgeons. You might, for example, see ten different approaches and then pick the methods you prefer to form your own technique. The longer you do it, the more 'hidden' knowledge and experience you gain.

Interviewee 2:

The more experiences you become, the more you start questioning the order in which things are done and taught, and whether it's actually relevant. Early on, you go through a lot of steps without thinking about why, and some of them don't affect the outcome, so there's no point in doing them.

Interviewee 3:

You learn during medical school, and then it's all about ambition! /.../ I've learned from different colleagues and watched videos. I've also visited the U.S and other places to see how others do it, and you have to use common sense. You need to be well-read, and everything comes down to motivation.

All surgeons agreed that medical school plays a significant role in their training, but they are also heavily shaped by experience throughout their careers. Furthermore, all interviewees placed great emphasis on ensuring the quality of their work in different ways. They explained that the most important thing for them is to be satisfied with their performance and to deliver high-quality surgical outcomes for their patients. This is ensured by incorporating specific steps during the procedures.

The results from the ethnographic interviews with nurses, assistant nurses and sterile processing technicians are presented thematically below. Initially, exploratory questions were asked at various points to understand how the system is structured. For example, in the preoperative unit, nurses were asked how they know when to begin preparing the patients for surgery. The response was that patients are prepared as soon as they arrive, meaning that it is the call schedule that determines when preparations begin. In a similar manner, questions were asked about how the corridor team know when surgery is finished and when cleaning of the operating room should begin, as there is no obvious external signal for this. Staff explained that they either check the computer system to monitor the surgery's progress, such as looking for the marker "anesthesia finished", which indicates that it's only a short time until the room will be ready for cleaning, or they simply peek into the operating room and wait nearby until it is time.

A recurring theme in conversations with the nurses at Art Clinic was the perceived stress and concern about having to work overtime. Many shared experiences from previous employment at large university hospitals in the public healthcare sector, where they encountered high workloads and stressful work environments. During the interviews, it became evident that all participants shared concerns about what it would mean if they were required to perform more surgeries per day than they currently do. The primary concern expressed was physical and mental fatigue from a more stressful work environment in order to complete every task each day. Secondarily, participants emphasized that they did not want increased workload to affect their working hours, nor did they want to work weekends, and many had specifically chosen Art Clinic to avoid those conditions. Furthermore, they expressed strong disbelief that performing more surgeries would be practically feasible, as there are not enough staff or instruments to make it possible.

The nurses and sterile processing technicians explained that if something goes wrong in the sterile processing room, or if an instrument is accidentally dropped during surgery, it sets off a chain reaction of delays that are difficult to recover from. In other words, they emphasize the sense that existing system is fragile and not equipped to handle sudden changes or errors without serious consequences. They also stated that this applied to scheduling and punctuality. During one of the interviews, nurses agreed that a five-minute delay in the morning would result in 30 minutes of extra work in the afternoon.

The sterile processing technicians also explained that, under the current system, a great deal of responsibility is placed on them to solve problems that are not necessarily visible from the outside. For instance, if there are delays or problems in the sterilize processing room, such as instruments arriving late from surgery, they are still expected to complete everything within the same working day, even if that requires working overtime. They explained that even when something goes wrong, they never let it affect the day-to-day operations, for instance by cancelling surgeries. Instead, they take it upon themselves to resolve the issue. This means staying late evenings, but also when the stock adds up storing instruments at non-ergonomically safe places.

6.4 Study Visit at Nacka

On Wednesday 25th of March 2025 a study visit was conducted at another hospital within the Aleris Group, namely Aleris Orthopedics Nacka, hereby referred to as Nacka. At Nacka, the same types of surgeries as those studied at Art Clinic are performed. The purpose of the visit was to gain inspiration for improvements for Art Clinic, and to get another perspective on how a hospital can be organized to perform these surgeries. The focus of the visit was the layout, operating room and sterile preparation room, and the findings from these areas will be presented in the following section.

6.4.1 The Layout at Nacka

A clear distinction between Art Clinic and Nacka is the layout of the facilities. At Nacka, the patients being prepared for surgery are placed in the same room as the patients in recovery after surgery, meaning that the preoperative care and postoperative care are located in the same area (figure 25). Moreover, another difference is the pre-surgery room, where the patient is placed, cleaned, and prepared for surgery. At Art Clinic, these activities take place in the operating

room and not in an additional pre-surgery room. A room absent in Nacka is the sterile preparation room, where instruments are set up prior to the surgery, as these activities take place in the operating room while the patient is prepared in the pre-surgery room.

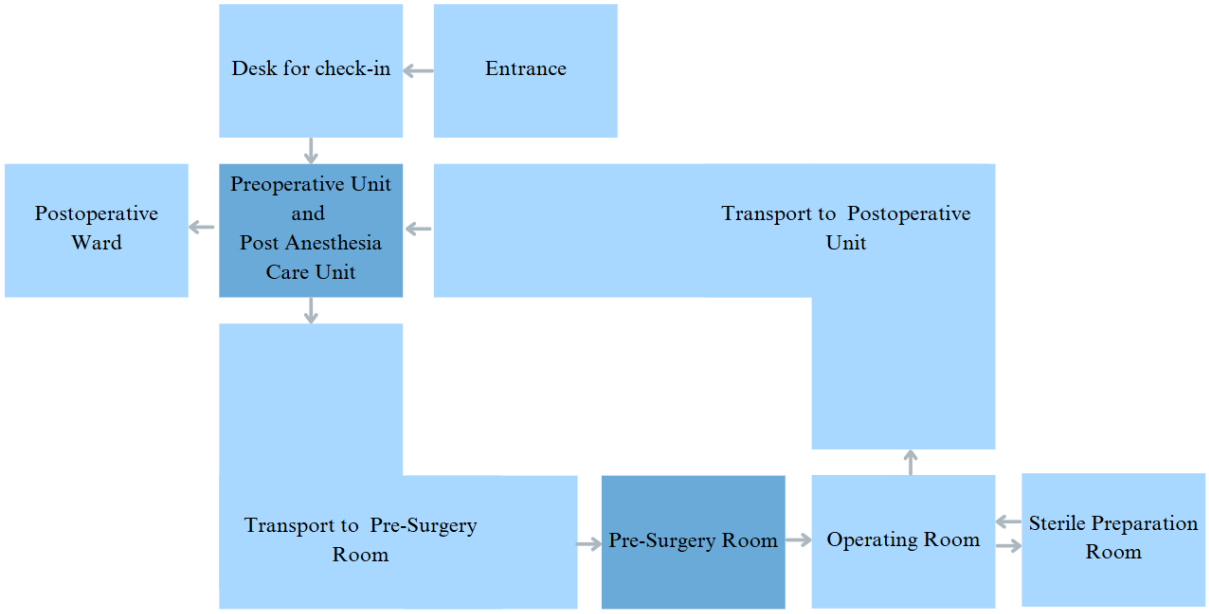


Figure 25: The different departments at Nacka, in dark blue: the difference between Nacka and Art Clinic.

