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Increasing Available Operative Time of the Operating Room

A Case Study at a Swedish University Hospital

Master's Thesis in the Master's Programme Supply Chain Management

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Abstract

The increasing trend on performing the prosthetic surgeries in Sweden has been indicated by researches. This is due to the fact that the quality of health care has been improved and new techniques have been developed to create comfort for the people. Notwithstanding the high quality of health care services in Sweden, there is space for efficiency improvement as budget and resources are limited and cannot respond to the demand. Operating rooms are considered to be the most expensive. However, the constraint in resources, increased waiting times and delays, late cancellation, lack of information sharing lead to inefficient use of these valuable resources as remarkable portion of operating room time is taken by non-operative activities. Implementing lean in the healthcare organizations, can help improve the quality of care by identifying the wastes and eliminating them from the procedures and create more efficient operations and reduce the time between operations.

This study has focused on identification of wastes that reduce the available operative time of operating room at the prosthetic section of an operation department at a university hospital in Sweden. Accordingly, the purpose of the thesis is defined as contributing to available operative time. The study has been performed to provide the operation department of the case study with clearer picture of where, how and why the wastes happen in the department, what are their impact, and provide some suggestions based on literature, so that the wastes can be mitigated and increasing available operative time become feasible.

The authors have observed the processes at the operation department for about four months and conducted several interviews with the staff of the department to gain understanding of the procedures and identify the wastes. Seven wastes of lean management have been used as a tool to discern what can be the waste activities in the operation department.

After the waste identification step, the cause of each waste has been analysed by means of fishbone diagram and it has been explained that the causes trace back to people, environment, method and equipment. Although, the causes were identified during observations and interviews with personnel, using fishbone diagram and previous studies helped at categorizing and build consensus with previous studies.

In the next step, impacts of identified wastes on available operative time were assessed through quantitative analysis and qualitative valuation. Efficiency measures such as non-operative time and changeover time were assessed to understand how the waste times and activities can lead to reduction of available operative time.

After assessing impact of wastes on available operative time, some particular wastes have been identified as the wastes with highest effect on available operative time, which are inducing anaesthesia inside the operating room, preparing instruments for total revision surgeries inside the OR, long changeover time and long patient preparation time in the OR. Correspondingly, the main causes are also identified as insufficient number of room for anaesthesia induction outside the OR, lack of space in instrument preparation room, lack of proper communication and information sharing among staff and absence of standardisation that prolong the duration of some activities. Finally, the identified wastes and their impact on reduction of available operative time have been compared to previous studies and literature, limitation of the study has been pointed out and the conclusion has been made.

Keywords: Operating room efficiency, Available operative time, Lean management

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1. Introduction

This chapter provides a background and motivation of this study, purpose and research questions, and scope of the study.

1.1. Background

Increasing human longevity in this last century by roughly 30 years, indicates that public health has been improved and has offered better services to the population. Correspondingly, expectations on public health, due to the technological development, medical improvement and increasing number of aged population, have increased (Carpenter, 2012). Sweden's healthcare system is known for its high-quality and sustainable care delivery and for many years, it has ranked as one of the most privileged in the healthcare industry (Swedish Healthcare, 2017). In Spite of high quality services, there is space for improvement in health care system in Sweden, as it can be constantly heard that the staff complain of the conditions in hospital namely, lack of space, bad lay-out, stock-out of material, excessive time spending on some activity, uneven flow of patients etc. (Protzman et al., 2011). Moreover, long waiting time for patients is another reason why the hospital needs to work more efficiently and effectively.

Nemes et al. (2015) have concluded that number of knee and hip osteoarthritis will increase in the future in Sweden due to increasing aged population, changing lifestyle and obesity, and people, mostly aged people, tend to undergo arthroplasty surgery as it improves the quality of life by relieving pain and letting them get back to their normal life. They have also predicted the increasing trend of only knee replacement surgeries based on the data from between 1975 and 2013, from 13,338 operations in 2013 to 21,700 in 2030, which shows remarkable increase in the number of operations.

Increasing demand of healthcare services by elderly population is challenging the Swedish healthcare system (Iversen et al., 2014). Hospital budget represents almost half of all the spending in most healthcare systems (Barbagallo et al., 2015). In addition, the operating room is considered as the most valuable resource in the healthcare, and associated with the high cost (Fehring et al., 2010). Regional councils in Sweden are responsible for almost all the costs associated with healthcare services and any regional development (sweden.se, 2017). Therefore, regional councils have to cope with the problems with increasing healthcare expenses and limited budget for better services that lead to long waiting lists for medical appointment and surgery (Hogberg, 2007). As the demand by growing aged population has increased, resources have become limited and economic constraints cannot compensate the gap between supply and demand, thus, efficiency improvement has become necessary in healthcares (Iversen et al., 2014). Taking into consideration the growing demand for surgical procedures, providing the high quality of care services with limited amount of resources and at the lowest cost, is arousing the interest of the managers and

scholars to focus on operating room efficiency (Barbagallo et al., 2015). Operating room efficiency can include study of patient flow, usage rate of operating theatre, and various processes in the operations (ibid.).

Healthcare system is perceived to be inefficient with many cancellations, waits and delays. Hospitals have responded to delays and the increasing demand by adding more resources. However, adding more resources is not the answer to the problems. In many circumstances, delays are not created from resource scarcity, but they are the result of flow problem. It is possible to minimise delays and waits by enhancing the flow of information and patient throughout the system. With better flow in the system, increasing access, reducing waiting time and cost, and improving throughput, safety and financial status can be achieved. Flow in healthcare depends on inherent variation in healthcare system. Some kinds of variability such as patient's condition (age, health condition, preferences etc.) cannot be eliminated or reduced but can be managed by using historical data, as well as, different level of staff ability. However, some types of variability driven by individual priorities such as heavy surgical schedule on specific day due to surgeon's preference should be eliminated. One important key to improve flow depends on decreasing variation in process flow (Haraden & Resar, 2004).

1.2. The department in focus

This thesis is conducted in a university hospital in Sweden. The focus of the thesis is on the operation department that is one of the largest departments at the hospital, where more than 3,000 operations, including orthopaedic prosthetic surgeries (elective/planned surgeries) and trauma surgeries (emergency orthopaedic operations), are performed per year. The operation department is divided into two separate sections that are named *prosthetic section* and *trauma section.* Each section has its own personnel, operating rooms, and instrument and supply storage room. However, they have some instruments and equipment in common, and rooms such as preoperative centre (pre-op centre), postoperative centre (post-op centre) and X-ray room are shared. The department consists of seven operating rooms (OR), where of three of them, which are OR2, OR3 and OR4, are allocated to prosthetic surgeries and the rest four, which are OR1, OR5, OR6 and OR7, are allocated to trauma surgeries. As mentioned above, the department consists of two sections, Prosthetic and Trauma, and this study has been only performed in the prosthetic section.

Primary and revision surgeries are two types of prosthetic surgeries undergone in the three operating rooms that belong to the prosthetic division. Primary surgeries are performed from Monday to Wednesday and revision surgeries are done on Thursday and Friday. However, exceptions exist as they might perform both types within the other weekdays. There are around 100 employees at the department including operating room nurses (OR nurse), nurse practitioners, specialists in anaesthesia and surgical care, cleaners, section leaders, instructor, and managers.

1.3. Problem description

During several observations and interviews conducted at operation department, different problems that create inefficiency in the flow have been discovered. These problems are such as delays at different stages of processes, late cancellation, lack of proper information flow etc.

Delays in the operation have been occurred due to many reasons: from anaesthesia processes, surgeons, staff, patient's health condition, lack of personnel and resources. For example, the time for the anaesthesia process cannot be accurately estimated and varies from person to person as patient's health condition depends on many uncontrollable factors. Therefore, sometimes the anaesthesia process may take longer time than expected, resulting in delay in the whole operation. Moreover, when OR is ready to be used for the next surgery but patient preparation and the anaesthesia process are not done, this shortens OR available operative time as the OR stays idle until the patient is ready. Regarding scheduling of this department, higher number of surgeries is performed during Monday to Wednesday, this creates unequal workload for the staff during working days and overburdening in the equipment.

Lack of proper communication between the different staff in different positions is perceived as another problem in this department as the nurses addressed that surgeons sometimes make changes without informing them.

The instrument unavailability is another critical issue at this department as it might happen that instruments are not available to be used for the planned surgeries, which results in postponing the operation to another time (cancelling) or keep the resources waiting (creating delays) for the instruments to be available for the operation. The unavailability of instruments at the operation department can have several reasons, of which the most important are as follows: incomplete set of instruments, unsterilized instruments, and long lead time at sterilisation department.

If any operation is delayed or cancelled, the impact would be on the subsequent operations as the delayed operations would exceed to the following operation/s scheduled time and it is accompanied by different consequences such as the patients' dissatisfaction, the staff frustration, cancellation of the next operations etc. Sometimes the cancelled operation can be replaced by another operation, however, it depends on how long before the surgery day the cancellation is clear to the schedule coordinator, so that he can provide a proper alternative surgery for the cancelled operation and it requires special conditions such as available required instruments by the that operation, duration of the operation, patient's readiness etc.

The process management in the healthcare has come into focus to illustrate how value for the patient is created through the process map (Hellstrom et al., 2010). Process improvement methodologies from manufacturing industry such as lean management have been adopted in healthcare organisation in an effort to improve healthcare operational efficiency (Radnor et al., 2012).

From the lean management, non-value-added activities that are performed can be considered as waste. There are other two concepts that are interrelated with waste: unevenness and overburdening. Unevenness creates process variation, and overburdening creates poor working conditions. Assessment of activities includes reviewing the performance of existing organisational processes in term of waste, flow such as waste walk. Waste occurred in healthcare can be staff walking, waiting, or looking for objects (Radnor et al., 2012). In the operation department, walking can for example be the nurses walking in the corridor to get instruments from storage area several times. Another waste occurred in this department can be the time that staff spend to find the instruments. Waiting time can be the patient waiting for medication or space in the preoperative centre during peak hour, other staff waiting for the surgeons, or staff waiting for available resources. These waiting times can cause delays to the operation.

1.4. Purpose and research question

Considering the issues such as delayed operation, delayed anaesthesia, instrument unavailability, delayed cancellation, lack of communication, lack of resources etc. that decrease the time during which operating room in the operation department can be available to admit the patient, *the purpose of this study is to contribute to increasing the available operative time of the operating room for the studied department*. In pursuit of this purpose, a structured analysis of wastes that shorten the available operative time at the prosthetic section of the operation department will be presented.

In order to achieve the purpose, we need to answer the below questions. The first question would help us identify the wastes that exist at the prosthetic section of the operation department. Then, the second question would guide us to find the root causes of the wastes. The answer to the third question clarifies the importance of the wastes by means of either quantitative or qualitative assessment in terms of their impact on available operative time so that it can reach the purpose of this study.

1. What are the wastes that impact available operative time in this department?
2. What are the causes of identified wastes in the previous question?
3. How does each waste decrease available operative time?

1.5. Scope

This study is conducted in the prosthetic section of the operation department where orthopaedic surgeries are undergone. The operation department belongs to an anaesthesia department of a Swedish university hospital. The study will focus on the specific context of operations in this department. Therefore, it will not come up with a general conclusion or framework to be used for other healthcare organisations.

At this department, there are two types of operations, *Prosthetic* and *Trauma*, which this study would only focus on the prosthetic section. The prosthetic surgery includes primary

and revision surgeries, which are planned ahead of the schedule, while the trauma section operates emergency or acute surgeries. The reason why we exclude the *Trauma* section from the study is that they are coordinated differently and managed separately.

The investigation would be done within the regular working time at the prosthetic section of the operation department, starting from 7:00 A.M. to 6:30 P.M., and by considering only the available resources including staff, equipment, and rooms. Thus, the time outside the regular shifts and any change in amount of the available resources would not be taken into account.

Activities performed in this department by the staff, from the point where all the patients get prepared for the surgery at pre-op centre until the point where the patients are left at post-op centre after the surgery, are included. These activities are patient preparation, instrument preparation, OR preparation, anaesthesia process, and activities during changeover time. Activities when the staff prepares instruments for the surgery are also included in the study. However, the activities performed inside the OR, from knife-in to knife-out, are not considered as the time taken to do the operations depends on the medical procedures and techniques, and many uncontrollable factors such as patient's health conditions, type of the surgery etc.

Activities done outside of the department including patients' experience in the hospital outside of this department before and after the surgery, activities in the sterilisation department are not taken into consideration in this study when considering the wastes in the operation department. However, when considering the causes of the wastes, external factors from sterilisation department, ward capacity and scheduling from the orthopaedic department are taking into consideration.

2. Method

This chapter describes the overall research processes including description of different sources through which data are acquired and the method applied to analysis. The chapter is divided into five parts: 1. The research process, 2. Literature study, 3. Data collection, 4. Data analysis, and 5. Reliability and validity.

2.1. The research processes

The study in this report concerns the healthcare processes in the operation department in a university hospital in Sweden in order to identify the waste activities that have impact on the available operative time.

The study has three stages that would be described here. The first stage was performing independent study in the field of the operation management in healthcare organisation simultaneously to meeting with two personnel of the hospital discussing the important issues to be studied. After discussion during several meetings, the focus of the study was determined and literature study has been conducted in the field of operation management and lean management in healthcare so that they can establish a background regarding the procedure in the healthcare and provide the required knowledge for the next stage. It should be pinpointed that although the focus of the study was specified during the first stage, the research questions and main purpose of the study have been evolved during the first and second stages.

During the second stage, empirical data were collected. Process observations and interviews were conducted simultaneously at the department. In the beginning, processes have been observed in order to provide a comprehensive overview of the workflow in the department. Then, detailed observations on each specific activity and process were conducted to identify the waste in each process. Moreover, the interviews with personnel from different positions in the department have been done (further would be discussed). Afterwards, quantitative data were obtained from the department database system and they were used for calculating the time intervals between activities in order to answer the third research question in result chapter.

After gathering all required data, the third stage was performed in order to validate the findings in previous stages from qualitative and quantitative. In order to answer research questions, firstly, wastes were analysed based on qualitative data and identified based on seven wastes of lean. Secondly, root cause analysis was used in order to identify the causes of the waste. Lastly, wastes were assessed based on both qualitative and quantitative data, and whether they shorten available operative time or not. Those wastes that shortened available operative time, were assigned the level of impact that varies from 0, which means there is no direct impact on available operative time, to +++, which means there is high impact on shortening available operative time. The research process of this study is illustrated in Figure 1.

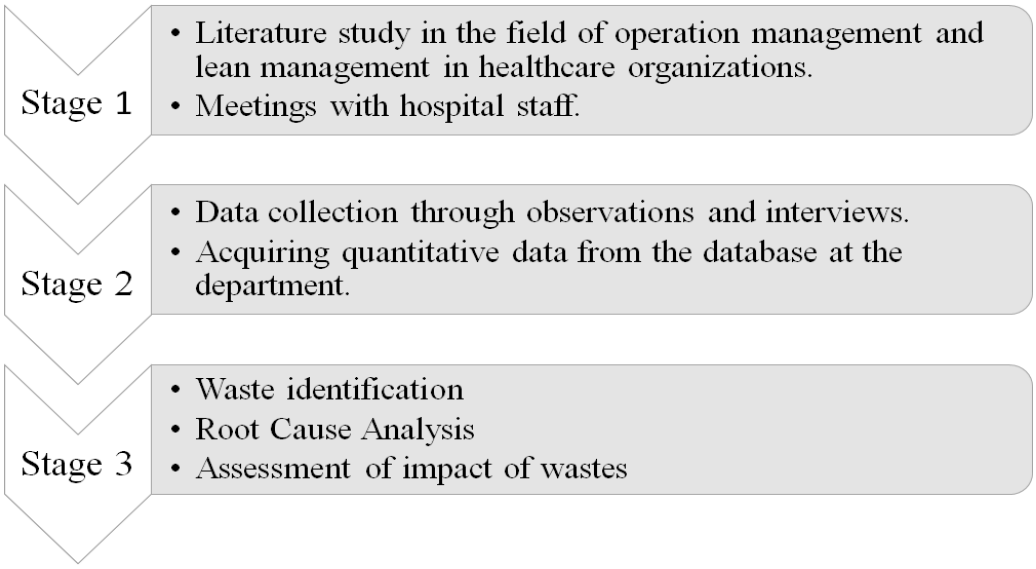

Figure 1. The research process of this study

2.2. Literature study

The literature study was performed to build an applicable framework for the research. Literature study, as a part of the data collection process, was conducted in the fields of process management in hospital, lean management, OR efficiency, scheduling etc. Literature study can be divided into three main processes.

First, the main sources of literature were obtained from Chalmers online library and search engines such as Google scholar. Keywords for searching were, for example, “healthcare process”, "operating room efficiency", "lean healthcare", "operating room scheduling", “lean management”. Scientific reports, chapters from books, and articles from journals related to the aforementioned fields were collected.

The second step was to review the relevance of each document by reading abstract and/or conclusions. Then, if the relevance and quality of the document, based on the published date, its references, and number of times it has been cited by others, were found good, the document was read thorough.

In the third step, key information was highlighted, useful and relevant information that can be used in the study were extracted from the document.

2.3. Data Collection

The data were gathered in different ways depending on the context. One type of the data is referred to as "soft" or “qualitative” data that can be gathered through observations, discussions and interviews and their softness means that the data can be intuitive to large extent that make them hard to be interpreted validly. Another type of the data is called "hard" or “quantitative” data that can be gathered through operational statistics, reports, etc.

(Coughlan & Coghlan, 2002). In this report, in order to distinguish the two types of data, we have called soft data as “qualitative data” and hard data as “quantitative data”.