6.4.2 The Operating Room at Nacka

At Nacka, hip and knee replacement surgeries are performed Monday to Thursdays. Two operating rooms are allocated for the surgeries on Monday-Wednesday and on Thursdays, three operating rooms are utilized. When planning and scheduling surgical procedures, the surgical coordinator ensures that one of the operating rooms is only allocated for knees and the other for hips. Another aspect that is thought of during scheduling is whether the surgery is to be performed on either the left or the right side of the body. Patients with the same surgery (in terms of hip or knee, and left or right) are, if possible, scheduled consecutively to minimize turnover time and instrument storage in the OR's. No surgical procedures are scheduled during the lunch break due to limited staffing of the corridor team during that period. The surgical team utilizes a staggered room system, where the surgeon alternates between two operating rooms, as viewed in figure 26. Once a surgery is completed, the surgeon exits the operating room and enters the second operating room to begin a new surgery. The timing between the

duration of the surgery and the duration of the turnover effects efficiency, where a shorter surgical duration is preferred compared to the turnover time (Rosenbäck, 2017).

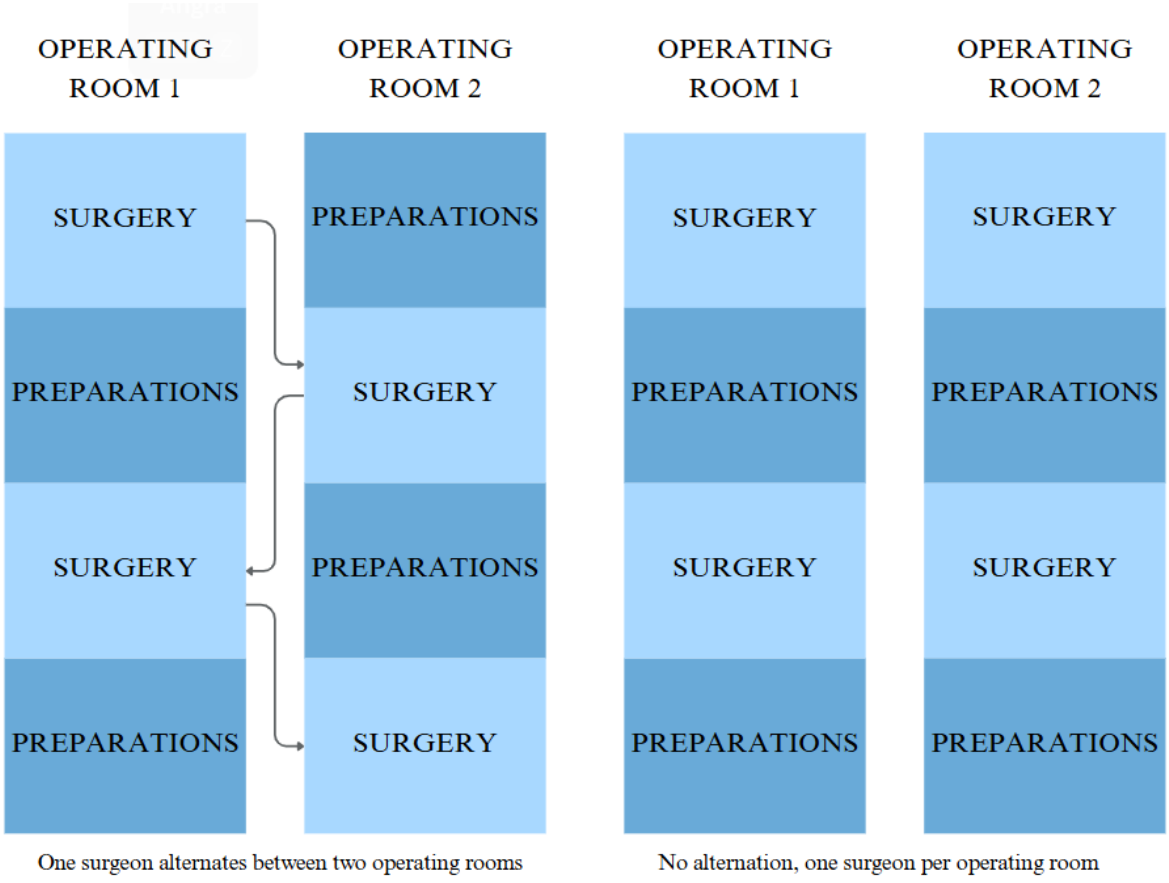


Figure 26: A description of a staggering system (left) and no alternation between operating rooms (right).

The surgical preparations and positioning are conducted in the pre-surgery room, meaning that the patient is ready for the procedure prior to entering the operating room. The first step in the operating room is the introduction of anesthesia through a laryngeal mask. When the patient is at loss of consciousness they are cleaned, sterilized and draped in sterile coverings. Once the surgeon enters the room the surgery begins. The average duration for hip- and knee replacement surgeries at Nacka is 28 minutes and during the visit, the duration of the surgeries varied between 24-36 minutes. The surgeon exits the operating room after closing the wound, subsequent tasks, including cleaning the wound and applying a wound dressing are carried out by the nurses.

6.4.3 The Sterile Preparation Room at Nacka

In the sterile preparation room at Nacka, there are three washers and two autoclaves and the cycle time for each machine is 85 minutes. The department can sterilize instruments from three surgeries at the same time: either three knee replacements, three hip replacements or a combination of both procedures, without causing a stock, illustrated in figure 27. The number of instruments required for a hip procedure is 91 (6 cages) and 118 (7 cages) for a knee procedure. Additionally, the instruments are stored in cages and no containers are used. To get an overview of the schedule and orders, a whiteboard is placed in the middle of the room to visualize the flow.