2.3.1. Qualitative data

This part is on-site data collection that was performed through using the qualitative methods by conducting both semi-structured and unstructured interviews with the staff, observing the current operation processes at the department, and taking notes from January to April 2017.

First, the staff who were interviewed are from different categories and positions including OR nurses, nurse practitioners, anaesthetist nurses, anaesthetist doctors, surgeons, prosthetic section leader, department manager, and one employee from the orthopaedic department who has responsibility of coordinating the schedule.

Fourteen semi-structured interviews were held; one with surgeon, one with the anaesthetist doctor, three with the OR nurses, three with the nurse practitioners, two with the anaesthetist nurse, two with the prosthetic section leader, one with the department manager and one with the orthopaedic schedule coordinator as shown in Table 1. Each interview took approximately 30 minutes to one hour. Questions for each interviewee were different based on the position and responsibility in the department and there were the same set of questions for each position. Question sets for the interviews can be seen in the appendix.

In addition, from the beginning of this study, several unstructured interviews with the prosthetic section leader were conducted that they are not recorded and the exact duration is not certain.

The same set of questions was used for the same position so that we can compare the answers to the same questions and in case the answers converge into the same point we can trust the answer. Some points that were not clear were asked again and checked with either other personnel at the same position, or the prosthetic section leader during the observations and other interviewees.

Notes were taken during the interviews and all the interviews were recorded with permission from the interviewees. Recording the interviews has the advantage that the interview report is more accurate than only taking notes (Opdenakker, 2006). However, recording interview without taking any notes can bring a danger in case the interviewer forgets to record or malfunctioning of the recorder. Taking notes allows the interviewer to check whether all questions have been answers (ibid.).

Table 1. Details of the semi-structured interviews

Date	Interviewee's position	Durations
Jan 31, 2017	OR nurse	30 minutes
	Nurse practitioner	30 minutes
	Anaesthetist nurse	30 minutes
Feb 8, 2017	OR nurse	1 hour
Feb 9, 2017	Nurse practitioner	30 minutes
	Anaesthetist nurse	30 minutes
Feb 21, 2017	Prosthetic section leader	30 minutes
Mar 2, 2017	Surgeon	30 minutes
Mar 6, 2017	Department manager	1.15 hours
Mar 15, 2017	OR nurse	30 minutes
	Nurse practitioner	30 minutes
Mar 16, 2017	Anaesthetist doctor	1 hour
Apr 11, 2017	Prosthetic section leader	1 hour
Apr 26, 2017	Orthopaedic schedule coordinator	1 hour

Second, process observations were conducted by following and monitoring the members of the department while they were performing their daily routines. This includes informal questioning the staff during the observations in order to obtain more information and have better understanding of the processes that they are involved in at the moment.

Nine process observations were conducted from the point when the patient arrives at the pre-op centre in the operation department until the patient leaves the OR including patient preparation processes, activities during changeover time, and instrument preparation process. The details of the observations are shown in Table 2.

Notes were taken during the observation. The data gathered from observations and interviews were put in the separate document first and only relevant data with our scope are included in the empirical chapter in the report.

Table 2. Details of the observations

Date	Details	Durations
Jan 31, 2017	Observing the overall processes	5 hours
Feb 7, 2017	Observing the instrument preparation process	3 hours
Feb 9, 2017	Observing the instrument preparation processes performed in the OR for revision surgeries	3 hours
Feb 15, 2017	Observing the processes at the sterilisation department	1.5 hours
Mar 1, 2017	Observing the activities performed in three ORs for primary surgeries	5 hours
Mar 13, 2017	Observing the activities during changeover time	2.5 hours
Mar 16, 2017	Observing the processes for revision surgeries	3 hours
Mar 27, 2017	Observing the instrument preparation process	3 hours
Apr 26, 2017	Observing the anaesthesia induction process	5 hours

The data that have been acquired from the observations and interviews with the staff on different positions based on different perspectives, focus on the problems that the staff has faced at different parts of the operation processes and their perceived feelings of those problems at the operation department.

2.3.2. Quantitative data

The quantitative data on operations has obtained from the department database system, through which the personnel such as surgeons, coordinators, nurses etc. have access to it from the different locations such as ORs, storage rooms, pre-op centre, post-op centre, dedicated sterile setup area for preparing instruments and supplies (instrument preparation room) etc.

The data were gathered between January to December of 2016 in order to have the whole data for one year (which is the most recent year) and to cover variations during different time of the year. The system contains some historical data of the operation department such as number of operations, time interval between knife-out and knife-in based on each OR, numbers and reasons of delay, average start time of the first operation etc. that can be applicable with our study. Some intervals that are not given by the department database system are calculated from the time when specific event occurs until the time that event ends. Those time intervals that are generated from calculation are non-surgical tasks time in the OR before the operation, OR emergence time, changeover time that includes cleaning time and unused OR available time.

2.4. Data analysis

Several interviews with the staff from different positions and process observations throughout the whole operations have been done. In addition, time intervals of operations have been obtained from the department database system. The analysis of the data is a combination of both the qualitative and quantitative method.

Raw data of all the operations during 2016 that have been obtained from the department, are put into a Microsoft Excel spreadsheet. The data include operating room (OR2, OR3, OR4 and others), type of operation (type of operations based on body part: hip, knee, shoulder and elbow/and if it is primary, revision or other types), anaesthesia start time, the time when patient goes to the OR, the time when the patient is ready for the surgery, knife-in time, knife-out time, operation finishing time, anaesthesia stop time, the time when the OR is cleaned and ready to be used for the next operation.

Relevant data are used for analysis while irrelevant data are neglected. Only prosthetic surgeries that are operated in OR2, OR3 and OR4 are taken into consideration. However, there are some incomplete data set from the raw data, which are removed from the data spreadsheet for some calculation.

As it mentioned before, the data were collected via qualitative (interviews and observations) and quantitative (raw data from the department database system) methods. First, the data were used to provide the general description of how the processes at the prosthetic section of the operation department look like. Second, the data were applied to answer research questions; identification of the wastes at the prosthetic section, the causes of which, and for those wastes that it was feasible to quantify their impact on reduction of available operative time. The data were used as measures that could ascertain the impact. Changeover time, durations of non-surgical activities performed during OR availability, unused OR available time are as such measures used in this study.

2.5. Reliability and validity

Reliability and validity are used commonly in quantitative method and now they are considered in the qualitative paradigm (Golafshani, 2003). Triangulation by definition means to use more than one approach toward answering the research questions (Heale & Forbes, 2013). The purpose of triangulation is to increase the confidence of the findings by means of using more than two independent approaches that can be both qualitative and quantitative (Patton, cited in Golafshani, 2003; Heale & Forbes, 2013).

The combination of qualitative and quantitative methods for answering the research questions can result in three different outcomes:

1. Convergence of the results from different methods that would be followed by the same conclusion,

2. Complementary results, meaning that the results are related to different phenomena but supplement each other, and
3. Contradictory or divergent results.

When the results converge, it is verifying the methods used for the research; complementary results pinpoint different aspect of the phenomenon and divergent outcomes, with more profound investigation, can result in more appropriate illustration for the phenomenon (Heale & Forbes, 2013).

Triangulation that was applied in this report is based on triangulation of data sources that are qualitative data from the semi-structured interviews and observations, and quantitative data obtained from the department database system, and literature study of previous research and case studies.

After the empirical chapter was finalised, it was checked by the prosthetic section leader to avoid having incorrect data, missing point and misinterpretation in that chapter. This process was done to increase the reliability of data and ultimately the results of this study.

3. Theoretical Framework

This chapter outlines key aspects that are necessary and relevant to achieve the purpose of this study. In the first subchapter "Definitions", the most relevant academic-medical terms used in the whole report are defined. The next subchapter "Efficiency in operating room" would explain the importance of efficiency of operating room and further discuss different measures how efficiency of activities and phenomenon surrounding operating room can be evaluated. Moving on to the "Operating room and scheduling" subchapter, scheduling of operating room would be characterised by considering the patient type so that it can clarify the way of scheduling operating room based on patient's characteristics. The next subchapter is "Lean management", which includes lean management in healthcare organisation, seven plus one types of wastes, overburdening people or equipment, unevenness, levelled schedule and visual management. In the last subchapter, "Root cause analysis", the applied technique for identification of root causes would be introduced.

3.1. Definitions

To be consistent and clear throughout the whole report, it is important to provide the readers with the definite terms. There are some terminologies used in this report that are in the academic, industrial, and medical context. However, there might be minor differences in the definitions used in the literature and the ones used in this document that need to be clarified to eliminate any kind of confusion for the reader. The definitions are:

- *Orthopaedic Prosthetic surgery*: It is an elective surgery that includes replacement of the joints, bones and ligaments, divided into the primary and revision surgeries that are planned ahead of the schedule**.**
- *Orthopaedic Trauma surgery*: It is a non-elective orthopaedic surgery that can be "emergency" or "urgent" that should be done in a short time.
- *Operating field/Surgical site*: The skin surface where the operation would be done on it.
- *OR total process time*: It is defined as the time previous patient is moved out of the OR to the current patient moved into the same OR (Sandberg et al., 2005).
- *Operative time*: Ready for the surgical preparation to surgery finish (Sandberg et al., 2005). It encompasses for the final preparation activities that needs to be done inside the OR, such as sterilising the operating field, and adjustment of patient position in accordance to the surgeon's order and patient safety.
- *Non-operative time*: Previous patient out of room to current patient ready for the surgical preparation plus surgery finish to patient out of room (Sandberg et al., 2005). Non-operative time is comprised of the anaesthesia induction plus the emergence time and the room changeover time.
- *Changeover time*: The time from which one patient exits the operating theatre to the time when next patient enters the operating theatre. During this time, the operating

theatre is cleaned and the equipment prepared for the next operation (Delaney et al., 2010). The changeover is the time elapsed from one patient leaving an OR to the next patient entering the same OR (Dexter et al., 2005). The changeover time is defined as the previous patient out of the room to the current patient in the room (Sandberg et al., 2005).

- *Unused available operative time:* The time that the OR is available between two operations to admit the next patient, but the OR is left idle. The time when the OR becomes available and can be used for the next operation until the time that patient is moved inside.
- *Anaesthesia start*: The time when the preparation for anaesthesia process begins.
- *Anaesthesia Induction time*: Anaesthesia induction to ready for surgical preparation (Sandberg et al., 2005).
- *Knife-in/Surgery start time*: Surgical instrument contacts patient (Sandberg et al., 2005).
- *Anaesthesia stop*: The time when the patient is recovered from the anaesthesia inside the OR and it is almost at the same time with the patient departure from the OR to the postoperative centre.
- *Knife-out/Surgery finishing time*: The time when the surgeon closes the incision with stitches or staples, bandage it and prepare the patient for recovery.
- *OR emergence time*: Surgery finish to the patient out of the OR (Sandberg et al., 2005). In the data set obtained from the department, the patient out of the OR is considered as the same time as the "Anaesthesia stop time".

3.2. Efficiency in operating room

Many authors have marked the importance of the operating room for healthcares as it accounts for more than 40% of the hospital's total revenue and it is the most cost-intensive division of the hospitals (Peltokorpi et al., 2009; Collar et al., 2012; Sandberg et al., 2005; Wright et al., 2010). The intensive activities, various types of equipment, number of personnel and surgeons' expensive time incur considerable expense to the hospitals and it is vital for them to take steps to improve the efficiency and reduce cost (Wright et al., 2010). Efficiency can be increased either in term of reducing cost or increasing the amount of work done during the specific period of time with the same amount of resources (ibid.).

In order to consider the efficiency of the surgical services, there are different performance measures used by different hospitals as well as researchers. Peltokorpi et al. (2009) have pointed out in their study that the performance measures can be divided into four efficiency measure categories:

1. Production system quality measures
2. Capacity utilisation and time measures
3. Technical efficiency measure
4. Economic efficiency measure

Each of these measures considers efficiency both internally and externally. However, they have revealed that efficiency has been being assessed more internally. Peltokorpi et al. (2009) summarise different factors for measuring the inefficiencies based on several studies in the Table 1.

Production system quality measures. To understand how exactly a production planning is accomplished, production system quality measures can be scrutinised. There are different reasons why it would not go according to the production plan; late cancellation as a result of improper information sharing and poor pre-operative processes, delays in surgeries as a consequence of either the urgent surgeries or shortages in the crucial resources, late start time of the operation, and the unpredictable surgery time as it might happen some surgical cases last longer than estimated time (Peltokorpi et al., 2009). Apart from late OR start and finish times, potential areas of inefficiency can be delays in moving the patients out of the OR after recovery from anaesthesia, and under-utilisation of the anaesthesia induction room (Divatia & Ranganathan, 2015).

Capacity utilisation and time measures. Capacity utilisation rates such as OR raw utilisation rate is a performance measure that considers portion of time that the OR is occupied by the patient. The non-operative time and changeover time are two other time measures that take the time interval of two consecutive operations when the patient is not inside the OR. These measures are useful to be used due to this assumption that consider OR time as an expensive resource for healthcare that must be exploited efficiently. By taking into account the underused and overused time, scheduling and resource management can be assessed. Underused OR time is the idle time of the OR during the office hours after the last patient leaves the OR, and overused OR time is the time after ending office hours, during which the OR is still being used for the operation (Peltokorpi et al., 2009).

Technical efficiency measure. In technical efficiency measures the relation between output and the resources used would be considered. Studies have focused on the standardised surgery times, required amount of time with constant throughput, number of total operations per time unit and other efficiency measures (Peltokorpi et al., 2009).

Economic efficiency measure. Economic efficiency measures are mainly used to maximise the profit or minimise the cost. However, it is worth mentioning that it is more usual to consider economic measures such as cost of care, workload per labour cost and contribution margin in competitive environment (Peltokorpi et al., 2009).

Table 3. Measures used for efficiency of surgical services (Peltokorpi et al., 2009).

	Production system quality measures	**Capacity utilisation and time measure**	**Technical efficiency measure**	**Economic efficiency measure**
Internal measures	Late cancellations	OR raw utilisation rate	Standardised surgery time per personnel hours	Cost of care episode
	Shifted operations	Non-operative time	Minimum OR blocks needed with constant throughput	Contribution to margin
	Start-time tardiness	Changeover time	Number of operations per unit time	Anaesthesia workload per labour
	Surgery time	First operation start time		Cost per output
		Overused/under used OR time		
External measure	In-hospital waiting time		Maximum ward beds needed	
	Total waiting time		Opening hours of ward unit	

In this study, in order to understand what decrease the available operative time, OR performance together with the relevant activities or phenomenon outside the OR should be scrutinised and observed in term of how efficient they are. To monitor, measure and benchmark the OR efficiency and performance, the abovementioned efficiency measures have been used by different studies. However, it should be determined which efficiency measures are relevant and can be applied to the case. This is due to the fact that the data required by that performance measure should be available in the OR/department/ hospital data information system (Fixler & Wright, 2013). Subsequently, not all the efficiency measures yet some of them mentioned in Table 3 would be used in this study. They would be discussed further in "Results" chapter.

Inefficiencies in the operating department can occur both during and between the operations and cause different problems such as frustration for the OR staff, anaesthetist doctors and

surgeons, and dissatisfaction for the patients as they would receive their services with delays that are consequences of inefficient way of activities (Harders et al., 2006). Similarly, Wong et al. (2010) claim that the delays in the operating room would affect the patients and healthcare staff negatively; even though the delays might not affect patient health, they can create anxiety and disappointment for the patients. Sandberg et al. (2005) define the OR total process time as the time between a previous patient's departure from the OR and the current patient's departure from the OR. In Figure 2, it can be observed that this time interval consists of "Non-operative" and "Operative" time. The non-operative time encompasses the preoperative and postoperative activities, including clean-up activities after the patient leave the OR, OR setup, OR anaesthesia time and emergence from anaesthesia. The operative time comprises for surgical preparation and surgery itself.

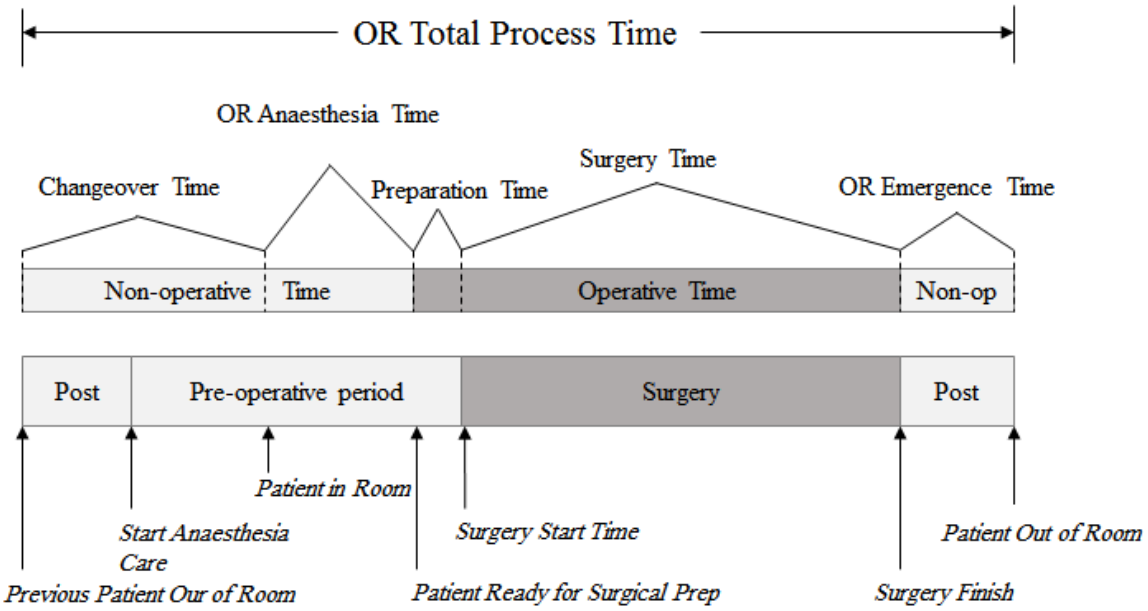

Figure 2. Illustration of time intervals used in this study (Sandberg et al., 2005)

As it can be seen in Figure 2, the OR total process time consists of operative plus non-operative time. In order to increase available operative time during the OR total process time, the non-operative activities during the non-operative time, and the non-surgical activities during the operative time should be reduced. If the non-operative time, as the portion of the OR total process time is reduced, the amount of time that is reduced is called "increased available operative time" that can be dedicated to surgical activities inside the OR. The Figure 3 explains how the available operative time is defined. There are different activities during different times as it can be seen in Figure 3.