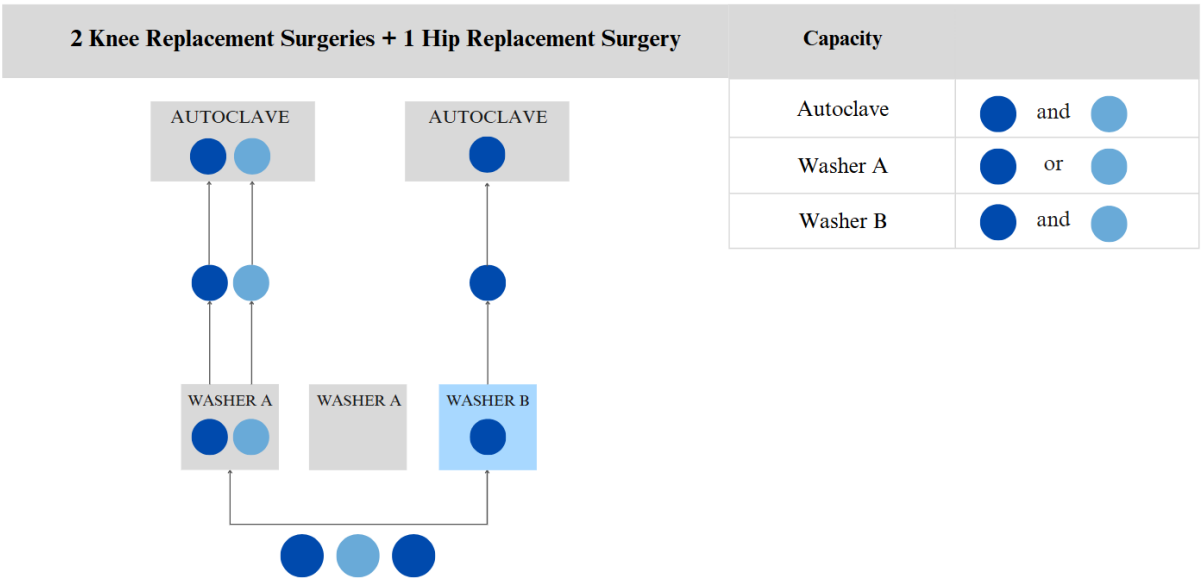


Figure 27: The flow of material for two knee surgeries (dark blue) and one hip surgery (light blue) as well as the capacity for the machines.

7 Discussion

In this segment, the two research questions will be discussed and analyzed by bringing together the results from the qualitative and quantitative studies, as well as the theoretical framework. The current capacity as well as process limitations will be discussed. Based on the discussion of the limiting factors, a discussion on how to improve capacity will be made. Additionally, a subsegment is used to discuss the implications from the quantitative and qualitative studies and their alignment.

7.1 Current Capacity

The capacity analysis focused on five main areas: the preoperative unit, operating room, post anaesthesia care unit, postoperative ward and the sterile processing room. The results from the preoperative unit showcased an effective capacity of treating 21 patients, a best case of 35 and worst case of only managing 14 patients. The operating room effective capacity was determined to be 8 surgeries with a best case of 11 and worst case of 7 surgeries. For PACU, an effective capacity was calculated to be 32 patients, with a best case of 39 patients and a worst case of 28 patients. For the postoperative ward, the number of available beds is 13, however not all are allocated for hip and knee replacement surgeries which can result in even lower availability depending on the number of other procedures taking place. The sterile processing room has an effective capacity of 10 autoclave cycles per day, with a best case resulting in processing instruments from 10 surgeries and in a worst case 6 surgeries.

To determine the current capacity, it is of importance to acknowledge the processes with the lowest number of treated patients per day as the maximum throughput of a process is determined by the process that produce the least amount (Holweg et al., 2018). Examining the effective capacity, the process with the lowest throughput is the operating room at Art Clinic, which on average can produce eight surgeries. Therefore, the other processes which are able to treat more than eight knee and hip replacement patients have a higher capacity than needed. However, as the effective capacity is based on the average duration of each process, it only captures a single value and does not show the effect of variation (Savage & Markowitz, 2012).

Evaluating the best- and worst-case scenarios, the sterile processing emerges as the process with the lowest overall capacity, with the worst case of six surgeries. Therefore, both the sterile

processing department and the operating room, due to their variation, is considered bottlenecks limiting a potential increase of the current capacity. Furthermore, the availability of beds in the postoperative care ward will be a potential limiting factor for an increase in capacity, depending on the need for postoperative care for other procedures.

7.2 Limiting Factors

This section identifies and examines the two main bottlenecks at Art Clinic limiting the number of surgeries performed: the operating room and the sterile processing room. These units restrict the capacity, mainly due to the variations the processes experience, which will be further discussed in the subsection 7.2.3.

7.2.1 The Operating Room

The best- and worst-case scenarios constructed in this study help illustrate the system's sensitivity to variation. In the worst-case scenario for the operating room, extended surgical duration was combined with a long duration for the support activities. This resulted in a lower capacity, where only 7 surgeries could be completed each day. Looking closer at this number, each operating room can complete an average of 3.75 surgeries, implying that the fourth surgery could not be completed within regular hours, causing the staff to work overtime. These outcomes are comparable to what Holweg et al. (2018) refer to as shifting bottlenecks, which are bottlenecks that are moving depending on the situation. Since all processes in the operating room showcase variation, the bottleneck will move depending on which process is performing at their lowest. For example, at some instances it might be the surgical setup, which is causing a delay, while at other instances it might be idle time or a prolonged surgical duration. Although these bottlenecks are less predictable than stationary ones, they still significantly disrupt the throughput and contribute to waste in terms of waiting (Nicholas, 2018). For example, if surgical setup is prolonged it causes a wait for the surgeon.

When examining the activities in the operating room, the activities experiencing the greatest variation were found to be the surgical setup, idle time and surgical duration. The variation in surgical setup could partly be explained by the type of surgery, where hip replacement surgeries often experience a longer surgical setup. Through observations, it was confirmed that the hip support is difficult to maneuver and can be difficult to place, potentially causing the increased setup time. During the study visit at Nacka, an alternative technique was observed, in which the

patient remained awake while the hip support was positioned. This approach reduced the time required. However, this method only works with another method of anesthesia, and since it involves medical decision-making, evaluating the possibility of changing the method of anesthesia at Art Clinic cannot be done, as it lies beyond the scope of this thesis.

For the surgical duration, an effort was made to analyze the surgical duration based on surgeon. The analysis showed that one surgeon is generally quicker, while the other surgeons have a similar surgical duration. However, only 12% of the variation could be explained by the difference in surgical duration between surgeons, the other 88% is variation within each surgeon's process. Additionally, the planning accuracy for surgical duration was explored and found to be lacking precision.

The idle time is defined as the time from the cleaning of the operating room being finished until the next patient enters. Ideally, this time should be kept to a minimum as wait is described as one of the wastes in lean production (Liker, 2004). At Art Clinic, the cause of the idle time was traced back to the patient not being prepared by the preoperative unit, due to the patient being scheduled too late due to the activities in the operating room being performed quicker than anticipated. Therefore, at some instances, the patient was scheduled to arrive at the clinic at the same time as the operating room became available.

Reducing one delay without addressing others does not improve the throughput (Balestracci, 2015), therefore, even if the surgical duration is shortened for the surgeons, the overall variation in the other processes will remain, meaning that the issue with predictability and thus delays remain. Consequently, a solution is needed to reduce the variation in all three activities.