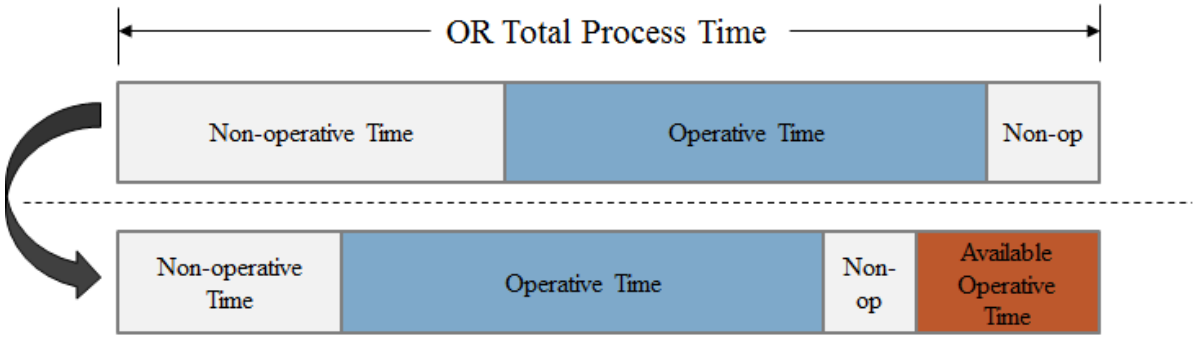

Figure 3. Illustration on how available operative time can increase.

During non-operative time, there is no operative activity performed by the staff and there is an opportunity to increase the efficiency of the OR by investigating how effectively this time period is used by the staff (Sandberg et al., 2005). Efficiency can be achieved by implementing new/improved technologies, modification of traditional OR design, improving work flow, and hiring more personnel in the department (ibid.). There are several different causes for delays recorded by several studies such as unavailable instruments and equipment, late patient, surgeon/anaesthetist doctors/nurse delayed, inoperable patient, longer cleaning time, unprepared patient etc. (Weinbaum et al., 2003; Sandberg et al., 2005).

Harders et al. (2006) indicate that the ultimate purpose for improving the OR efficiency is to provide condition at which the capacity of the operating room would be increased and more operations can be performed in the operating room. One approach to increase the efficiency and number of operations is to decrease non-operative time. Harders et al. (2006) have used process redesign and improvement in technology to reduce non-operative time. They have considered three factors in their study by which they could have reduced non-operative time:

1. Elimination or moving of nonsurgical tasks out of the OR;
2. Performance of activities in parallel whenever feasible and safe, and
3. Minimisation of nonclinical disruption.

Considering the first two points, Smith et al. (2008) have performed a study for reducing non-operative time for joint arthroplasties in a university hospital through parallel processing outside the OR. They have changed some pre-operative activities and improve flow of the patient through different practices that are non-surgical and can be done outside the OR in parallel with the performing operation. The practices include performing anaesthesia process inside the anaesthesia induction room, preparing the instrument inside the dedicated instrument setup area (or instrument preparation room), and additional anaesthetist nurse that takes patient from the OR to the post-op centre that allows the anaesthetic team to induce the next patient in parallel with changeover time.

Regarding the third factor they have provided an automated medication dispensing machine inside the OR that eliminate the additional transporting the basic medication between cases, a radios system for communication that allows the staff inside the OR to inform other

personnel about timing of the ongoing operation and let them know when to prepare the next patient and notify the cleaning personnel to stand by the OR at the right time (Smith et al., 2008).

Smith et al., (2008) have proved through the process redesign that parallel processing can result in nearly 50% reduction in the non-operative time and is accompanied by decreasing the operative time by 12% that let the OR staff perform additional procedures.

In study by Dexter & Macario (1999) they have pointed out that reduction and saving in the changeover time and case duration might have no benefit in improving the efficiency in term of increasing number of operations as the number of minutes decreased for each case is not sufficient as it must be to allow an extra operation to be performed. However, they have marked that it is more possible to add an extra case when the operation duration is less than two hours as it is usually in case of the orthopaedic operations. Moreover, Wong et al. (2010) highlight that even if time savings cannot lead to accommodating at least one extra operation, the time saved can be used for other purposes such as teaching, research, and extra operative patient care by surgeons. For the OR staff, the time when they can save by more efficient process design can let them engage with other activities, and for the patients, more satisfaction can be achieved by reduction in time.

3.3. Operating room scheduling

3.3.1. Patient Characteristics

Patients can be classified into two major group, "elective patients" and "non-elective patients". The elective patients are those who will be informed about their surgery planning time in advance while the non-elective patient would be noticed for short time before their surgery is planned. There is also a classification for the non-elective surgeries namely "emergency" and "urgent". The former is the one that should be performed immediately and the latter can be postponed for a short time. The elective patients can be either "inpatient" or "outpatient" depending on if they are hospitalised before or after surgery at the hospital (inpatient) or they are only present at the hospital for surgery time, and they would be discharged after the surgery (outpatient) (Denton et al., 2013).

3.3.2. Scheduling

Scheduling is described as defining the sequence of the operations by which it can be understood what operation should be done at what time and when it should be finished (Cardoen et al., 2010). The objective of scheduling the daily operations is to arrange operations execution time in a way that suits the available resources (Jebali, et al., 2006). Scheduling includes both the preoperative and postoperative patient care management (Gupta, 2007). The preoperative stage can include different medical tests, preparation for the surgery, educational service on how the patients should care for themselves before and after the surgery etc. Postoperative phase happens in Post Anaesthesia Care Unit (PACU) or

Intensive Care Unit (ICU), and other post-operative cares for recovering the patient after the surgery and controlling their health condition, and these postoperative procedure types and duration depend on the patient needs.

There are different issues regarding scheduling the surgical facilities that should be considered from different stakeholders' point of view and within three different time horizons: Long-term horizons (6 months or more), medium-term (several weeks) and short-term (daily) (Vargas et al., 2008; May et al., 2011). Very long-term horizons consider issues regarding the repurposing, creating and upgrading the facility, examples are determining the layout and number of ORs to be constructed to meet the demand (May et al., 2011). For long-term horizon, scheduling decisions are usually made based on the population demographic, the medical practices, and stakeholders such as policy makers, hospital administrator, and doctors. At this stage, the capacity planning addresses the target market and the customers and it is closely linked to the strategic planning of the institution. The decisions on long-term horizon can constrain the scheduling on the medium-short term horizon, however, they are not included in this research (Vargas et al., 2008; May et al., 2011). During the medium-term, staff scheduling and estimation on the procedures time would be done. The short-medium-term scheduling has to handle the flow of the people who are related to the operating room such as surgeons, hospital staff, and patients, and it is done few weeks/days before the surgery day, therefore, it is expected that deviation from the schedule happens (Vargas et al., 2008).

The aim of the short-term OR scheduling is to arrange operations in a way that surgeons, anaesthetist doctor, nurses, operating theatres, supplies, and equipment can respond to the schedule in a timely manner. It must be noted that inappropriate scheduling method, that do not consider the availability of resources, would not let the procedures be performed at the right time, and that is why the schedule during short-term perspective should be monitored. There are other issues that result in deviation from the planned schedule such as emergency cases and uncertainty of the specialists regarding the exact duration of all procedures and they may last longer than scheduled or expected. This deviation from the schedule is due to the characteristics of the operation, surgical team, and patients (May et al., 2011). Correspondingly, Cardoen et al. (2010) state that one of the major problem with accurate operating room scheduling is the intrinsic uncertainty associated with surgeries. The uncertainty found in operating room scheduling can be mostly in two types, arrival uncertainty and duration uncertainty. The arrival uncertainty is related to for example lateness of surgeon, unprepared patient etc. The duration uncertainty is the deviation from planned duration of the activities related to the surgery processes. Apart from these type of uncertainties, there is another uncertainty that can be addressed, which is shortage in resources such as surgeons, nurses, instruments etc. (Cardoen et al., 2010).

3.4. Lean Management

3.4.1. Lean Management in healthcare organisation

Lean method was initially developed by Toyota and can be one of the approach that is used in healthcare to improve efficiency, improve processes, set standard and eliminate bottleneck in the system (Belson, 2010). Lean has been successfully applied to healthcare industry (Aherne & Whelton, 2010). Moreover, it has helped many healthcare organisations to provide successful quality care (Belson, 2010). It emphasises on waste identification and elimination, and flow improvement so that time, materials, resources, and procedures can be utilised as efficiently as possible (Belson, 2010; Aherne & Whelton, 2010).

The aims of lean are to create more efficient workplace, create smooth work and patient flows, and eliminate waste in time or work that adds no value for the customer (patient). Moreover, lean also aims at continuous improvement of operational processes to have quality services. Lean method is particularly effective when waste is obvious and an organisation suffers from lack of standardisation (Belson, 2010). Applying lean to operating room procedures can help reduce the time taken between the operations resulting in increasing the number of operations that can be proceeded and make the operating room more effective place for the surgeons and operating staff (Aherne & Whelton, 2010). However, value adding for customer, which is the patient in healthcare, differs from customer in manufacturing as the main goal of healthcare is to provide cure or prevention (Manos, 2006).

3.4.2. Waste

Carreira & Trudell (2006) give the definition of waste as an activity that adds cost and does not generate revenue, on the other hand, an activity that generates revenue is considered not waste. Any activity that does not add value from the patient's point of view is considered as wasteful or non-value-added activity (Aherne & Whelton, 2010). In healthcare, some wastes are unavoidable due to regulatory requirements, therefore, reducing the waste without harm to the patient is challenging (Belson, 2010). Activities in any process can be divided into three categories, which are value-added, non-value-added but necessary, and non-value-added or waste (Aherne & Whelton, 2010). Activities that do not add value to product or service but are necessary, cannot be avoided since they provide circumstances at which a value-added work can be performed. For example, the instruments or tools need to be prepared in advance for the surgeon so that they can perform the value-added activities (Liker and Meier, 2006). Eight wastes in manufacturing can also be applied in healthcare (Manos, 2006). Eight types of waste or non-value-added activities in business or manufacturing process, with the examples from the healthcare industry, are presented below (Liker and Meier, 2006; NHSIII, cited in Radnor et al., 2012):

1. Overproduction
   Producing unnecessary items, or producing earlier or more than required by customers creates other types of wastes such as inventory, transportation. In healthcare organisation, overproduction can be seen as requesting unnecessary documents or keeping investigation slots available just in case of an emergency care.
2. Waiting
   Staff have no work and have to wait for the next processing step. Waiting can be waiting for patient, theatre, medicines and prescription.
3. Transportation
   Unnecessary transports that are created from carrying work in process (WIP) from place to place or moving materials into or out of storage are considered as one of the wastes. Staff walking to the other end of the department to pick up papers can also be one type of transportation waste.
4. Over processing or incorrect processing
   Inefficiently processing due to poor tool and product design causes unnecessary motion and produces defects. Waste is generated when producing higher quality products than needed. In healthcare organisation, over processing can be for example duplication of information or asking for patients' information several times.
5. Excess inventory
   Excess raw material, WIP or finished goods causes longer lead time, damages, obsolescence, transportation and storage cost. Extra inventory also hides problems such as production imbalance, and long setup times. Waiting lists of the patient in the system can also be considered as excess inventory.
6. Unnecessary movement
   Any motion that staff perform during their work other than adding value to the part such as walking, looking for etc. Not having basic equipment in every examination room can create unnecessary motion for staff.
7. Defects
   Production of defective parts or correction. Waste is generated from repairing of rework, replacement production, and inspection. Readmission of the patient because of failed discharge is another kind of defects.
8. Unused employee creativity
   Losing time, skills, improvements, and learning opportunities by not engaging or listening to your employees.

Unused employee creativity is not considered when identifying the wastes in the chapter 5.1, as it is not related to available operative time of the operating room. Therefore, only seven wastes will be applied with this study later on. Apart from waste elimination, there are other two issues that should be focused on to make the process more efficient. Eliminating unevenness in the production schedule and eliminating overburden to the people, and equipment are as important as eliminating waste (Liker, 2004).

3.4.3. Overburdening

Overburdening is the opposite of waste as it means pushing a machine or person beyond natural limits. Overburdening the equipment results in breakdown and defects. Overburdening people crates safety and quality problems (Liker, 2004). The unreasonable works imposed on workers and machine are such as carrying heavy weights, carrying things around or working significantly faster than usual (Caldwell, 2008). It can be avoided by having standard work disciplines. Then every process must be reduced to its simplest elements by taking simple work elements and combining them into standard work (ibid.).

3.4.4. Unevenness

It is said that unevenness is the resolution of waste and overburdening the people and equipment. It could be that there is more work than people or machine can handle at times and there is lack of work at other times. Unevenness can be created from an irregular production schedule or fluctuating production volumes. Unevenness means that it is necessary to have available resources such as materials, people and equipment for the highest level of production, even though average level is lower than that (Liker, 2004). Mura focuses on implementation and elimination of fluctuation at the scheduling or operations level. It can be avoided through just-in-time system by supplying the production process with the right part, in the right quantity, at the right time, to the right place and on first-come-first-serve-basis (Caldwell, 2008).

3.4.5. Levelled schedule

Levelled schedule means levelling out the production schedule in both variety and volume. In order to have stable system and minimum level of inventory, levelled schedule is necessary. Achieving levelled schedule is fundamental to eliminating unevenness, which is fundamental to eliminating waste and overburdening. It is easier to level out the schedule in high-volume manufacturing than lower-volume service environments as lead times on service works vary a lot case by case. However, the solutions in service operations are similar to the solutions in manufacturing. For example, doctors try to fit customer demand into a levelled schedule so that the workload can be levelled. Another requirement to level out a work schedule is to establish standard time for different types of procedures. Doctor can predict the time that will be required for a specific procedure (Liker, 2004).

3.4.6. Visual Management

Visual control is an important step in the process of developing standardisation. The reason for visual control is to identify normal state, and then, to see or recognise any abnormalities or deviations from that standard (Liker and Meier, 2006). A good visual control system can help increase productivity, reducing mistakes and defects, improving safety, lowering cost and providing the workers with more control over their environment. The amount of time that the workers spend on finding the information on the computer or searching for

documents, and items etc. can create frustration and prevent workers from working efficiently. Visual management makes it possible to see abnormalities by a glance, and know what is going on of this moment so that no problems are hidden. Charts and graphs can be used to see the current status (Liker, 2004).

3.5. Root Cause Analysis (RCA)

RCA is a qualitative method for seeking the underlying causes of a given problem by aiming at answering the questions of "what", "how" and "why" it happened and "what is the solution to that" (Phillips and Simmonds, 2013). RCA is being applied more and more in the healthcare service sectors as well as other types of industries to find the source of the problems in both systems and individuals (Pearson, 2005; Heher, 2017). This method requires the users to obtain the data from the medical and nursing records, statements from staff, instructions, literature, etc. and then investigate those data to identify the root of the problem, evaluate or quantify the impact of each cause and plan actions to prevent or mitigate those causes (ibid.).

Problems at healthcare are usually due to failures at multiple levels of complicated processes, therefore, there can be several root causes and not just a single one (Heher, 2017). It is important to acquire knowledge regarding the variations in healthcare processes as they can be causes of the problem that leads to inefficient or unsafe processes. There are different techniques that can be used in the root cause analysis that one of them would be described here.

Reid & Smyth-Renshaw (2012) have discussed the most common techniques and scenarios used by other researchers for identifying root cause analysis including tools such as FMEA, Pareto, Fishbone or Ishikawa diagram, Ford's 8D model, and A3 thinking. Among these tools, Fishbone diagram is useful to be used for identification of human performance and other factors in the healthcare industries.

The Fishbone diagram, also known as an "Ishikawa diagram" or Cause and effect" diagram, divides the possible causes to different categories namely people, equipment, method, environment, material and measurement (Phillips and Simmonds, 2013). One drawback with this method is that it does not specify the correlation to the unpleasant outcome and links between different causes in a rigorous way but it can guide the user to find any relevancy among them (Heher, 2017). The Fishbone diagram also limits the performers to specific set of causes and if those performers miss some causes, the result would not be precise, however, it is a simple, comprehensive and can be used in a timely manner (Latino, 2015). Moreover, it is a good way for structuring the causes based on the different categories and seeing all of them in one picture.

In this study, the fishbone diagram would be used so that the major causes, which drive the processes and activities to be inefficient and wastes occur in this department, can be recognised. In Figure 4, one example of the fishbone diagram has been developed by a team

of researchers to speculate the possible reasons why and how time might be lost before the surgery (Tolga et al, 2007). This fishbone diagram is applicable with this study and is used to help gather the data and analyse them. Problem and causes that have been identified by Tolga et al. (2007) are similar with our study, even though the problem is not the same and there can be more causes than the causes that are presented in the fishbone diagram in our study. Therefore, this example would help search for the similar causes in the four categories.

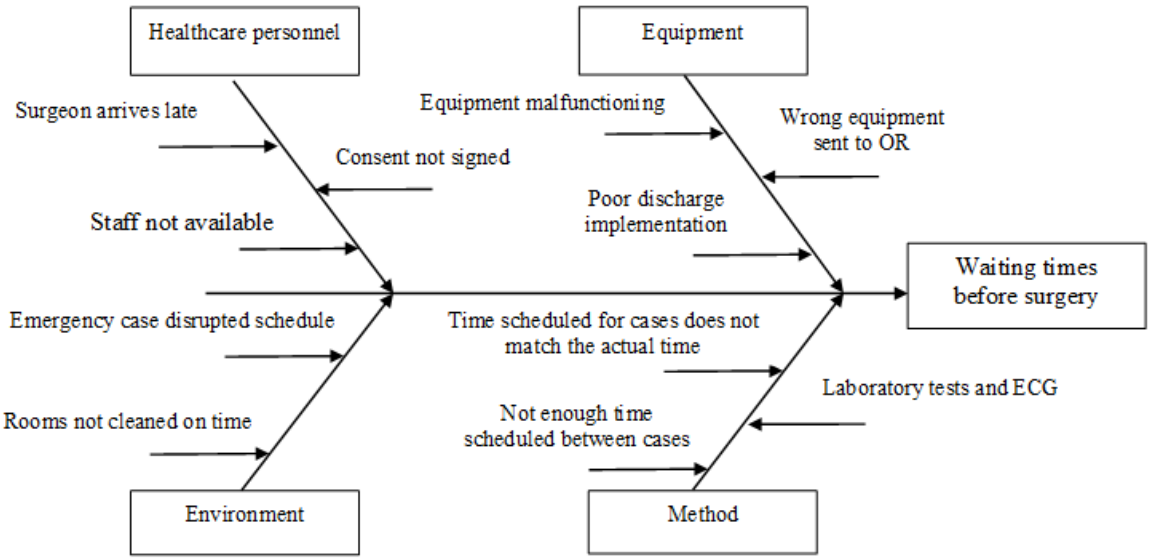

Figure 4. The example of root cause analysis for increased waiting times before surgery (Tolga et al, 2007)

4. Empirical Data

This chapter provides detailed description of the activities and processes done at the prosthetic section of the operation department. In addition, the quantitative data that belong to the operations performed during 2016 acquired from the department database system, are depicted such as number of operations, knife-in time of the first operation, delays, and late cancellations.

4.1. Number of operations

In 2016, there were 1503 surgeries operated in the prosthetic section. Type of the surgery can be divided into three categories, which are primary surgery, revision surgery and others (including shoulder, elbow, and minor orthopaedic operations such as realignment of broken bone etc.) as shown in Table 4.

Table 4. Total number of operations in 2016

Type of surgery	*Total number of operations*
Primary	1103
Revision	173
Others	227
Total	1503

The surgeries that were operated in the operation department were mostly knee and hip surgeries: 612 operations for knee, and 800 operations for hip, which were 94 percent of all operations in 2016. The rest were shoulder and elbow operations and during 2016, there were 60 shoulder operations and 13 elbow operations for both the primary and revision surgeries. Table 5 shows number of operation based on each type of surgery and each OR that was used to operate the surgery in 2016.

Table 5. Types of surgery that are operated in each OR

Surgery Type / *OR*	*Hip*	*Knee*	*Others*	*Total*
OR2	319	273	7	599
OR3	240	189	16	445
OR4	141	131	55	327
Others	100	19	13	132
Total	800	612	91	1503

4.2. Processes at the prosthetic section of the operation department

There are seven operating rooms at the operation department. Three operating rooms (OR2, OR3 and OR4) are allocated to the prosthetic section, while four of which are allocated to the trauma section. The layout of the operation department is illustrated below. This layout does not include the other four ORs allocated to the trauma section.

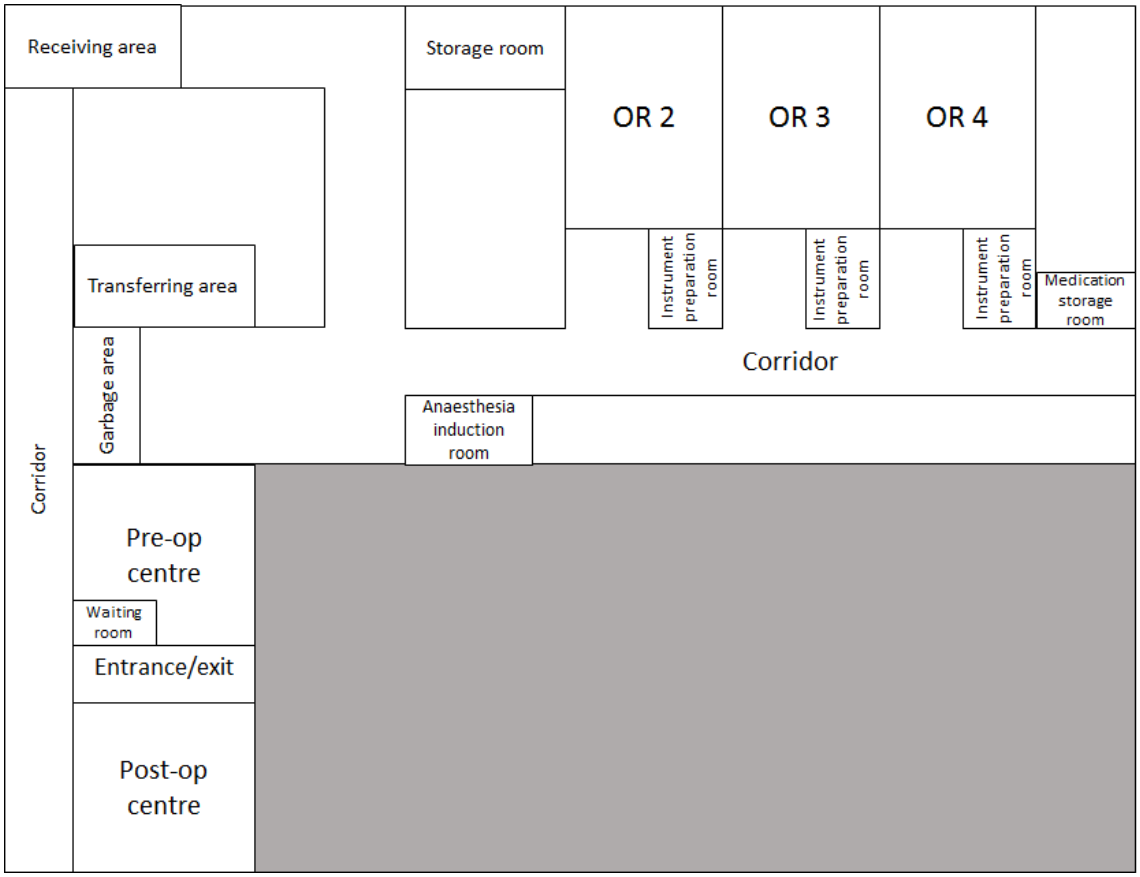

Figure 5. Layout of the operation department

There are two working shifts at this department during day-shift working hours. The first shift starts from 7:00 A.M. to 1:00 P.M., and the second shift starts from 12:30 P.M. to 6:30 P.M.

There are two types of prosthetic surgeries at this department, which are primary and revision surgeries. From Monday to Wednesday, the primary surgeries that are less complicated and take shorter time are scheduled to OR2, and primary surgeries that are more complicated and take longer time are scheduled to OR3 and OR4. The revision surgeries are operated on Thursday and Friday.

The reason why the operation department operates revision surgeries on only Thursday and Friday is that the patient needs to stay longer time at the hospital for this type of surgery, so they would rather to keep the patient at the ward during weekend when there are more free

spaces. Less demand for revision surgeries in comparison to primaries is another reason. Lastly, revision surgeries are quite complex surgeries and not all surgeons have the proficiency to operate these kinds of surgeries and there are few who can operate

The OR team consists of an anaesthetist nurse, an OR nurse and a nurse practitioner. The anaesthetist nurse has responsibility to prepare the patients for the surgery when they arrive at the pre-op centre and controlling patient's condition during the surgery. The OR nurse and nurse practitioner have responsibilities for preparing the instruments for the next operation and working inside the operating room during the surgery. Two surgeons are assigned to each OR and they have to operate all surgeries that are allocated in that specific OR the whole day. For each surgery, one surgeon operates as the main surgeon and the other as assistant, and they change their role for the next operation.

The surgeries that are operated in OR2 are the ones that are easy to handle, not complicated and take short time to finish, since the operation department gives priority to this operating room in order to have number of operations in OR2 per day higher than those of OR3 and OR4. This is due to having students in other ORs and the department believe that it is easier to manage and control processes in this way. There are fewer operations performed in OR3 and OR4 in comparison to OR2 as the department does not have sufficient staff to support the fast performance and there should be students inside the OR and it leads to lower pace.

From Monday to Wednesday when there is only primary surgery in all three ORs, there are usually four operations per day in OR2, while there are usually three operations per day in OR3 and OR4 as shown in Figure 6. Therefore, in order to have higher number of operations in OR2, there are two OR teams operating in OR2 in morning shift, however, there is only one OR team for OR3 and one for OR4. There is another OR team in the corridor or corridor team that assists preparing the instruments in both OR3 and OR4. Corridor team consists of one anaesthetist nurse, one OR nurse, and one nurse practitioner. They have responsibilities to prepare the patient and the instruments for the next operation simultaneously while the current operation is being operated in the OR and support the OR team in case they ask for any assistance. For afternoon shift, one OR team is assigned to each operating room and one corridor team supports all the ORs.

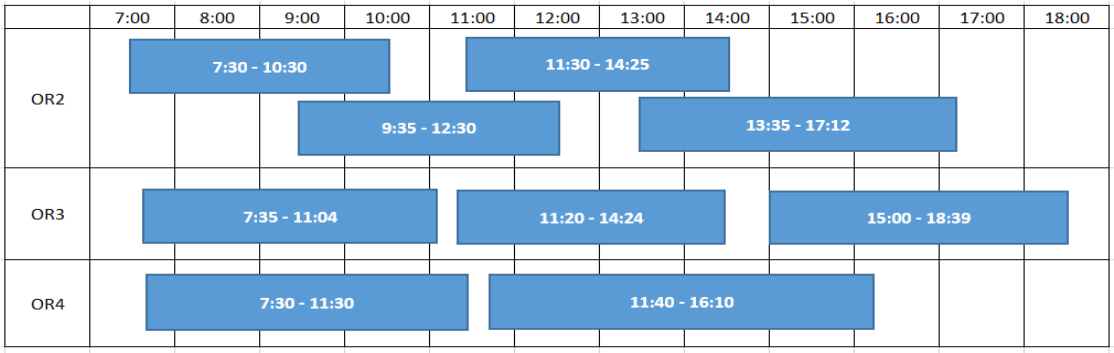

Figure 6. Example of the planned schedule of primary surgeries during Monday to Wednesday

However, on Thursday and Friday, revision surgeries operated in all ORs usually takes long time to operate as shown in Figure 7. There are usually 2 operations in each OR, therefore only one OR team is assigned to each OR and one corridor team supports the operating rooms and helps prepare the instruments for all ORs when surgery is being operated inside the OR. In addition, OR4 is not used for the prosthetic section on Friday and it would be scheduled for trauma section.

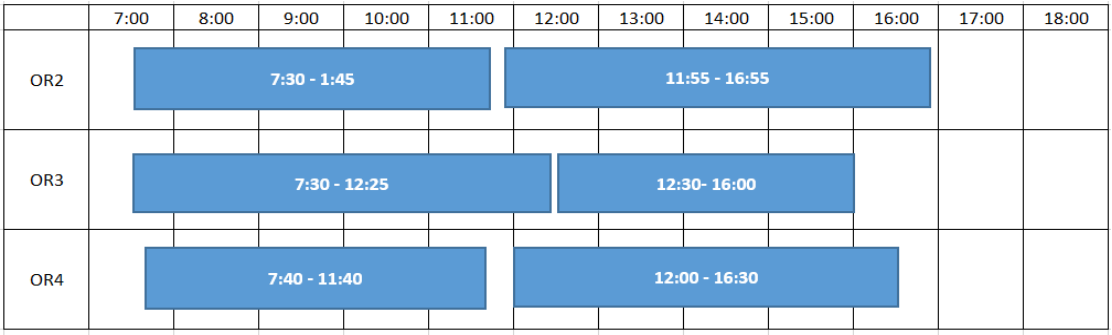

Figure 7. Example of planned schedule of revision surgeries on Thursday

All the patients that arrive at the operation department for both the prosthetic section and the trauma section need to be prepared at the pre-op centre where there are four slots for the patients. There is one anaesthetist nurse at the pre-op centre. When the patient arrives at the pre-op centre, the anaesthetist nurse who will be in the operation with the patient has responsibility of giving medication and preparing the patient before going into the OR. At the same time, the OR nurse and the nurse practitioner are preparing the OR and instruments for the surgery inside the instruments preparation room.

There is one anaesthesia induction room that is mainly used to prepare the patient who is taken to OR2, but it is sometimes used for patient of OR3 and OR4. There are two types of anaesthesia; spinal anaesthesia and general anaesthesia. Spinal anaesthesia for the patient can be proceeded outside operating room in the anaesthesia induction room before the patient going inside the OR, and it takes shorter time. So, the operation department usually assigns only patients that need spinal anaesthesia to OR2 to shorten the time in the OR as the operation can start after the staff finishes setting position of all the equipment and the patient inside the OR without an anaesthesia process. However, the general anaesthesia needs to be proceeded inside the operating room, so it requires longer time to put the patient to sleep and to wake up the patient after surgery is done. The staff may move the patient from patient's bed to surgery bed at the preparation room or in front of the OR if that patient goes to the OR directly after the pre-op centre.

Average first knife-in times in each OR are different as shown in Table 6. OR2 usually starts the operation before the other two ORs as more number of operations are operated in OR2 per day.

Table 6. Average first knife-in time in each OR during 2016

Operating theatre	*Average first knife-in time (A.M.)*
OR2	8.32
OR3	9.02
OR4	9.06

After the surgery, the anaesthetist nurse has responsibility to take the patient to post-op centre where the patient is left for couple of hours before going to the ward. After the patient leaving the OR, the cleaning personnel need to clean up the OR and it usually take approximately 10 to 15 minutes in this process. At the same time, used instruments and table are taken to the transferring area to the sterilisation department where the trash from the surgery are thrown away, then, the instruments are transported to the sterilisation department afterward. The staff prepares operating room for the next surgery when the OR is cleaned.

4.3. Preoperative centre

At the operation department, actual operations start and finish time differ from the planned ones leading to waiting time for the patients and waste of time for the staff. This variation in time, at the first sight, can be seen as a result of lack of space at the preoperative (pre-op) centre where there are only four beds for preparing the patients, both for the trauma and the prosthetic section, while it is supposed that seven operations should start almost at the same time especially in the morning. It is also possible that the patients arrive to the pre-op centre simultaneously in other time of the day than in the morning yet it happens less as surgeries have different ending time. Inefficiency here, appears in two forms:

1. *Unprepared patients but prepared both ORs and instruments*: When the patients are already at the department but the operation cannot begin on time because the patients are not prepared on-time at the pre-op centre or at the ward while the ORs are available.
2. *Unprepared instruments or OR but prepared patients:* When the OR or instruments are not prepared while the patients are available.

Considering the first issue (Unprepared patients and prepared ORs and instruments), there are two reasons behind.

The first reason is that patients need to receive medications, injections and any other special care that the doctor has ordered, however, the available area is only for four patients and it creates a queue for the patients as they should wait until they get prepared for the operations. It goes back to patients' conditions such as age, health condition, special care etc. that can prolong the preparation processes; for instance, there are two types of the anaesthesia for the prosthetic operations, the regional anaesthesia that affect the patient sooner and general

anaesthesia (putting patient to sleep) that lasts longer to affect the patient, and depending on the patient preference or medical diagnosis, it differs patient to patient. This special care for the patient can lead to late start of the operation and whether it is the general or regional anaesthesia should be known to the staff.

Second, unprepared patients can be as a result of lack of proper communication between anaesthetist doctors, surgeons and nurses as they have to update each other regarding the patients' health conditions, special care or any particular medication before the surgery. Subsequently, this lack of information of the patient requires the staff at pre-op centre to contact the surgeon/anaesthetist doctor in charge of the patient so that the staff knows what exactly he has to do for the patient before the operation.

The second issue (unprepared instruments or OR and prepared patient) is explained in the subchapter 4.5.5.

4.4. Anaesthesia process

Anaesthesia process begins with the preoperative evaluation of the patient's health condition one day to one week before the surgery day. The length of time when the patient should be under supervision of the anaesthetist doctor differs patient to patient depending on the health condition, type of the surgery and age. Several factors can affect and necessitate the choice of anaesthesia method for the patient, namely, patient's health condition, age, difficulty of the surgery, other illnesses, and the patient consent and preferences that require anaesthetist doctor to check up the patient in advance.

There is a questionnaire with different questions about the patient's health condition that should be filled out by the patient and after the anaesthetist doctor has met the patient who has been examined by the doctor, the anaesthetist doctor fills out a preoperative medical form related to anaesthesia process including the type of anaesthesia, patient's health condition, medication needed before and after anaesthesia, patient's personal information such as weight, height etc., they might call up the patient for further consideration. The patient safety is the most important issue, as sometimes they have to consult with other specialist to control the patient's condition regarding specific disease.