7.2.2 The Sterile Processing Room

Having discussed the bottleneck in regards of the operating room, there is still an ultimate, stationary bottleneck within Art Clinic, that is the sterile processing room. No matter how many surgeries the operating room hypothetically can perform, a limiting factor will be the sterile processing room. The sterile processing room constitutes a stationary bottleneck (Holweg et al., 2018), primarily constrained by the limited throughput of the autoclaves. As established in the capacity result, the effective capacity of the sterile processing rooms is 10 autoclave cycles per day, considering that six cycles are allocated to non-joint replacement surgeries. However,

this is only an estimate done for the sake of this study and the available autoclavations can vary depending on the incoming variation of different procedures, hence the instrument inflow. In theory, this allows for processing instruments up to 10 joint replacement surgeries per day under ideal conditions.

However, this theoretical capacity is sensitive to the type of procedure schedule, as different surgeries require different volumes of instrument sets. For instance, knee replacement surgeries place a greater burden on the autoclaves compared to hip surgeries. Scheduling beyond six knee replacement surgeries would exceed storage limits and delay processing, illustrating the tight resource constraint of the system. During interviews and observations, variations in instrument use between surgeons were found. Interviews revealed that while some surgeons, such as interviewee 3, only have instruments deemed necessary prepared in the operating room, others prepare significantly more than are typically needed. This might point to a lack of standardization, and as emphasized by Liker (2004), standardization is a prerequisite for both stability and improvement in complex systems.

Although the current workflow in the sterile processing room manages the existing instrument volumes, the system operates within minimal slack and regularly relies on overtime to maintain the capacity. These findings suggest that the sterile processing lacks resilience to variation or increase in demand. This, in combination with the previously mentioned variation in the overall system, creates a need for close coordination between surgical coordinators and the sterilization team, to avoid overworking the system. By aligning surgical schedules with the autoclave's capacity limitations, as well as reducing necessary instrument variation, the throughput could be increased.

7.2.3 Understanding Variation

One of the major reasons behind the limiting, has proven to be the high degree of variation present across all processes, making the system fragile and difficult to predict. As presented in the results, all investigated processes are statistically stable, meaning that the variation is predictable over time and primarily caused by common causes within the system (Deming, 1982; Montgomery, 2013). As Muralidharan (2016) emphasizes, it is the amount of variation, not solely its existence, that determine the capability of the system. To clarify, the variation at

Art Clinic is not the issue, but rather the range it varies between making it difficult to predict and plan the daily operations.

At the beginning of this study, there was a concern raised regarding differences in surgical duration between surgeons, which was initially interpreted as special cause, something that should be addressed separately. This is not uncommon, Gitlow and Gitlow (1987) argues that approximately 85% of all process variation is due to common causes and yet organizations often mistakenly treat them as special causes. In the earlier discussion, Art Clinic's current capacity and system bottlenecks were examined, and both findings ultimately highlight that its cause stems from systematic variation and the unpredictability that follows. For example, the duration of both main- and support activities fluctuate significantly, ranging from 40-70 minutes and 40-76 minutes respectively. Thus, as explained earlier regarding the capacity, the system is perfectly designed to produce the result it currently delivers, and staff within the system are working to their full potential (Balestracci, 2015), which at Art Clinic normally is eight surgeries per day.

Similarly, Deming (1982) highlights that improvement is impossible without first understanding and reducing system-level variation. In other words, it is unrealistic to expect that the current system can remain unchanged and still achieve higher output. With this in mind, the initial question: how to treat more patients, hence working faster, needs to be reconsidered. When visiting Nacka, one of the wishes with the study visit was to examine the difference in surgical duration, as a couple of the surgeons there had shorter ones compare to Art Clinic. With the information gathered now, the more relevant question would be to examine *if* and *how* Nacka has managed to reduce variation in various part of their system and what consequences have followed. As this was not further investigated it cannot be clearly stated whether or not they have. However, as Liker (2004) notes, a pull system requires a standardized and reliable process to work efficiently, supporting the assumption that the variation in surgical duration at Nacka is likely low.

Another interesting observation made was the planned surgical duration versus the actual outcome that showed no correspondence, proving low accuracy. This essentially means that the clinic currently plans for on average 9-10 minutes of waste during each surgical procedure, that at the end of the day adds up to a lot of time. Adding on to this, the planning is based on surgical

duration and not total utilization time of the operating room, meaning that the necessary, but non-value-adding support activities, such as surgical setup and cleaning, is not accounted for in the planned time. Combining the variation in both surgical duration, support activities as well as the idle time, while at the same time not having the common cause variations identified or explained makes it practically impossible to plan accurately. Supported by the theory, high process variation complicates planning and resource allocation, as it reduces predictability and hinders effective capacity utilization (Montgomery, 2013; Muralidharan, 2016). When variations are not fully understood or controlled, improvement efforts risk failing to address the underlying causes (Muralidharan, 2016; Gitlow & Gitlow, 1987).

Summarizing all the findings, it is evident that the perception of variations has been previously misunderstood. With all the processes being stable, actions to map and identify the common causes should be further investigated to be understood entirely. The questions to be asked are: what are the common cause factors contributing to this variation, and what consequences do they have for the system as a whole?

7.2.4 How Variation Affect Staff and Perceived Workflow

Now that we understand how variation affects capacity, there remains one final aspect to consider before increasing it. The last limiting factor, strongly connected to the variation, highlighted through qualitative interviews, the workshop and observations, is the people working in the system.

In the beginning of this study, concerns about increased capacity were raised. Beyond logistical concerns like instrument availability, the workload in the sterile processing department and the physical layout at the unit, the staff expressed deeper worries about their work environment. Primarily, fear about an increased workload would lead to a stressful and unpleasant workplace was expressed, which in turn could potentially damage Art Clinic's reputation, hence hinder the future recruitment and retention. Surgeons and nurses explicitly emphasized that increased stress could in worst case compromise patient safety and care quality, a constraint that must not be disregarded or negotiated according to the company standard. This would ultimately limit the capacity increase.

In this discussion it is critical to distinguish between perceived stress and actual workload. While staff currently believe increasing capacity with additional surgeries is unfeasible, quantitative analyses indicate that higher throughput is possible, however the quality must be carefully taken into account. According to the quantitative analysis, it is possible to increase the number of surgeries, it the variation is lowered, and the staff work at the upper limit of the clinic's capacity. Given the current situation, the increase would not be sustainable over time as the system puts a lot of pressure on the staff as there is almost no room for errors without causing a domino-effect of delays, causing them to experience stress.

Highlighted previously in the discussion, there is no surprise that the current system fully occupies the staff with both value-adding and hidden waste in the non-value adding activities in their daily tasks, meaning that the thought of an increase seems impossible. However, if the key to increasing capacity lies not in doing more, but rather do things differently, would it then be possible?