On the day of surgery, the anaesthetist doctor should be at the operation department at 7:30 A.M. to start preparing the first patient for the surgery. Each anaesthetist doctor would be assigned to either two or three OR, depending on how much the patient condition needs to be monitored during the surgery and this depends on the patient's health condition, in other words, it depends on the workload. If the patient is healthy, it usually takes less time to do anaesthesia, needs less direct care of the anaesthetist doctor and the patient can be controlled by the anaesthetist nurse. In addition, after wearing off anaesthesia, recovering process would also last shorter.

For the upcoming surgery, the coordinator of the operation department who has the control over the ongoing operations, has to call up the anaesthetist doctor for the next patient. It is hard and rather impossible to predict how long the anaesthesia process would last for each patient and they do not provide any approximate time duration for this process as it can have unexpected result.

Communication plays an important role for this process as the anaesthetist doctor should have the proper knowledge regarding the surgery procedure, duration, level of pain and any other hard condition that the patient is going to experience during the surgery. Similarly, the anaesthetist doctor has to provide detailed and complete information for the anaesthetist nurse regarding the pre-operative process and medication needed for the patient. The whole procedure is collaboration of the staff and the more they have experienced on their positions the more efficient communication would be provided for information sharing that would help take care of the patient more precisely. The communication can be done through oral conversations and official written reports.

The anaesthetist nurse has responsibility to prepare the medications for the patient based on the preoperative medical form that has been filled out by an anaesthetist doctor before the day of operation and prepare the patient for the anaesthesia. All the anaesthesia medications are stored in the same medication storage room for both the prosthetic and trauma section.

The anaesthetist nurse addresses that sometimes the preoperative medical form is missing as the document is a hard copy and needs to be transferred between this department and the ward. The anaesthetist nurse may need to spend time finding the document. Moreover, the preoperative medical form is sometimes incorrect or incomplete. It might happen that the anaesthetist doctor changes the method/type of anaesthesia for one patient while he/she does not inform the anaesthetist nurse regarding that change in the plan, or the preoperative medical form does not include complete information of the patient or include incorrect information. In these cases, the anaesthetist nurse needs to contact the anaesthetist doctor to ask for more information. On the other hand, if the preoperative medical form is incorrect and the anaesthetist nurse finds out later after the anaesthetist nurse prepared medications, he/she needs to redo preparation of medications. Redoing medication preparation creates stress as the nurse needs to work faster and sometimes affects start time of the operation. The reason for the incorrect form can be due to the change in patient's health condition during the time that patient has been examined until the time when surgery is operated, as it can be one or two weeks between these two occasions. Therefore, the method and medications need to be changed. The anaesthetist nurse may need to walk back and forth several times between the medication storage room, operating theatre, and pre-op centre to fetch and transport all required medications and medical devices.

As it was mentioned before, there are two types of anaesthesia that are administered at the prosthetic section: the regional (spinal) anaesthesia and the general anaesthesia. The duration of both are not known to anyone until they are performed since this process is highly dependent on different uncontrollable factors such as those mentioned before. However, it

should last for at least 30 minutes to ensure the patient's safety but it can last longer too. The staff addresses that it takes longer time for the anaesthesia process for the patient that comes from home on the day of the surgery as the patient has not been prepared for the preoperative process.

The spinal anaesthesia is usually done in the anaesthesia induction room for OR2 and sometimes for OR3 and OR4. If the anaesthesia induction room is occupied by another patient, they inevitably should do the spinal inside the OR room. The general anaesthesia is almost always done inside the OR as the equipment and more personnel for monitoring patient's condition are required for this type of anaesthesia, however, it can be done in the anaesthesia induction room and it has happened at the prosthetic section to do so.

After performing anaesthesia, the anaesthetist doctor either stays with the patient or leave the patient for the surgery time and it again depends on how the patient condition looks. If the anaesthetist doctor leaves the patient, the anaesthetist nurse is responsible for monitoring and controlling patient status during the surgery and would call the anaesthetist doctor in case there would be any problem.

When the operation is done, the anaesthetist doctor and the anaesthetist nurse should be at OR to reverse the anaesthesia to allow the patient to wake up and move the patient to the post-op centre. It can happen that the anaesthetist doctor performs recovery process but does not wait until the patient is totally recovered. The duration of this process varies patient to patient and it can last about one hour. For the Spinal anaesthesia, the patient usually is moved to the post-op centre 5-10 minutes after operation is finished and the anaesthetist doctor should ensure that the patient can move the part of the body that were under spinal anaesthesia. In case of the general anaesthesia, the anaesthetist nurse has to stay with the patient until the patient wakes up from sleeping, before moving the patient to post-op centre.

It can happen that the operation is cancelled due to the anaesthesia process; if the patient has some health issue that the anaesthetist doctor perceives it as a risk to the patient's health, anaesthetist doctor would ask for other anaesthetist doctor with specialty in that type of the patient to perform it or it can happen they call for it from other hospitals.

4.5. Instruments preparation

Instrument preparation process begins with bringing all the instruments to the instrument preparation room, which is a small room located next to each operating room. The OR nurse is responsible for fetching the instruments and preparing (kitting) processes. Nurse practitioner has responsibility to support OR nurse in preparing process. In this section the information regarding instruments would be described in details.

4.5.1. Instrument Coordination

Every Wednesdays at the prosthetic section of the operation department, the schedule coordinator has meeting with the resource coordinator who is the prosthetic section leader

(who is responsible for providing instruments and implants at the prosthetic section) and surgeons to provide them the schedule for the next two weeks. From this schedule, both the resource coordinator and the surgeon would know what kind of instruments are required. However, if any change occurs to the planned schedule, the resource coordinator should apply the change to the arrangement of instruments and implants. The resource coordinator and surgeons have access to the department information system through which they can store the data of required instruments and implants for each surgery in the OR2, OR3, and OR4.

The resource coordinator has to ensure the availability of instruments and implants for the day of the surgery through contacting the sterilisation department and implant suppliers and placing the order.

The surgeons have to inform the list of the required instruments and implants with any specific information related to those instruments in the meeting with the resource coordinator who will input those data in the system one week before the operation. Then, the OR nurse would look into the system and see the instruments list to prepare the instruments before the operation begins. However, it might happen sometimes that the surgeons do not provide all the required information on the list, leading to longer preparation time for the nurses as they have to call the surgeons to have the complete information of the instruments or implants for preparation processes. The surgeon may update or change some instruments without informing the OR nurse not long before the operation begins when the nurse has already logged into the system and started preparation process or finished preparing the instruments.

The instruments are all in the specific set, and they are put either in the rigid container with specific serial number that defines they are a part of which surgery, or special pouch package and non-woven textile if they are not a part of the particular container. The serial number is used in the information system as they can track and trace the instruments specially to know in which OR the instruments have brought, for instance, if there is an urgent need to the special instrument that is not available in the storage room the staff can bring it to that emergency operation, or in a case the infection occurs in the patient as a result of the surgery, it can be traced back which instrument were used and caused infection.

There are some basic instruments that are used in all surgery types and their availability should be ensured during the weekdays especially from Monday to Wednesday when primary surgeries are undergone and during these days more operations are performed in comparison to Thursday and Friday when the surgeries are in revision type.

4.5.2. Instruments in the sterilisation department

The sterilisation department is located in another floor at the hospital and it is connected to each floor with a specific elevator. All the instruments at the hospital become sterilised at this department. Three persons work at this department from 7:00 A.M. to 9:30 P.M. Monday to Friday, and 9 A.M. to 18.00 P.M. on Saturday - Sunday (2 shifts per day).

At the prosthetic section of the operation department, the instruments for the first operations of the day can be received the day before or early in the morning, depending on the availability of instruments. If the instruments are delivered the day before, it can be both in the afternoon or at night, the nurses who work during the night shift would fetch the instruments and place them inside the preparation room, and the preparation process would be done in the morning.

In the sterilisation department, they receive the used instruments that are placed all in their respective sets by the nurses after operations. The empty containers are all put in the trolley by the nurse practitioner after the instrument preparation process is done and are moved back to sterilisation department by the personnel at the operation department. The sterilisation process is usually done in FIFO method (First-In-First-Out), unless there is an urgent need to specific instruments that leads to immediate sterilisation.

After receiving the instruments, the process of sterilisation begins and it takes around 8 hours for those sets of instruments that are placed in one disinfection machine. The process of sterilisation includes disinfection, checking, sorting, packing, sterilisation in the Autoclave steam machine and finally, they put the instrument containers and packs for one operation on the special trolley to hand over to the prosthetic section. After disinfection process is done, the personnel have to check all the instruments to be put on the right set, ensure they are clean. If any instrument is broken and needs to be repaired, it should be taken out from that set and be replaced by the new one so that the set is complete. The checking process is based on the list of the instruments and matching each set with its serial number.

4.5.3. Fetching instruments from storage area to instrument preparation room

Storage rooms for instruments and implants of the prosthetic and trauma section are separately located in different area. However, some basic instruments such as scissors, knives etc. are stored at both the prosthetic and trauma storage room and the nurse can fetch those instruments from the trauma storage room. For the prosthetic section, there are two storage areas located approximately fifteen metres far from the instruments preparation rooms for keeping the instruments and implants. One storage room is used for implants and some instruments. In addition, there is another area called receiving area where sterilised instruments on instrument trolley that are transported back from sterilisation department are placed. Instruments are stored at receiving area until the nurses transport them to the instrument preparation room when they are needed.

When the nurses prepare instruments for the next operation, they should pick up some instrument containers from storage room and instrument trolley from receiving area together and transport them to instruments preparation room. The OR nurse has responsibility to fetch all required instruments to the instrument preparation room. The nurse can see the list of required instruments in the system in a computer inside storage room. There are printed files of different category and set of instruments for each type of surgery at which the OR nurse

can take a look in case the nurse is not sure which instruments should be taken to the preparation room.

When the instrument containers are taken out from the storage area, the nurses do not have to input any information in the system. It may happen that an instrument container is missed, or the nurse forgets to bring it or brings the wrong container to the preparation room. Therefore, the OR nurse may walk back and forth several times between the storage area and the instrument preparation room in order to transport all the required instruments.

The OR nurse also needs to check that all sizes of the required implants are placed on the rack before moving it to the preparation room as it may not be filled up after the previous surgery is finished.

It may take 10-20 minutes to transport all the required instruments and implants from the storage area to the preparation room if the order is not complicated and all the instruments are available. However, if the instruments are missing, the instruments order is complicated, or it is hard to find all the required instruments, it may take longer time, up to one hour depending on the type of the surgery, to find the instruments and fix the problem.

4.5.4. Instrument preparation in instrument preparation room

For the OR2, OR3 and OR4, each operating room has its own small instruments preparation room in front of the operating room where the instruments can be prepared inside the room. However, there is not enough space in the instruments preparation room for the total revision surgeries[1]. As this type of surgery requires more instruments than primary surgery and revision surgery, and has many instrument trolleys and tables that cannot be fit in the small instrument preparation room. Therefore, in this case, the staff needs to prepare the instruments inside the OR before the surgery can begins instead. According to the historical data obtained from the department, there are 126 total revision surgeries in 2016.

The instrument preparation process inside the preparation room usually takes 30 to 40 minutes. However, it depends on how experienced is the OR nurse and for which operation type they need to prepare instruments. It may take up to one hour for preparing instruments for complicated order such as the total revision surgery or around 15 minutes for the small surgery like fingers.

For the instruments preparation process, after all the required instruments are transported to the preparation room. One OR nurse and one nurse practitioner go inside the room. The OR nurse has responsibilities to prepare all the instruments, while the nurse practitioner has responsibilities to help and support the OR nurse and input the data in the system. The detailed processes are described below:

[1]Total revision surgery is a surgical procedure in which all original failed implants are taken out and replaced. In the revision surgery, however, only those parts that are damaged would be taken out of the patient's body.

1. The nurse practitioner helps the OR nurse dress up in the sterilised cloth.
2. The OR nurse covers the instrument table with a sterilised sheet.
3. The nurse practitioner opens each instrument container, then, the OR nurse takes the instrument basket out from each container and places it on the instrument table. This process also includes instruments in other plastic packages.
4. The OR nurse should check whether the instruments in the list are all existing in the baskets and they are clean.
5. The OR nurse also needs to assemble some instruments together.
6. The nurse practitioner enters the data related to the instrument sets such as their codes and names into the system, so that they understand which instruments are used in which OR. This data can be used to trace back in case of any issue such as infection to the patients.
7. Finally, the OR nurse covers all the instruments with special sheets and they transport the empty containers on the trolleys to the transferring area from where they will be sent to the sterilisation department afterward.

It may happen that some instruments are not clean or missed. For example, in a specific situation, some instruments like scissors are closed when they are gone for sterilisation and some blood might remain on the gaps. The staff at the sterilisation department should check all the instruments if they are totally clean. However, it might happen that the OR nurse finds any kind of dirt on the instrument and has to return the whole set of instruments back to the sterilisation department. In this case, when the nurses are inside the preparation room they cannot go out until they are finished with instruments preparation processes due to safety issues for sterilised instruments. Therefore, a new container that contains same set of instruments must be brought to the instrument preparation room by another staff who is not inside the preparation room.

4.5.5. Instrument Unavailability

Instrument unavailability is one of the main problems in this department stated by almost all the staff. The OR nurse and nurse practitioner who have the responsibility of preparing instruments for ORs, often have problem with the disorganisation of available instruments as some instruments are missing, or not sterilised when they are required. The instruments preparation process is done in parallel while current operation is being operated in the OR, therefore sometimes the problems can be fixed before the next operation begins so it does not affect available operative time. However, it can have an effect on late starting of the operation, if the problems cannot be solved before the time that the next operation should begin.

It could also happen that instruments are not clean even though they have been sterilised and checked from the sterilisation department. The OR nurse has to double check the cleanliness of the instruments in preparation process and check whether all required instrument sets are transported to the preparation room. Furthermore, lack of instruments can sometimes be related to the type of operations of the day as some operations demand for the same

instruments while there are limited sets available at the department. This can be referred to the planning schedule meaning that the coordinator should plan the surgeries based on the information of the kind of the instruments required by each surgery type. There are four occasions when the instruments are not available, and each of which requires different actions to be taken.

Occasion 1: It can happen either before starting the operation or during the operation that the specific sets of instruments are not available. In this case, if it is possible to use the other type of instruments instead of the missing ones or change the method of the surgery in a way that it would be feasible to use the other type of instruments (this decision has to be made by the surgeon), they would do it and it does not incur any remarkable delay in the successive operations.

Occasion 2: It can happen either before starting the operation or during the operation that the specific sets of instruments are not available. If the missing instruments are already available for another planned operation that is going to be started in another OR later on, then the instruments would be brought to the current operation to avoid any delay for that surgery as the patient has already got prepared for the operation or the surgery is ongoing, however, it will delay further operation in the other OR.

Occasion 3: It can happen either before starting the operation or during the operation that the specific sets of instruments are not available. This occasion happens when the instruments are not available at the hospital at all and they need to request another hospital to check if it is possible to send them the instruments or force the sterilisation department to prepare them as soon as possible.

Occasion 4: It happens when the operation is not started and the instruments cannot be available at all; in this case, they have to cancel the surgery and postpone it to another time, which disturbs the planning schedule.

4.6. Activities during knife-out one patient to knife-in the next patient

During the surgery, when the surgeon considers that the current surgery is going as planned and it can be finished as expected, the surgeon can inform nurse to contact staff in the corridor in order to call for the next patient to be prepared for the next surgery. After the surgery is done, the OR nurse has to check whether all the instruments used during the surgery are in the correct instrument basket before sending them to the sterilisation department. When the patient is moved out of the OR to the post-op centre after the surgery by the anaesthetist nurse, the staff who are in the OR during the surgery would call the cleaning personnel to clean the OR. The nurses have to sterilise some medical equipment, such as monitors, lamps, OR bed etc. by themselves. An instrument table is transported to the transferring area. Trash bags are almost always transported to the garbage dump area by the cleaning personnel and it might sometimes happen that the nurses do it.

The cleaning personnel leaves the cleaning equipment outside the OR and enters the OR after the patient leaves, then they sterilise and clean the surgery bed, all the chairs and tables, and medical equipment in the OR with alcohol. Then, the cleaning personnel have to get a mop that is placed in front of the OR to clean the floor inside the OR. Floor cleaning are done twice. Next, they clean the area in front of the OR. It usually takes approximately 10 to 15 minutes to clean the OR after the surgery.

There are two to four cleaning personnel depending on the different working shifts in this department. It may happen that two surgeries in the different operating theatres are finished almost at the same time when there is only one cleaning team. In this case, one room needs to wait until at least one of the cleaning personnel can join the other OR, and until that time, the nurses start cleaning the equipment by themselves. Furthermore, it can happen that the nurses clean the OR immediately after the surgery when the cleaning personnel are late.

After the OR is cleaned and ready for the next operation, staff may set up some pieces of equipment inside for the next operation before the patient going inside. For the OR2, the spinal anaesthesia and moving the patient to the surgery bed are usually done in the anaesthesia induction room while the current surgery is proceeding inside the OR. However, this does not include the first operation in the morning of which anaesthesia process is usually done inside the OR. For the other ORs that do not have anaesthesia induction room, staff transport the patient on the patient's bed to in front of the OR and move the patient to the surgery bed, then the spinal anaesthesia induction is done inside the OR. However, if the anaesthesia induction room is empty, they might use it for the other ORs.

For the general anaesthesia, the anaesthesia induction process almost always proceeds inside the OR, even though it is possible to be done in the anaesthesia induction room. After moving the surgery bed to the OR, staff place the patient in a particular position for the surgery, clean and sterilise the patient's skin surface on operating field, set up the position for the instruments, devices and equipment, cover green sheet in front of the patient before the surgeons coming in. For elbow and shoulder surgeries, they require much longer time before the surgery as it is harder to position patient on surgery bed equipped with accessories and extensions. After the patient is moved to the surgery bed, the general anaesthesia is induced to the patient, which requires time in forms of putting all the medical equipment and devices on the patient's body. Moreover, sterilising operating field on the patient's body after the patient is anaesthetised also requires two people to do this process as there is no equipment to hold the patient's arm up. Both elbow and shoulders surgeries are mostly operated in the OR4.

It may happen either the OR is ready to be used but the patient is not ready or the patient is ready for the surgery but the OR is not available.

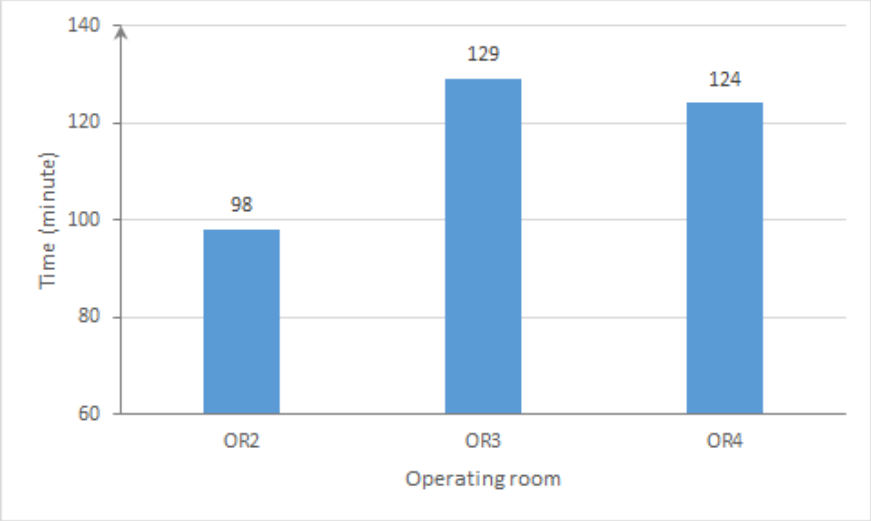

Figure 8. The average time between operations from knife-out of the previous operation to knife-in of the next operation during 2016

Figure 8 shows average non-operative time between operations of each OR in year 2016. It can be seen that non-operative time in OR2 is significantly less than non-operative time of OR3 and OR4. This is due to OR2 has higher number of operations and there are two OR teams in morning shift during Monday to Wednesday, therefore, the staff can work in faster pace and have shorter time between knife-out and knife-in in OR2.

According to the interview, the surgeon addressed that the time between operations is too long, approximately 1.5 hours or quite often two hours. The data obtained from the interview is consistent with the historical data illustrated in Figure 8. Long time between two operations during the day makes the surgeon finish the last operation late.

4.7. Flow Process Chart

The current process at the prosthetic section of the department has been mapped as shown in Figure 9. The patient preparation process, OR preparation, and instruments preparation processes for the next patient can be done in parallel and simultaneously for the first surgery of the day. For the latter surgeries, the patient preparation process and the instruments preparation process are done when the current surgery is performed inside the OR. However, the OR preparation process is done after the OR is cleaned from the previous surgery.

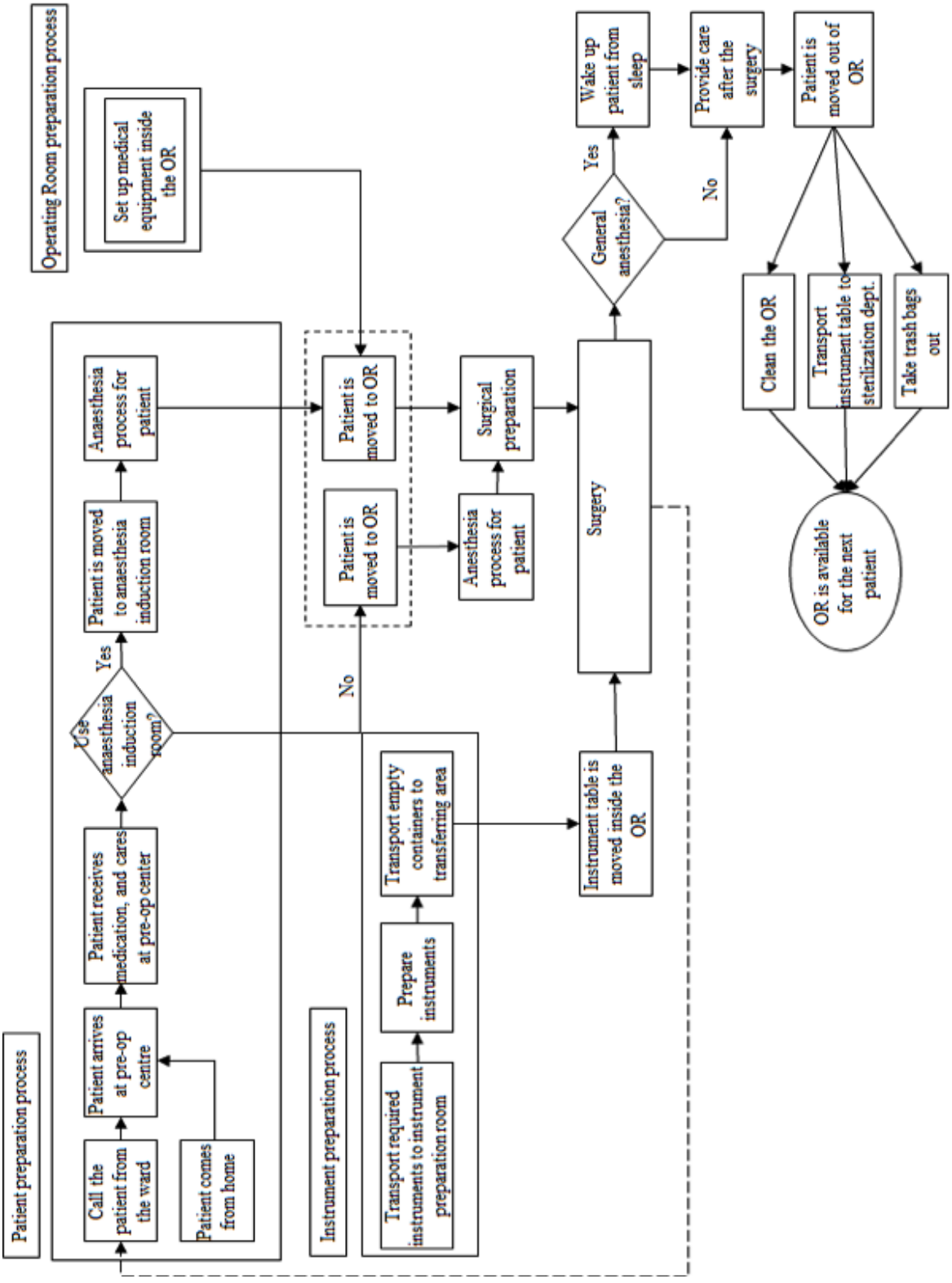

Figure 9. The process steps in the prosthetic section for one surgery

4.8. Scheduling

Scheduling operations for the prosthetic section of the operation department is done by the schedule coordinator at the Orthopaedic department. The schedule coordinator should consider several factors for planning the schedule. Patient lists and surgeons' schedule are included as first elements for decision-making. The coordinator should first look at the waiting list and the urgency of the cases. The surgeon and the anaesthetist doctor should meet the patient before scheduling the operation to do some tests on the patient, check the patient's health condition and see whether he/she is operable or not; patients have to fill out a health declaration form there are different problems that can postpone the operation date, for instance, if the patient smokes, he/she has to stop smoking for 4-6 weeks before the surgery. The anaesthetist doctor should also examine the patient to decide on the type of the anaesthesia, medication etc. that should be induced on the surgery day. The coordinator has the surgeon's schedule in advance and based on the patient's need of surgery and surgeon's specialty, he would allocate the surgeries to the surgeons.

Policy regarding number of surgeries, both at the hospital level and even at higher level from outside the hospital, can affect planning process of the hospital and consequently it would influence scheduling. The policy makers are those who decide on the number of different type of operations that should be performed in a long term (a year). Therefore, the schedule coordinator should consider the amount of different surgery types that are required to be performed in each year. Then, the waiting list of the patients, the priority of the cases, and surgeons' schedule are the next factors that should be taken into account for the scheduling.

Apart from the abovementioned factors, there are other issues that can affect the scheduling. Instruments availability can be one reason of planning, changing or revising the schedule as there are certain amount of instrument sets available at the operation department and the coordinator is aware of this limitation. The other cause for changing the schedule for the prosthetic section is the work load and emergency cases for the trauma section as they might be forced to perform some emergency cases of trauma (or even prosthetic) in the prosthetic section.

4.9. Delays and cancellation in operation

The department has recorded delays in the operation during 2016. There were 496 delays from approximately 1,500 operations. These delays cause 9,682 minutes late in total. Figure 10 shows reasons of delays divided into six categories; anaesthesia process, operation, ward, surgeon, patient and medication. More than 50 percent of the delay times are as results of anaesthesia processes, which can be due to delays from the process itself, waiting for anaesthetist doctor, complication of anaesthesia etc. Operation delays include instruments and equipment problem.

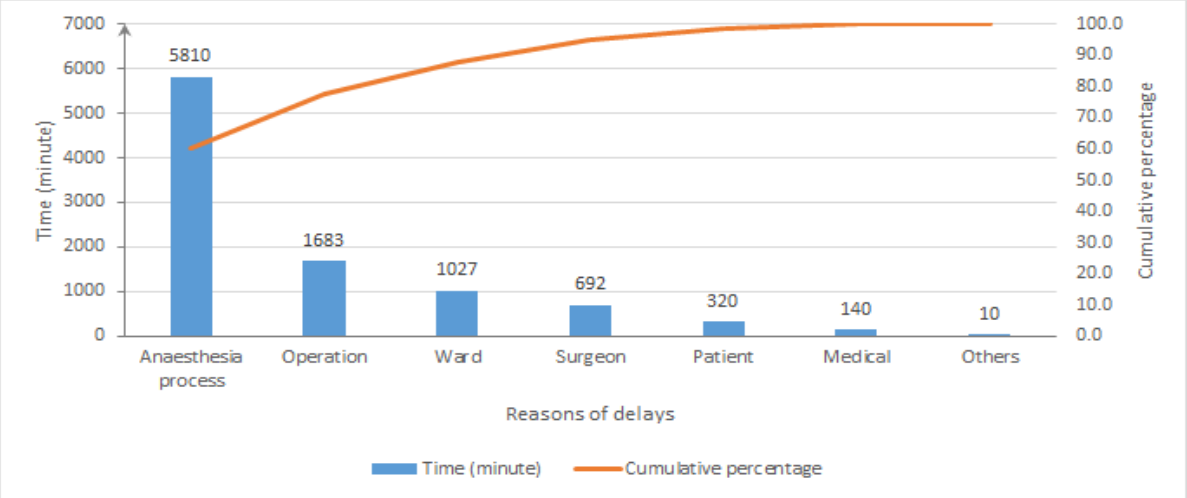

Figure 10. Reasons of the delays in operation in each category during 2016

Figure 11 shows reasons of delays in details. 80 percent of the delays in operation are caused by 11 main reasons. The largest part of delays, approximately 30 percent, are as consequences of delays in anaesthesia process. The second reason is because of waiting for anaesthetist doctor. The third reason is due to equipment problems that is related to the instruments. Patient arrives late at pre-op centre from the ward, instruments conflict, anaesthesia complication, incomplete pre-op preparation, unavailability of anaesthetist doctor, anaesthetist doctor tutorials, waiting for surgeon are the reasons for delays from the most frequent to the least frequent ones respectively.

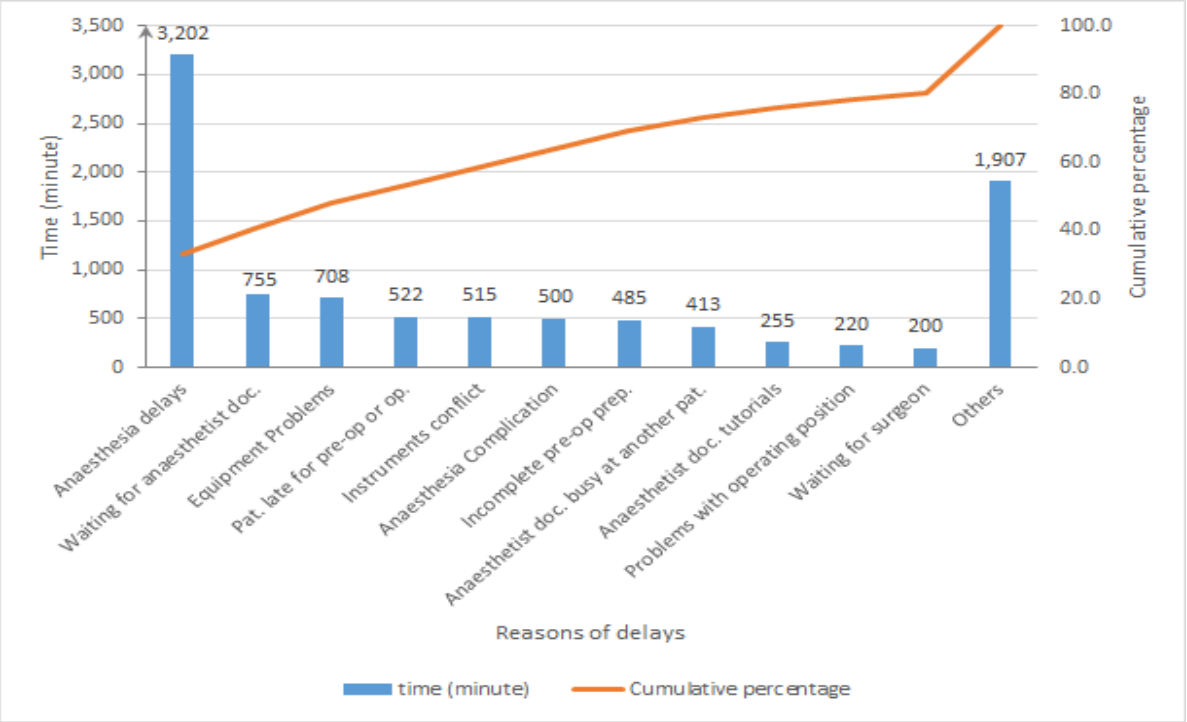

Figure 11. Detailed reasons of the delays in operation during 2016

During 2016, there are 71 operations that were cancelled. 61 out of 71 operations were cancelled one day before the surgery or on the day of the surgery, and ten operations were cancelled just before the operation began. In Figure 12 and Figure 13, the reasons of cancellation and number of occurrence in 2016 have been recognised.

From 61 operations that were cancelled one day before the surgery or on the day of the surgery, 46 operations were cancelled due to patient's health condition and if the patient was operable or not, seven operations were cancelled due to lack of space in ward to keep the patient after operations, six operations were called off as a result of emergency operations, one operations were postponed to another time as patient requested rebooking, and one operation were cancelled because there were not enough staff to perform the operation.

Among ten operations that were cancelled right before the operations began, eight of them were because of medication reasons, while the other two surgeries were cancelled because there was additional emergency surgery.

There is no information whether the cancelled operations were replaced or not. However, according to the interviews, if the operations had been replaced, they would have been replaced by trauma operations.