By introducing the MPU-factors, as a part of the effort of capacity improvements, the current system can be better understood (Almström, 2024). Currently, as brought up in the interviews, there are no standardized ways of performing the surgical procedures, which can lead to unnecessary movements in the operating room and longer surgical durations. Explained by Liker (2004), both unnecessary movements and wait are classified as waste, which falls under the category of non-value adding work. Improving the method (M), could free up time by redesigning or adjusting the approach, without requiring the staff to work faster. Further, as stated previously in the discussion, the goal is to decrease the variation as it is otherwise not possible to increase the capacity. Hence, the performance factor (P) in this case, while important in other contexts, does not bring as much value to this discussion. Adding on to this, it was evident in the results that even though one of the surgeons had on average 14 minutes short surgical duration, the total time spent in the operating room was almost the same for everyone regardless of the surgeon. Lastly, the most important factor for Art Clinic to understand in order to increase the capacity is the utilization factor (U). As mentioned in the theoretical framework, the U factor captures how much of the available time is spent on productive work (Almström, 2024). In the current system, as discussed earlier, a significant portion of the time is lost due to "hidden waste" caused by variation, such as idle time in the operating room. By reducing the non-value adding time spent during the surgical duration, but also during the support activities,

staff would experience less time pressure and a better flow in their tasks. This would make the quantitative results of the capacity feel more achievable, without increasing the stress and perceived workload, while still keeping the quality of the results high.

7.3 Increasing Capacity

The results of the study showcase that while Art Clinic performs consistently under current conditions, the system is limited not by effort or staff capabilities but rather variation within their processes. To enable capacity improvements, this variation must first be identified, understood and where possible, be reduced. Variations in processes in healthcare settings risk impacting patient safety, care quality and the work environment (Rosenbäck, 2017), hence the proposed improvements will be based on two main areas: refined planning based on understanding variation and reducing variation through organizational learning.

The three identified bottlenecks have a capacity of 10 surgeries per day, if they are performing at their upper level, referred to as the best-case scenario. For the sterile processing room and the postoperative ward, this entails that the inflow of instruments and patients is ideal. For the sterile processing room, this means that the inflow is 10 hip replacement surgeries, and for the postoperative ward, that the other surgeries performed at the clinic only require three overnight stays. However, for the staff to perform 10 surgeries in the operating room, the time spent in the operating room should not be more than 92 minutes, and no idle time is allowed.

On certain days, observations revealed that five surgeries were performed by one surgeon. Primarily, this was observed when a version of staggering was used where a surgeon performed four surgeries in the same operating room to then immediately proceed to a second operating room to perform a fifth surgery. By employing this tactic, the surgical setup is performed in parallel with the fourth surgery in a second operating room. As a result, the internal surgical setup time was transformed into an external setup time, in line with the SMED methodology (Che Ani & Shafei, 2013). However, this means occupying one extra operating room, which can be viewed as wasteful in line with the lean concept (Liker, 2004). While it allows a smoother flow for the surgeon by reducing the wait between surgeries, it can be seen as inefficient from the perspective of the operating room utilization, as it requires a second operating room. Therefore, whether this strategy is viewed as beneficial depends on which resource is considered a bottleneck, the surgeon or the operating room. If the surgeon is

considered to be a bottleneck, the method reduces the idle time for the surgeon, while if the operating room is considered a scarce resource, it might indicate a suboptimal usage of the operating rooms. For Art Clinic, the operating rooms are of high value, as they can be utilized for more profitable surgeries. Additionally, at Art Clinic the surgical duration is equal to the support activities, which is not the most efficient ratio for staggering (Rosenbäck, 2017), therefore having a staggering system is not advised.

During the observed instance where five surgeries were performed in the same operating room, it was observed that such outcomes were achievable through coordinated, system-wide efforts. The surgeon performing five surgeries was prioritized in terms of staff allocation and cleaning aid by the corridor team to temporarily optimize the supporting functions to accommodate the increased workload. These observations therefore represent the best case, or theoretical upper limit of the clinic's capacity during optimal conditions. However, such performance is not reflective of a sustainable operational model. Performing five surgeries in one operating room has only been done once and with the quicker surgeon. While it worked this time, the variation in the processes in the operating room might not make it possible to perform this at a consistent pace.

7.3.1 Planning Accuracy

One of the main issues caused by the variation is the difficulty with accurate planning, as there is little correlation between the planned duration of surgeries and their actual duration. Variation in one process step creates incoming variation for the next step, which in turn causes that process to carry as well, similar to a chain reaction. This aligns with Rosenbäck's (2017) theory, which states that variation tends to multiply through sequential process steps, meaning that instability in one part of the system increases likelihood of variation in subsequent parts. For example, variation in surgical duration and other processes within the operating room can lead to misalignment with the patient flow from the preoperative unit. As a result, idle time may occur when the operating room is ready, but the next patient is not yet prepared for surgery.

Since the operating room is a bottleneck, whereas the preoperative unit is not, the non-bottleneck resources should be scheduled in a way that supports the bottleneck process, in line with Rosenbäck's (2017) reasoning on flow optimization. In other words, the bottleneck should not be empty, and the other processes should have a patient ready to enter the operating room

as soon as it is available. As suggested by Rosenbäck (2017), this can be achieved by establishing a small buffer or queue in front of the bottleneck, ensuring that patients are fully prepared and ready to enter the operating room as soon as it becomes available. Currently, due to differences between planned and actual surgical duration, there are instances where the next patient is scheduled to arrive at the clinic at the same time as the operating room becomes available. This occurs due to the steps in the operating room being at their low level of variation. For example, surgeon 1 consistently performs procedures approximately 20 minutes faster than planned, underscoring the need to adjust not only to the planned surgical duration, but also the timing of the patient's arrival to the preoperative unit. All these improvements are needed to ensure better synchronization with actual workflow.

Additionally, current planning is only using estimations on the planned surgical duration without considering the outcomes from the support activities in the operating room. When analyzing the variation by stratifying the data based on type of surgery, it was concluded that hip replacement surgeries generally have a longer setup time than knee replacement surgeries. To improve the accuracy of daily scheduling, additional time should be allocated between surgeries when a hip replacement procedure is performed, due to its generally longer setup. Even though this insight might aid in planning the actual duration for the set-up time, the variation in other processes within the operating room will continue to challenge accurate planning and make it difficult to predict the exact timing of subsequent steps.