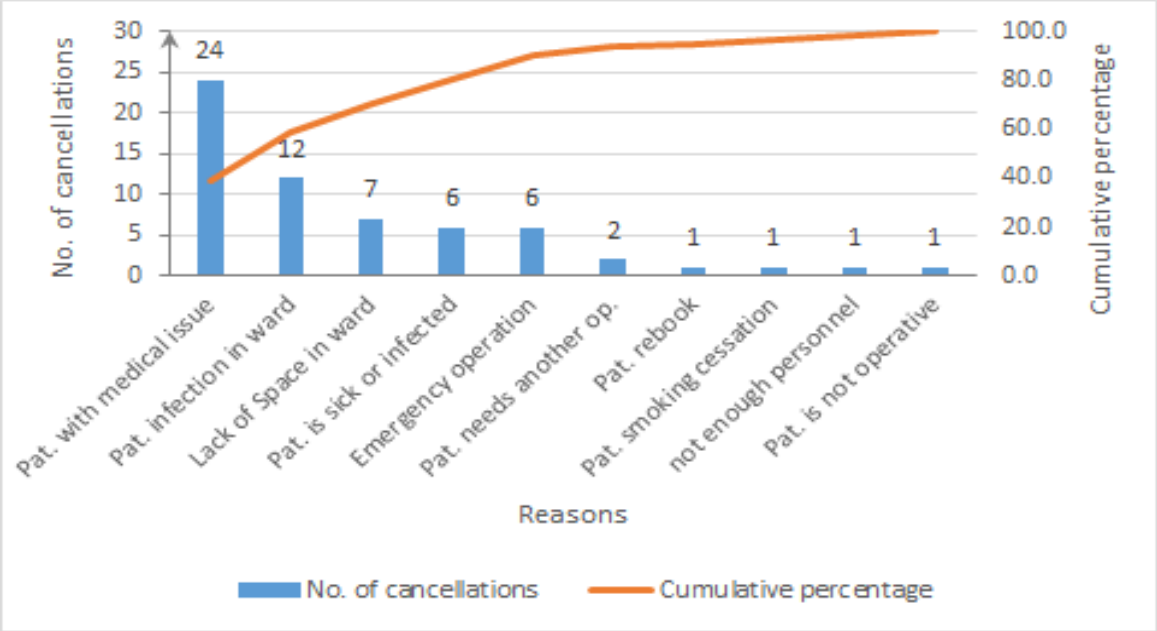

Figure 12. Operation cancellations that happened one day before the surgery or on the day of the surgery during 2016

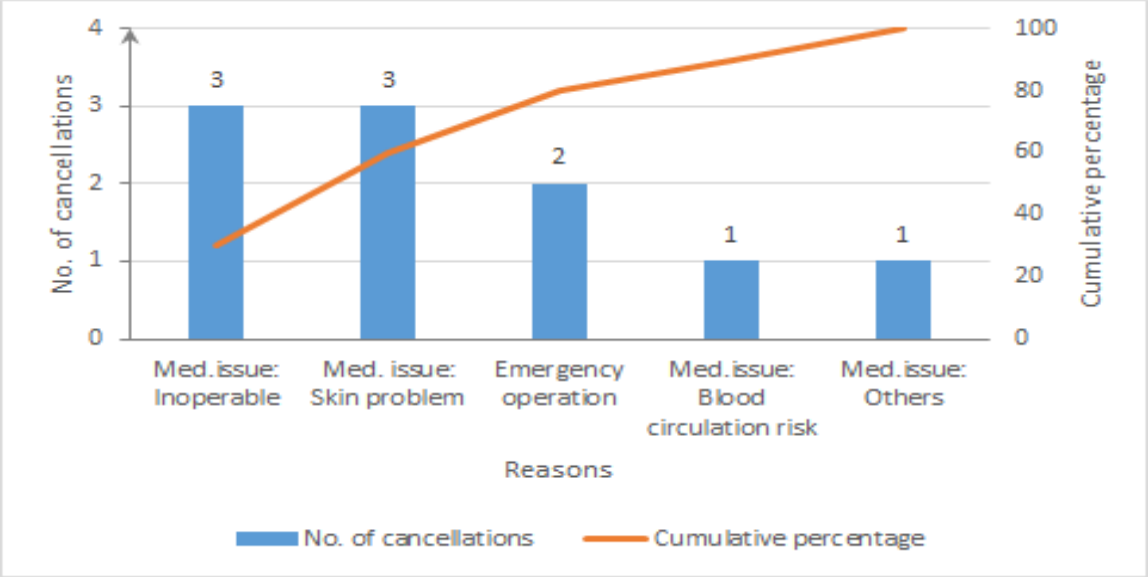

Figure 13. Operation cancellations right before the surgery during 2016

5. Results

In this section, findings through the empirical study at the operation department at a university hospital is combined with the theories, first in order to recognise what can be identified as waste at this department, second, find the causes of the wastes, and then assessing their impacts on the efficiency and the available operative time.

5.1. Wastes in this department

According to waste classification of lean, described in subchapter 3.4.2, there are eight types of wastes that can be applied to the healthcare system. However, *unused employee creativity*, which is one type of waste, is not considered in this study. Therefore, this section is divided to seven subchapters. Theory on seven wastes of lean, and OR efficiency are applied to the qualitative data from interviews and observations, and quantitative data obtained from the database system in chapter 4, to identify the wastes and causes of which at the operation department. The processes and activities during pre-operation processes, changeover time activities, and instrument preparation process are investigated through waste-identification process.

5.1.1. Overproduction

The wastes under overproduction category can be created from late cancellation on operation. According to ten operations that were cancelled, when the patient has already arrived at the department, which is around 0.7 percent from all operations in 2016, it means that the instruments were prepared based on each specific surgery for those operations. Those containers that have been opened but the instruments inside have not been used, would be sent to the sterilisation department. Staff's time and efforts are wasted. It also creates other types of wastes in the process such as the transportation of instruments within department and from/to sterilisation department (Liker & Meier, 2006).

Furthermore, if the department cannot replace the available time with other operations, it indicates that the OR is available and would stay idle until the next operation can begin and it would result in inefficient use of the OR. Peltokorpi et al. (2009), late cancellations can be due to poor information sharing and poor pre-operative process.

Another situation when the planned operation is cancelled happens due to an emergency operation that needs to be performed immediately. The emergency operations are usually planned shortly before the operation; therefore, one elective operation would be cancelled so that the acute one can be performed.

The reasons for late cancellation can be due to the uncontrollable factors like patient's health condition and unexpected event like the emergency surgery. However, it can also be due to lack of communication, poor information sharing between the operation department and the ward that the patient stays overnight, poor pre-operative process (Peltokorpi et al., 2009).

5.1.2. Waiting

Waiting in this department occurs in different ways:

1. Waiting for resources: instrument unavailability
2. Delayed anaesthesia
3. Late start of the operations
4. Waiting time between operations
5. Patient waiting at pre-op centre
6. Waiting for the OR during instrument preparation inside the OR
7. Waiting for the anaesthetist doctor
8. Waiting for the patient to be recovered from anaesthesia
9. Waiting for the OR to be available for the next operation.

Each waste and its cause are presented in detail below.

Waiting for resources: instrument unavailability: One of the waiting times that can be seen is staff waiting for resources. Instrument unavailability is one of the main problems in this department as explained in subchapter 4.5.5. When instruments are not transported back from sterilisation department, as sterilisation department has fixed schedule for transporting instruments back to the operation department, the staff have to wait until the instruments are ready to prepare the instruments for the next surgery. Moreover, it includes when instruments are not available or not finished with sterilisation process. Therefore, instrument unavailability might affect available operative time resulting in waiting of staffs and patient before instruments are ready.

One of the causes of instruments unavailability is long lead time in sterilisation department, as it is stated by sterilisation department's personnel that it takes approximately 8 hours to sterilise one set of instruments. Moreover, desynchronisation between the working schedule of personnel at the sterilisation department and the surgery schedule of the operation department can be considered as one of the causes. For example, the last surgery finishes at 5 P.M. and those instruments are needed in the morning on the next day, but the personnel at sterilisation department work until 9:30 P.M., therefore, if the operation department does not have another set of instruments available, this can cause operation delay.

Moreover, unevenness in the OR schedule also affects instruments availability in the department, which can cause operational delays. More sets of instruments are required during Monday to Wednesday because the operation department allocates two types of the surgery on different days during weekdays, therefore, it creates overburdening of the instruments and higher possibility of the instrument shortages. It is necessary to have available resources such as materials, equipment to serve highest level of production (Liker, 2004). In addition, unevenness scheduling can be cause of the other wastes including waiting when instruments are missing, and excess movement and transportation when staff tries to fix the problem.

Delayed anaesthesia: According to Figure 10, it shows that one of the main reasons in late start time of the surgery is due to the anaesthesia process. In case the anaesthesia induction process, which is done in the anaesthesia induction room, is not finished when the OR becomes available for the next operation, the delayed anaesthesia induction process can affect the OR available operative time as the OR remains available after the previous surgery but would be idle until the anaesthesia is induced for the patient. Similarly, if the anaesthesia induction process is done inside the OR, it shortens the OR available operative time.

As mentioned by many staffs at the department, the anaesthesia induction time cannot be estimated because it depends on many factors that cannot be predicted or controlled, for instance, patient's' health condition, difficulty in anaesthesia etc.

However, when there is desynchronisation between the anaesthesia process of the next patient and current surgery process, the next patient may have to wait until OR is available in case the operation takes longer time, or the surgeons and the OR team for the next operation have to wait if the anaesthesia process takes longer time than expected. Another reason for delayed anaesthesia is due to not well-prepared patient for preoperative process whether from the ward that the patient stays overnight or not well-prepared when the patient comes from home.

Late start of the operations: According to Table 6, average knife-in time of the first operation of the day differs based on each OR. OR2 starts at 8:30 A.M., while OR3 and OR4 start at approximately 9.00 A.M. on average. Late start of the first operation in the morning would affect all the successive operations that are operated later on in that day and it would not follow the plan (Peltokorpi et al., 2009). Moreover, it also creates waiting for the surgeons who operate the operation, other related staffs and patients of the next operations.

Late start of the first operation can be as a result of several factors. As an example, the patient does not receive sufficient preoperative care from the ward or patient has not been prepared if the patient comes from home in the morning. When the patient is not well-prepared in these cases, the anaesthesia process and the patient surgical preparation take longer time than expected.

Waiting time between operations: The surgeon addresses that the time between operations is quite long as stated in subchapter 4.6. Considering the time between knife-out of current patient and knife-in of the next patient in Figure 8, it shows that this time interval in OR2 is significantly less than that in OR3 and OR4. The surgeons who work in OR2 have 30 minutes less between two surgeries than OR3 and OR4, as it takes 1.5 hours on average for OR2 during a day from Monday to Wednesday when primary operation are performed, while it takes 2 hours on average in OR3 and OR4. For the primary operations in OR2, surgeons have approximately 4.5 hours non-operative time in total between the surgeries per day (1.5 hours * 3 changeovers for 4 operations a day), while they (OR3 & OR4) have approximately 4 hours non-operative time between the surgeries per day (2 hours * 2 changeovers for 3 operations a day).

The reasons are due to delays in anaesthesia process and limited resources at this department including OR team and anaesthesia induction room that make non-operative time between operations longer. There is only one anaesthesia induction room at the department for three ORs, and it is mainly used for induction of spinal anaesthesia for patients operated in OR2. Therefore, the processes are done in parallel in OR2 as the next patient is receiving spinal anaesthesia in anaesthesia induction room while the current operation is being processed inside the OR2. On the other hand, for OR3 and OR4, spinal anaesthesia process usually happens in the OR in sequence after the room is cleaned. Therefore, non-surgical tasks performed inside the OR during its availability for the surgery affect available operative time of the OR (Harders et al., 2006). However, OR3 and OR4 can use anaesthesia induction room if it is available, and this happens when surgeries in these three ORs have different start times or finishing time.

Moreover, another reason can be because of lack of standardisation in preparing patient for shoulder and elbow operations that are mostly operated in OR4 resulted in longer time to prepare the patient for these two types of operations. As staff may have to adjust extension part of the surgery bed after it has been set and it requires one staff to assist and hold patient's arm up when patient's body is sterilised.

Patient waiting at pre-op centre: The patient waiting for the bed to receive care and medication at pre-op centre in the morning when seven patients are admitted to the operation department. As seven operations should begin almost at the same time, while there are only four available slots in pre-op centre as explained in the subchapter 4.3.

This can be seen as a resource problem, as there is not sufficient preparation room for each OR where patient can be directly moved to the specific room; it can also be seen due to lack of space at pre-op centre where the beds should serve seven patients almost at the same time in the morning.

Waiting for the OR during instrument preparation inside the OR: For the total revision surgery, instrument preparation process is usually done inside the OR as stated in the subchapter 4.5.4. The OR is occupied and preferably no one should enter the OR when instruments are prepared due to safety issue during that time. Therefore, setting up the equipment inside the OR, and OR preparation should be done after this process. At the same time, patient can be prepared outside the OR but the patient may need to wait to receive general anaesthesia induction inside the OR before the operation can begin so it shortens available operative time of the OR.

The main cause of this waste is because of limited space in instrument preparation room where many instrument trolleys cannot be fit inside.

Waiting for the anaesthetist doctor: One anaesthetist doctor has responsibility to take care of more than one patient at the same time or the anaesthetist doctor may have to go to the other department when he/she is needed. Therefore, the other staffs and patient have to wait for the anaesthetist doctor if he/she is needed but is not available or busy with other tasks at

that specific moment resulted in delay in the operation as shown in Figure 11 that waiting for the anaesthetist doctor is the second highest reason that can affect the available operative time as the OR is available for the next patient to receive preoperative care or be operated inside.

It can be considered that lack of personnel is the cause of this waste. However, scheduling can be perceived as another cause too, for example, if two operations need to be started almost at the same time and both operations need the anaesthetist doctor, one has to wait until the anaesthetist doctor is available. This can be because of uncertainties in the operation both from duration uncertainty and arrival uncertainty that leads to the possibility of same start time for two operations (Cardoen et al., 2010).

Waiting for the patient to be recovered from anaesthesia: The anaesthetist nurse needs to stay with the patient after the surgery is done to control patient condition and wait until the patient is at the stable state as explained in subchapter 4.4. This is especially for the general anaesthesia that requires longer time for the patient to be recovered. If there is not enough anaesthetist nurse at that specific time to take care of the next patient, the next patient needs to wait until he/she can receive care and medication before the anaesthesia induction process, which can affect start time of the next operation.

This case is similar to abovementioned waste (number 7) from waiting for the anaesthetist doctor. As it can be both because of not enough personnel or lack of precise scheduling due to the duration uncertainty from the previous operation and arrival uncertainty from the next operation that make the anaesthetist nurse unavailable for the patient (Cardoen et al., 2010)

Moreover, OR emergence time can be considered as non-surgical task that is operated inside the OR due to patient's safety as all the medical devices are still attached to the patient body to monitor heart rate, oxygen level in blood etc. until the patient wakes up from anaesthesia inside the OR. The OR cannot be completely cleaned and used until the current patient is moved out, so this can shorten the available operative time and create waiting for the other staff and successive processes.

Waiting for the OR to be available for the next operation: The cleaning personnel usually enter the OR to start cleaning the OR when the patient has already left the OR. Sometimes they wait outside the OR while patient is still inside the OR so that they can enter the OR immediately after the patient leaves. However, sometimes the patient already left the OR before the cleaning personnel arrive that creates longer changeover time between the two operations. The OR is not available for the next operation until the cleaning process is done.

The cleaning process usually takes ten to fifteen minutes as explained in subchapter 4.6, however, it depends on the number of persons that are included in the cleaning team, as it varies during different work shifts (2 in the morning, 3 during noon, and 4 in the afternoon). Sometimes, due to late or not precise communication of the staff, the cleaning personnel are delayed and they are not on standby outside the OR before the patient exits the OR. Another probable reason can be when two operations finish almost at the same time as both need to

be cleaned up while there are not enough cleaning personnel. Then, the cleaning personnel need to do the first OR and then move to the other one.

5.1.3. Transportation

Transportation wastes in this case can be identified as follows:

1. Instrument transportation
2. Medication transportation.

The details of each waste are presented as below:

Instrument transportation: It can be seen that the OR nurses waste their time by walking several times between storage area and instrument preparation room in order to transport all required instruments, and implants as stated in subchapter 4.5.3. This also includes instrument table, placed in the transferring area that needs to be moved to instrument preparation room.

One of the reasons is that if there are more than two instruments and implant trolleys that need to be brought to instrument preparation room, one OR nurse cannot transport them in just one time. Another reason is that the nurses may take the wrong containers or forget to fetch some instruments as they do not have any checklist or monitoring system that can be used to verify that all required and correct instruments are taken, in another word it can be due to lack of standardisation.

Furthermore, storage room is not located close to instrument preparation rooms as shown in Figure 5. Therefore, long distance between storage room and instrument preparation room can also create excess transportation in instrument transportation process.

Medication transportation: The anaesthetist nurse walks between pre-op centre, medication storage room, and operating theatre several times to fetch documents, required medications, and medical devices as explained in subchapter 4.4. If medications are missing when the operation has not begun, anaesthetist nurse can walk out from the operating theatre and fetch those medications. On the other hand, if the operation has started, staff who are inside the OR need to call another anaesthetist nurse who is in the corridor to bring medications or medical devices.

The cause of this waste can be due to needed medications and medical devices are not in the OR when they are required. As staff might realise later when they are already inside the OR and start preparing patient or even when the surgery is being operated. This can be because of lack of standardisation.

5.1.4. Over processing or incorrect processing

Over-processing occurs in different ways in this department:

1. Checking the implants
2. Checking the cleanliness of instruments
3. Redoing instrument preparation process
4. Redoing medication preparation process

Each waste and its causes in details are discussed below.

Checking the implants: The OR nurse has to check whether all sizes of required implants are placed in the rack before transporting it to instrument preparation room as they are not sure whether new implants are restocked after the previous surgery as stated in subchapter 4.5.3. This can be considered as process duplication if the other staff already checked and put the new implants in the rack.

This is due to lack of proper inventory controlling system in the storage room where implants are put there and lack of standardisation whether who should have responsibility to restock implants on the rack after one is used.

Checking the cleanliness of instruments: According to subchapter 4.5.4, the OR nurse checks the cleanliness of the all instruments inside preparation room after each container is opened due to safety issue for the patient. Even though sterilisation department already did it before storing instruments in the container. This is double inspection that can be considered as over processing.

As the patient's safety is the most important factor, they need to check the cleanliness of instruments as it can happen that instruments are not cleaned. By improper putting the instruments in autoclave machine in sterilisation department, instruments might not be cleaned and sterilised completely and they might keep the dirt from the previous operation. Thus, in order to avoid infection in the patient body caused by using unclean instruments, the re-inspection is done inside the instrument preparation room by the OR nurse while he/she is preparing the instruments for the next operation.

Redoing instrument preparation process: The nurses address that surgeon may make changes or update instrument list either shortly before or after they started preparing instruments without informing the nurses as stated in subchapter 4.5.1. If surgeons update the instrument list later, nurses have to proceed this step twice as some instruments might be replaced with new set. It also creates excessive transportation as new instrument sets should be fetched to instrument preparation room.

This waste is created from lack of proper communication and information sharing between surgeon and nurse.