A method proposed by Rosenbäck (2017) is to identify subgroups that affect the variation, and by adjusting the planning method according to the subgroups, predictability and planning is improved. This method should be employed to understand the variation in surgical duration, as it is not yet understood and could not be thoroughly explained by type of surgery or surgeon. Therefore, it is recommended that data is collected on surgical duration connected to different subgroups. During observations, it was indicated that one possible factor to examine is patient related data, such as gender, height, BMI and so on. Another interesting factor to examine is the accuracy of X-ray images, since the interviews revealed that at Nacka, the confidence in the X-ray images is higher, resulting in them not having to perform extra process steps such as measuring. Therefore, it would be interesting to measure the accuracy of X-ray images at Nacka and Art Clinic to see if it influences the surgical duration and if there is any difference in accuracy between the clinics. Furthermore, the limitations in the capacity of the sterile

processing room should also influence the planning. Art Clinic should when planning, take into consideration the number of available autoclavations, and the number of autoclavations needed for the planned surgeries.

One planning action that is not recommended is planning based on average surgical duration, based on the last performed surgeries. While it might seem reasonable that the next surgery will take approximately the same time as the last couple of surgeries, this approach overlooks the fact that the surgical duration varies from case to case. According to Savage and Markowitz (2012), plans based on average assumptions are usually wrong. Therefore, using averages to plan surgical duration seem to not improve planning, as the actual surgical durations deviate a lot from the mean. Therefore, the focus should be to define the variation, to then be able to plan more accordingly.

7.3.2 Standardization and Organizational Learning

During the observations and interviews, it became clear that the processes experiencing the largest span of variation are the surgical duration, the idle time and the surgical setup. Explained by Rosenbäck (2017) the processes experiencing the greatest variation should be the focus for improvement efforts. Additionally, the sterile processing room was also defined as a process constraining capacity due to the incoming variation of planned surgeries, allowing a maximum of six knee replacement surgeries. Due to this unit being a shared resource, it is also a process where improvements will have a big effect (Rosenbäck, 2017).

An obstacle for reducing the variation in these processes lies in the lack of standardized work routines. Although formal clinical guidelines are followed, the execution of processes vary between clinics and staff members. For example, for surgeons, their preferred surgical process is based on their initial training and learnings along the way, resulting in each surgeon having their own technique. Although, the variation between surgeons was confirmed to be low, this still hinders improvement processes, as it is difficult to evaluate processes and employ improvements when standardized procedures are lacking (Medinilla, 2014). This case of different execution of procedures is not only evident within Art Clinic but can also be found when comparing the methods used between clinics, in this case Nacka.

Medinilla (2014) note that meaningful process improvement is nearly impossible without standardization. However, attempts to enforce rigid protocols could be counterproductive. Surgical work is complex, and as highlighted in the interviews, professional autonomy is important as the surgeon is the one responsible for the quality of the performed surgery. Literature emphasizes that while some variation is inevitable, a balance must exist between autonomy and coherence to protocols (Lightner & Bagian, 2021). The quality registry (Rolfson et al., 2024) confirms that current quality is high across different clinics despite the variation in process execution, indicating that all techniques are clinically valid.

Rather than enforcing strict standardization, Art Clinic should build a learning organization. According to Jacobsen and Thorsvik (2021), this involves individual reflection, knowledge sharing, de-learning and applying the knowledge in practice. Both tacit (experience based) and explicit (documented) knowledge must be enhanced. To create a learning organization, socialization, externalization, combination and internalization must be fostered. Currently, Art Clinic has few opportunities for staff to reflect on their learning. As Jacobsen and Thorsvik (2021) describes: socialization, externalization, combination and internalization are all needed in order to create a learning organization.

Instances of informational learning were observed during surgeries involving two surgeons, where knowledge was shared through observation and social interaction. However, transferring tacit knowledge to explicit, is limited, as articulating skills and insights are rarely done or shared. By capturing personal techniques and converting them into shared explicit knowledge, this can be done. Combination can be supported by collectively analyzing the different practices, and developing best practices that balance safety, efficiency and quality. Encourage internalization by allowing staff to integrate the practice into their routines, while still having professional autonomy. By moving from isolated individual routines to a culture of shared, reflective learning, Art Clinic can reduce variation while preserving the benefits of professional judgement. This environment needs to act as a safe space for staff, allowing them to feel safe to voice concerns and question current practices (Edmondson, 1999).

To provide two concrete examples of how standardization and organizational learning can be introduced at this stage, the focus will be on instrument usage and a proposed signaling system. As previously presented, the instrument usage per surgical procedure is significantly lower at

Nacka compared to Art Clinic. The number of instruments used has a direct impact on the capacity of the sterile processing room, and for Art Clinic, where conditions are already more constrained, this presents a valuable opportunity for mutual learning. It is encouraged that discussions take place across organizational boundaries, but also internally between sterile technicians and surgeons at Art Clinic, to evaluate whether the number of instruments can be reduced in a way that supports more efficient workflow.

Another system observed at Nacka is the signal system, brought up in chapter 6.4 used to determine when the next patient should begin preparation for surgery. This aims to optimize the handover between the outgoing and incoming patient and minimize idle time, thereby reducing waste. At Nacka, this signaling system works well due to the high predictability of the surgical process, allowing for accurate timing across departments. At Art Clinic, however, the existing variation in surgical duration currently makes this more challenging. Currently, in the preoperative care unit, patients are taken care of as they arrive and thus are helped without considering the actual demand from the next step in the process, the operating room. The lack of a signal creates a push system, where the departments don't wait for a consumption signal until they initiate preoperative care (Liker, 2004). Because of the high variability, it is difficult to anticipate when the next patient should begin preparation to be ready at the optimal time. However, a question raised during this study is whether there is still potential to learn from Nacka's system.

Once the variation in surgical duration at Art Clinic is better understood and becomes more predictable, it may be possible to identify a distinct point during the procedure that consistently indicates a certain amount of time remaining. This could then be aligned with time required to prepare a patient in the preoperative unit. In that case, the surgical team could call the preoperative unit at that specific point to signal start of preparation. For this system to function reliably, the variation in surgical durations must be first mapped and understood, so that shared guidelines can be developed to estimate how much time remains in the ongoing procedure.

7.3.3 Operational Adjustments and Resource Optimization

Additionally, to the previous suggestions, Art Clinic could benefit from reevaluating parts of their operational structure, including unit layout, working hours and potential investments.

First and foremost, to resolve the potential bottleneck in the postoperative ward when overnight beds are allocated to other surgeries, it is worth evaluating whether beds in the PACU can be utilized. As previously presented in the results, the PACU has an effective capacity of 35 beds and is only used between 08:00-20:00, leaving the unit unused for 12 hours each day. By exploring the possibility of converting part of the PACU into overnight accommodation when needed or making it a permanent change, the bottleneck in the postoperative ward could be avoided while making better use of existing resources. The strongest argument in favor of this solution is that an uneven allocation of capacity, specifically exceeding the capacity of the bottleneck, will not increase throughput, but instead generate waste (Holweg et al., 2018), which in this case is unoccupied beds.

Secondly, since the sterile processing room constitutes the stationary bottleneck in the process, it is essential to plan and align working hours with its operational capacity to prevent constraints (Rosenbäck, 2017). In the current schedule, there are a maximum of 10 autoclave cycles per day for knee and hip replacement surgeries. In the worst-case scenario, if only knee replacements are performed, this number decreases to only six. However, by ending the shift by starting two autoclave cycles, the number of available autoclavations rise to 12, or up to eight knee replacements per day, corresponding with the effective capacity of the operating room. A dialogue needs to be held between the management team and sterile processing technicians to evaluate the benefits and drawbacks of this proposal, with the goal of reaching a mutual understanding and a decision that best support operational efficiency and employee well-being.

Lastly, it should be considered whether the autoclaves in the sterile processing room should be replaced. The current machines are old, and there is a tangible risk of breakdowns, which causes delays in the already fragile system. It is important to emphasize that replacing the autoclaves should not be seen as a miracle solution for increasing capacity, as space limitations prevent the installation of larger-volume units. However, the investment in new autoclaves may serve

to remain existing capacity by reducing the frequency of equipment failures, thereby minimizing the risk of further delays in what is already the slowest process.

7.4 Merging the Quantitative and Qualitative Findings

This section discusses the integration of the quantitative and qualitative findings, in line with the convergent parallel mixed methods design employed in the study, the aim is to determine whether the quantitative and qualitative results align and offer complementary insights or diverge in their interpretations. The findings connected to the sterile processing room indicate that the autoclaves are a contributing factor to limiting the capacity, which was confirmed both through the quantitative and qualitative findings. Quantitative data demonstrated clear limitations in capacity related to process throughput, while the qualitative findings gathered through the AIM-workshop and direct observations confirmed this by identifying the sterile process as a key area of concern.

Furthermore, interviews and observations revealed a variation in the sequence and execution of process steps throughout the workflow, both between clinics and among individual staff members. These qualitative findings point to a lack of standardization in how the processes are carried out. The quantitative findings suggest that while things are done differently, those differences don't consistently lead to better or worse outcomes in terms of time. Although this might appear contradictory, the findings are in fact complementary. The quantitative results showcase that there is general unpredictability, and both the quantitative and qualitative results point towards inconsistent processes where the main issue is not individual performance but rather a lack of process control and standardization.

The qualitative data expressed concerns among participants regarding the potential to increase capacity, due to the high variation in process durations. This aligns with the quantitative findings, which demonstrate that variation in process durations poses a challenge to scaling the capacity. The presence of variation increases the risk of failing to meet the required scheduled working hours. In summary, the findings from the quantitative and qualitative approaches converge: the sterile processing workflow is a limiting factor, procedural variability hinders efficiency, and there are shared concerns regarding increasing capacity during current conditions.

8 Conclusion

This chapter summarizes the key findings of the study and reflects their implications in relation to the research questions. It also outlines practical conclusions based on the results and highlights areas for future improvement and continued research.

Q1: What is the current capacity in the joint replacement surgery flow and what factors limit its potential increase?

The current capacity at Art Clinic is estimated to four surgeries per operating room in use, equalling a total of eight surgeries per day as normally, two operating rooms are in use. The processes contributing to limiting the capacity has been defined as the activities in the operating room and the sterile processing room. The three processes in the operating room experiencing the most amount of variation is the surgical duration, idle time and surgical setup. Notably, the variation in surgical duration is lower between surgeons than within surgeons. For the sterile processing room, the variation in surgeries performed at the clinic contribute to restraining the capacity, specifically if knee replacement surgeries are performed. Ultimately, the variation needs to be understood prior to any capacity increase.

Q2: What changes can be introduced to increase capacity?

To be able to increase capacity in a future state, Art Clinic must first understand and reduce variation. The consequences of variation include high uncertainty in process output; therefore, planning should be improved. By identifying factors contributing to common cause variation and adjusting the planning accordingly, the accuracy and reliability of scheduling can be significantly improved. Secondly, planning should make sure, by creating a small buffer in the preoperative unit, that the operating room has no idle time. This is done by scheduling the arrival of patients earlier.

Further improvements include measures to standardize and create best practices within the organization. Since professional autonomy is important, the standards should not be rigidly enforced. Instead, following the principles of organizational learning is recommended. By fostering a learning organization in which tacit knowledge is expressed, externalized and subsequently adapted to individual approaches, a platform for knowledge sharing and

continuous learning can be established within the organization. To enable open discussions about working methods, it is essential to create a safe space where all individuals involved feel comfortable enough to express their opinions. To support the principles of a learning organization, the following three suggestions are proposed:

1. Capturing and sharing tacit knowledge among staff and implement structured methods for integrating this knowledge into existing routines.

2. Create a safe environment for open reflection and dialogue between staff.

3. Encourage best practices without undermining professional autonomy.

8.1 Recommendations

The recommendations are divided based on the three identified bottlenecks for an increase in capacity. Firstly, the operating room is recommended to identify and understand why there is a variation in surgical duration, by utilizing the concept of creating subgroups and analyze their effect on surgical duration. Examples of factors to examine are patient related data and the effect of x-rays. To reduce the idle time, planning should be updated where patients are called earlier, and it should be investigated if a signal system can aid the synchronization between preoperative care and the operating room. As the surgical setup was found to be longer for hip surgeries, this should be adapted into the planning as well. Furthermore, changing the method for anesthesia should also be evaluated to reduce surgical setup time. Additionally, creating a best practice through learning within the organization, where knowledge sharing is possible between surgeons, nurses and sterile technicians is important. To make sure the proposed solutions are sustainable, it is important to understand who is responsible for the change. Taught by (Balestracci, 2015), systems with common cause variation are to be handled by the management team, however as also discussed it is still essential to involve the staff at the clinic in order to make it sustainable. In other words, it is a collective effort especially with the organizational learning, but the management team must lead the way by starting the process of identifying the variation. Until this is done, one cannot expect increased capacity, nor people in the system to work faster. No-blame, thinking about the system as a whole, simply focus on facts and ask the right questions beginning with *why* and *what* will lead to results.

For the sterile processing room, it is of importance that their capacity is considered when planning to avoid working overtime. By reducing the number of instruments, through taking inspiration from other sterile processing rooms, more instruments will fit in the autoclaves. Another recommendation is to oversee the schedule for the sterile processing technicians, to plan the schedule to optimize the number of autoclave cycles. A third recommendation is to invest in new autoclaves, if a reduction in the number of instruments is not sufficient.

The postoperative ward should be evaluated in terms of bookings of overnight patients and the occupancy of beds in the PACU. As it seems to be an over-capacity in the PACU and under-capacity in the postoperative ward, turning beds in PACU into postoperative ward is needed to increase the capacity.

8.2 Future Research

Future research is recommended to focus on identifying common cause variations, for instance patient-specific factors that may explain variations in surgical durations and setup. Furthermore, it should evaluate the impact of support processes, such as x-ray accuracy. Additionally, further research should assess the impact on the proposed changes to the organization.

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Appendix A – Interview guide

This guide formed the basis for all interviews. Due to the semi-structured nature of the interviews, the phrasing and order of the questions were adapted and follow-up questions varied depending on each respondent's answer.

Information given to the participants before starting the interview

- The information obtained from this interview will be used as input for our master thesis.
- If any question is unclear, the respondent is welcome to ask for clarification at any time. It is also entirely acceptable to avoid answering any question.
- All information provided will be treated confidentially.
- The respondents will be anonymized in the final report to ensure openness and protect their identity.
- This is intended to be an open conversation in which we collaboratively explore the questions I have prepared.

Interview questions

1. Step by step, can you describe how you perform the joint (hip or knee) replacement surgery?
2. What is the purpose of trying out different prothesis?
3. What determines how many prothesis you test before deciding?
4. How often does the preoperative X-ray image match the actual anatomy of the patient?
5. How quickly can you tell if the X-ray reflects the patient's actual condition?
6. What specific steps or actions do you always include to ensure the quality of your work?
7. How did you learn to perform surgery?
8. Are there "right" or "wrong" ways to perform certain steps, or how does one develop their own method?
9. Are you free to carry out the procedure however you choose, as long as you deliver a good result and can stand behind the final result?

10. Regarding surgical instruments: do you use everything that is included in the trays and containers?

    a) If there are instruments that are prepared but not used: why are they present, if they can be brought in during surgery when needed?

11. Is there anything else you would like to add that I haven't thought of asking?

Appendix B – Interview Durations

Interview 1 – 24 minutes and 47 seconds

Interview 2 – 24 minutes and 38 seconds

Interview 3 – 1 hour 47 minutes and 6 seconds

Appendix C– Effective Scoping Template

Process owner (org): Art Clinic	Project sponsor: Godtycklig på företaget	Six Sigma champion, MBB: Hannah Oliv & Nina-Li Blom // Peter Hammersberg

Effective Scoping of continuous improvement projects

The sequence in itself of questions Q1-Q4, Q5-Q7 and Q8-Q9 below, is key to facilitate consensus in the shift of an organisation's mindsets from push to pull, in accordance with the principles of Lean Six Sigma

Supplier	Input		Process	Output		Customer
8b. Who supplies the inputs?	Q8a. What are the inputs to the system?	Q9. What does the system require of the inputs?	Q7a. Team/project jurisdiction of changes	Q1. What comes out (of the physical flow) - OUTPUT?	Q3. What is required of the output from this particular user (List of big Y's and improvement proposals)	Q2. Who uses the output?
There are three ways a patient can be booked for a knee and hip prothesis: 1) Referred from Sahlgrenska University Hospital 2) Through healthinsurance-policies 3) Private booking For materials: Prothesis-company (Johnson & Johnson) Sterile processing department Pre-OP: Operating doctor	Patient in need of a knee or hip replacement surgery	Patient showing up on time Pre-surgery assessments Patient identification Anesthesia clearance Infection control	Planning/Schedule Changeover time Work routines Patient check-in procedures Pre-operation preparations Staff coordination Communication between surgery	A patient with a new knee or hip prothesis	Quality of the prothesis (according ledprotesregistrets-requirements), increase quality of life Improved joint function and mobility, reduced pain Delivery precision, completed within optimal timeframe (90 days) Short lead times during operation day Feeling safe and satisfied Correctly done prothesis according to the requirements Safety during operation	Patient Healthcare team + surgeon Ledprotesregistret Physiotherapist Operations Manager
			Q7b. What competences are needed in the team (WHO)?		**Q4. What ONE MEASURE /y should be understood and improved? The y that scope the project and drive further exploration. Each small y has its own underlying system of influencing parameters, sometimes overlapping. Use one template per y to reduce complexity Scope on y (not x - upstream) and don't proceed until Q1-Q4 is thoroughly understood!**	
			Analytical skills Help from healthcare professions (nurse, doctor, coordinator…)		Identify all bottlenecks and how they vary depending on the different surgeries	
			Name of the underlying system that build up the y to be improved:		Q5. What is the baseline of the y and can that precis y be measured today (and can old data be trusted)? In other words: What is the **facts** behind the problem that form the base for our improvement promise? Show the data/proof of a problem!	
			Preoperative scheduling and preparation *Operating room scheduling and availability* *Resource allocation* *Transition and communication between teams* *Delays*		Time measurements in regards of the activities before and during surgery Planned time versus actual time Some measurements are missing in the early steps of the process	
			From where is the physical output shipped?		Q6. What other Y can not be lost in the process (constraints)?	
			From the operating room		The quality of the outcome Patient safety The daily operation, no disturbances of the other surgeries performed	

Appendix D – Guide for Validating Company Data

Instructions for Data Collection during Observations

The observations should be conducted on a room-based basis, meaning the observer remains stationed in the operating room and does not follow the surgeon's flow. This approach enables the observer to capture a comprehensive view of all the different stages involved before, during and after the surgery.

Columns to be completed and their definitions

- **Date –** Date of the observation
- **Type of procedure** – Knee or hip replacement
- **Observer ID** – NLB = Nina-Li Blom, HO = Hannah Oliv
- **OR** – The operating room in which the observation is conducted
- **Surgeon** – The person performing the surgery
- **Scrub Nurse –** Nurse(s) assisting during the surgery
- **Assistant Nurse/Anesthesia nurse –** Assistant nurse or anesthesia nurse: in this context, the person entering time stamps in the software (Metodika)
- **Preparation Start Time –** Time when instruments are set up for surgery (not observed, only noted)
- **Patient In –** Time when the patient enters the operating room
- **Anesthesia Start –** Time when IV medication is administered (note: patient is not yet asleep)
- **Ready for Surgery –** Time when the patient is sterilized, draped and ready for incision
- **Incision Start –** Time of the first surgical incision
- **Incision End –** Time when the wound is closed and the final dressing is applied (if the patient is wrapped, this refers to the final piece of tape, otherwise the plaster)
- **Anesthesia End –** Time when the patient has been extubated and is breathing independently (occurs just before the patient exits)

- **Patient Out –** Time when the patient is wheeled out of the operating room
- **Cleaning Start –** Time when the cleaning begins (immediately after patient has exited)
- **Cleaning End –** Time when the operating room is fully cleaned (floor mopped and waste removed)
- **Time Until Next Patient In –** Time between the room being ready and the next "Patient In" timestamp
- **Visible Deviations –** Non-medical deviations clearly visible to the observer

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