Redoing medication preparation process: According to subchapter 4.4, the anaesthetist nurse addresses that sometimes he/she has to redo medication preparation process for the patient if the medication form is incorrect. Or he/she has to contact the anaesthetist doctor if the list is not complete or not clear to ask for more information.

One of the causes is created from uncontrollable factors like the patient's health condition that has changed during the time that it is planned until the time that the patient has to be operated. Another cause is that the preoperative medical form is not properly prepared from the anaesthetist doctor, so the information are missing. This can be due to experience of the anaesthetist doctor. Lack of communication can be another cause of this waste as the anaesthetist doctor should provide complete information to the nurse to make everything run smoothly.

5.1.5. Excess inventory

Excess inventory can be created when all sizes of required implants must be taken to the OR as it cannot be confirmed which size is needed until the time when the surgeons want to use implants in the middle of operation. Even though it is unavoidable, it creates excess inventory in storage area as all sizes of implants must be available to fit the patient body. However, this type of waste does not have any impact on available operative time.

5.1.6. Unnecessary movement

Unnecessary movements can be divided into three categories as follows:

1. Searching for instruments
2. Fetching basic instruments
3. Searching for documents

The details of each waste are described below:

Searching for instruments: The time that the OR nurse spends for looking for the correct instrument containers in storage area can be considered as unnecessary movement (Liker & Meier, 2006). The nurses address that sometimes it is hard to find instrument container in storage area especially for complicated order list or incomplete order list from the surgeon as stated in the subchapter 4.5.3.

The causes can be due to lack of standardisation in the instruments list that is provided to the nurse, and lack of communication between the nurse and the surgeon. The lack of standardisation means that the surgeons should provide enough information regarding the instruments into the system so that it becomes clear enough to the nurses what should they prepare for the operation. Moreover, the lack of standard, and good visual control in the storage area make it harder to find instruments since instruments are not arranged based on systematic way. Experience of the nurse is another factor that leads to longer time in instrument picking as stated by nurses that the more experience of the nurse, the easier to look for instruments in storage room.

Fetching basic instruments: The OR nurses may walk another round to storage rooms to fetch some basic instruments and supplies such as scissors, knives, forceps, cottons etc. that

are stored separately (not in specific container) in the storage room after transporting all the required instrument containers to the instrument preparation room.

Lack of enough space for storing all types (ordinary and specific) of instruments and supplies in one storage room and shared the ordinary instruments and supplies between the prosthetic and trauma section have led to having two or three different storage rooms in the operation department, consequently, sometimes the nurses have to go to the different storage rooms to complete all the required instruments and necessary items. Moreover, this can be due to lack of standardisation and checklist to see whether all the instruments are fetched to the instruments preparation room or not. Lack of space for storing some basic materials in preparation room or in the OR makes the nurse walking several times to fetch those materials (NHSIII, cited in Radnor et al., 2012).

Searching for documents: The anaesthetist nurse sometimes spends time looking for the document like the preoperative medical form that is missing as stated in subchapter 4.4.

Important documents such as the preoperative medical form cannot be accessed online in the hospital system as it is still written in hard copy. It needs to be transferred between the ward and the operation department and sometimes the document is not there when it is needed.

5.1.7. Defects

Defects in this case refer to contamination of the instruments. According to subchapter 4.5.3, in specific situation where the instruments are not cleaned and it is discovered in the instrument preparation room by the OR nurse, when they are preparing the instruments, even though sterilisation department already checked the cleanliness of all instruments. As a consequence, the whole instrument container needs to be replaced. Waste is created from repairing of work, and inspection (Liker & Meier, 2006).

The cause to this waste is by improper putting the instruments in autoclave machine in the sterilisation department, instruments might not be cleaned and sterilised completely and they might keep the dirt from the previous operation. It can be considered as lack of standardisation in the sterilising process.

5.2. Causes of wastes that affect available operative time

To find out the reasons behind the wastes identified in the previous section, the root cause analysis has been done. During the study period, several observations including direct following of different OR team, corridor team, and cleaning personnel; direct observation of flow of specific processes such as instrument preparation, patient's journey from the pre-op centre to the OR, anaesthesia process, activities in sterilisation department; and both semi-structured and informal interviews with different personnel at different positions have been done and quantitative data have been obtained from the department database. Causes of the wastes that affect available operative time both direct and indirect are identified.

Fishbone diagram is the method used for identifying the possible causes of the reduction in available operative time. The problem is defined as "reduction of available operative time" and the causes are classified into four groups: People, Method, Environment, and Equipment as shown in Figure 14.

The fishbone diagram in section 3.5, illustrated in the Figure 4, has been used as a guide to look for the similar causes that exist in the case study. Even though the problem in this example is not the same with the one discussed in this research, they are related to each other as waiting time before surgery is considered as one factor that have impact on available operative time. Therefore, what causes the waiting times before surgery, can be a cause for reduced available operative time. This point should be mentioned that the investigated case in the example from Tolga et al. (2007) does not have the same processes, thus, some causes may differ with each other.

Causes of wastes in this study can be created either from uncontrollable factors such as patient's condition, difficulty in anaesthesia, or from controllable factors such as lack of communication between staff. The four categories of causes in Figure 14 are defined as follow:

- *People:* Including all staffs who are related to the operations and patient.
- *Environment:* Including limitation of resources in this department and factors affected from other departments in the hospital.
- *Method:* Including the lack of systems supporting the work, standardisation in working environment, desynchronisation between processes, and scheduling.
- *Equipment:* In this case means instrument unavailability and instrument contamination.

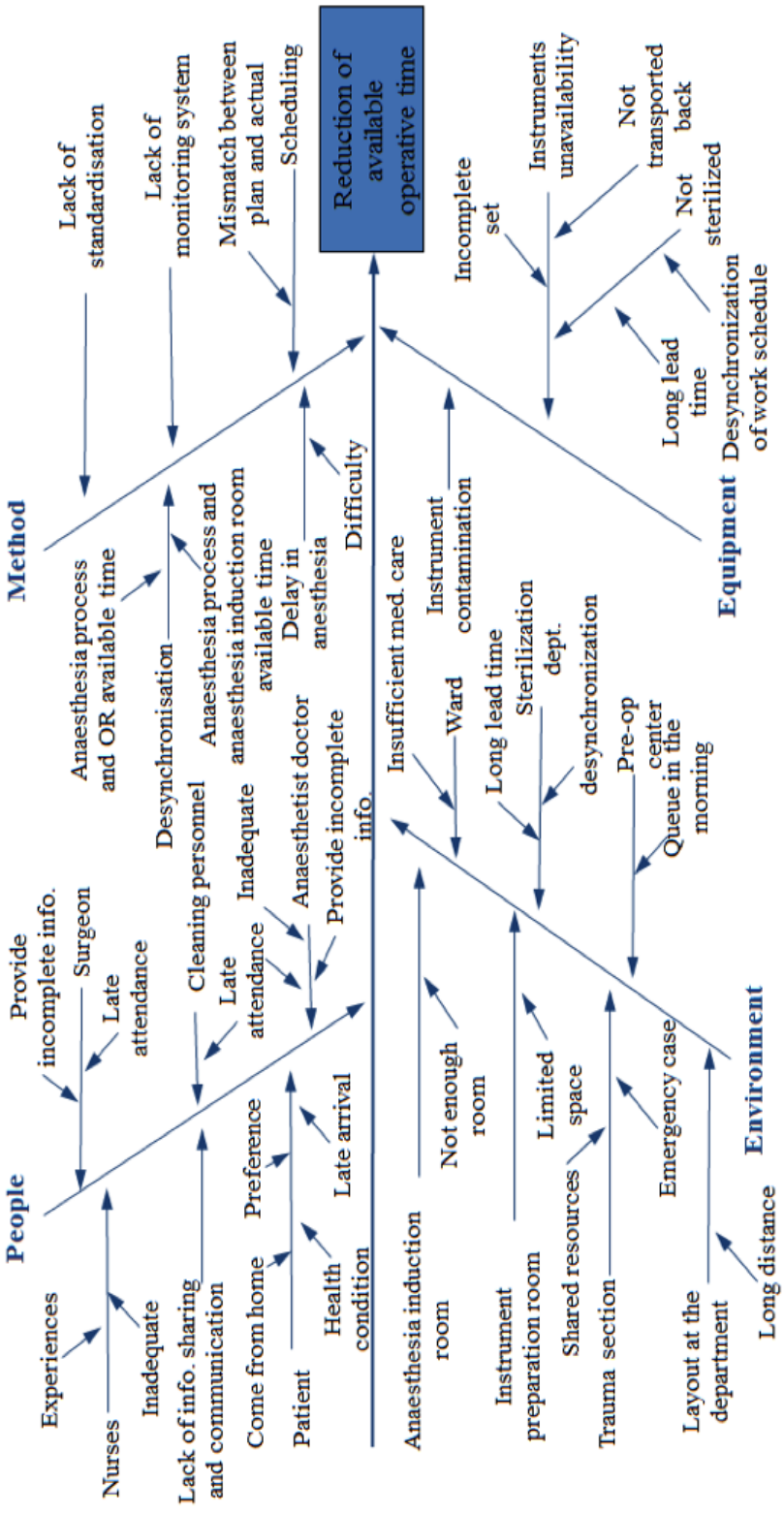

Figure 14. Fishbone diagram of reduction of available operative time

Other causes that are identified, such as lack of standardisation, monitoring system in instrument preparation process, can create excess transportation. The wastes as a result of these causes may not have direct impact on shortening available operative time, as they

happen in parallel with the current surgery being operated in the OR. However, if the staffs can work more efficiently and do not have to waste their time by looking for instruments, transporting them several times, walking back and forth in the corridor, they can help perform other activities such as preparing patient for the next operation (Wong et al., 2010).

Scheduling can be a cause for reduction in available operative time, as inappropriate sequence of surgeries with regard to the available resources and inaccurate estimate of duration of procedures can create delays, waiting times in operations, and not efficient use of the anaesthesia induction room and the OR as in case of overused and underused OR (May et al., 2011). However, scheduling is a very challenging task and there are different factors that affect it, policy makers, hospital administration, surgeon availability and specialty, staff working time, emergency cases, amount of available resources needed for each operation, patients' case severity, emergency cases etc. As it mentioned in the empirical chapter, scheduling is planned in the orthopaedic department and not in the operation department. Therefore, we would discuss it briefly as an external factor that have impact on the efficiency and available operative time at the operation department.

5.3. Assessment on impact of wastes on available operative time

Impact of wastes on available operative time is assessed in this section in order to answer the third research question on how each waste decreases available operative time. The analysis is based on both qualitative and quantitative data. This section is divided into two parts. First, for quantitative data, time intervals from the department's database system are calculated in subchapter 5.3.1. to be used in the second part. These time intervals include non-surgical activities before surgery, OR emergence time, changeover time, cleaning time, and unused OR available time. Second, the impact on available operative time is assessed in subchapter 5.3.2.

5.3.1. Data analysis

In this subchapter, efficiency measures that can be considered as quantitative measurements, are presented. OR non-operative time for non-surgical activities including instrument preparation, OR anaesthesia, OR emergence and activities during changeover time are calculated. The data were obtained from the department database system. The data consists of time records including (Operation date, operation type [hip, knee, shoulder, and elbow], time when the patient enters the OR, start time to prepare the OR, anaesthesia start time, the time when the patient is ready for surgery, knife-in and knife-out, operation finishing time, anaesthesia stop time) for 1,503 operations performed during 2016.

By considering the data that have been obtained from the database at the hospital, and with regard to this notion that not all performance measures (described in chapter 3.2) can be relevant to the purpose of the study (Fixler & Wright, 2013), efficiency measures that can be used to quantitatively benchmark impact of related activities (that would be further discussed) on available operative time are selected as: Non-operative time (non-surgical

activities include: anaesthesia process and patient preparation, instrument preparation for revision surgeries, and OR emergence time) and changeover time. Those efficiency measures that cannot be expressed in numbers, would not be mentioned here, however, they would be used in a qualitative manner for analysing the impact.

5.3.1.1. Anaesthesia process and patient preparation

There are always some non-surgical activities that are done inside the OR during its available time and before the operation starts. This portion of time, regardless of the operation types and the places where the anaesthesia is induced to the patient (the anaesthesia induction room or inside the OR), can be calculated by the following formula:

The portion of OR available time that used for non-surgical activities before surgery starts = [The time when patient is ready for the surgery - The time the patient is moved to the OR]

When the anaesthesia is done in the anaesthesia induction room (571 operations), the time between the patient is moved inside the OR until when the patient is ready for the surgery is 35.57 minutes on average and in total is 20312 minutes, which equals to 338.5 hours in 2016.

When the anaesthesia is done in the OR (624 operations), the time between the patient is moved inside the OR until when the patient is ready for the surgery is 58.71 minutes on average and in total is 36632 minutes, which equals to 610.5 hours in 2016.

The time taken to perform the anaesthesia induction in the anaesthesia induction room is approximately 30 minutes on average.

Figure 15 shows non-surgical tasks time on average or the time between the patient is moved inside the OR until when the patient is ready for the surgery inside the OR before the operation begins.

It must be notified that for this calculation, the number of operations (mentioned in subchapter 4.1 in Table 4) has been reduced from 1,503 to 1,195 operations as in this assessment only hip and knee operations (not shoulder, elbow and other minor surgeries) that have been performed in OR2, OR3 and OR4 (and not other ORs at this department-trauma section) are considered; moreover, after calculating the non-surgical time, there were some negative value for durations that must be excluded. It is not possible to have negative value for time, therefore, the total number of operations considered for this part is 1,195.

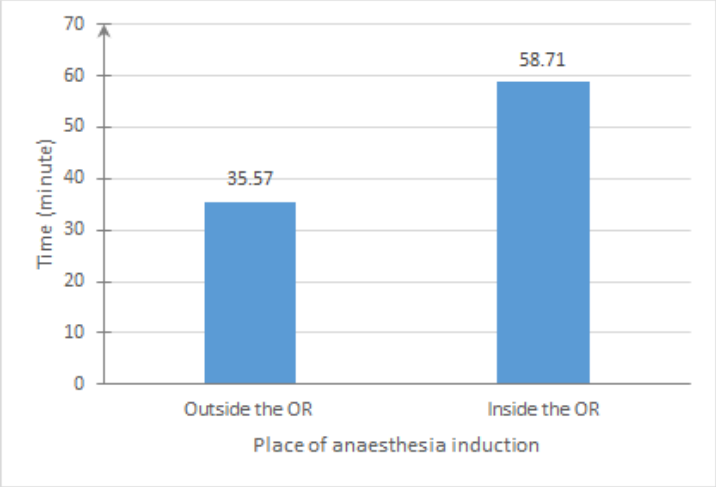

Figure 15. The average time taken for anaesthesia process and patient preparation inside the OR before the operation begins during 2016

From the data sets obtained from the department, it can be concluded that if anaesthesia start time is after the time when the patient is moved to the OR, then anaesthesia process is done inside the OR. On the other hand, if anaesthesia start time is before the time when patient is moved to the OR, either anaesthesia process is completely done in anaesthesia induction room, or part of anaesthesia is done outside and the patient is moved inside then the process continues in the OR. However, it cannot be identified from the data the place where anaesthesia is induced. Therefore, those operations that their anaesthesia start time is before the time that the patient is moved to the OR are included in 'anaesthesia induction outside the OR'.

Table 7 shows the number of operations based on the location in which anaesthesia process is done during 2016.

Table 7. Number of anaesthesia process done for each OR during 2016

	Anaesthesia done in anaesthesia induction room	*Anaesthesia done in OR*
OR2	324	233
OR3	156	235
OR4	91	156
Total	571	624

Operations on shoulder and elbow are considered separately as it requires longer time to prepare the patient for the surgery due to the different patient positioning, and mostly patient needs to receive general anaesthesia induction. Average non-surgical tasks time in the OR before the operation starts during 2016 are shown in Table 8. The non-surgical times for performing anaesthesia inside the OR for shoulder and elbow surgeries are calculated:

For the elbow surgeries (13 operations), the time between the patient is moved inside the OR until when the patient is ready for the surgery is 85.5 minutes on average and in total is 111.5 minutes, which equals to 18.5 hours in 2016

For the shoulder surgeries (60 operations), the time between patient is moved inside the OR until when the patient is ready for the surgery is 78.3 minutes on average and in total is 4,698 minutes, which equals to 78.3 hours in 2016.

Table 8. The average time for the non-surgical tasks in the OR before the surgery begins for the elbow and shoulder surgeries during 2016

Type of surgery	*Non-surgical tasks in the OR (minutes)*
Elbow	85.5
Shoulder	78.3

From 90 percent of all operations in 2016 that were hip and knee surgeries, the anaesthesia induction of more than 50 percent of the operations were done in the OR. For the rest 10 percent of the operations that were shoulder and elbow surgeries, anaesthesia induction were mostly done in the OR.

According to Figure 15, considering hip and knee surgeries, it takes 23 minutes more (58.7-35.5) on average to proceed anaesthesia induction inside the OR. Therefore, considering 1195 operations that are used to calculate the time differences between two types of anaesthesia, it shows that it takes 23*624 = 14352 minutes or 239 hours more for the anaesthesia induction done inside the OR. Although this is not a precise comparison of the numbers, as there are several variations in duration the anaesthesia process as a result of patient health, type of anaesthesia etc., it can show that in the same condition it will reduce available operative time if the anaesthesia induction is performed inside the OR.

However, performing the anaesthesia induction outside the OR also depends on the availability of the anaesthesia induction room. At the moment, there is only one anaesthesia induction room at the operation department that is mainly used for the fast-track OR2 and cannot be used for more than one patient at a time. Therefore, one anaesthesia induction room is not able to respond to the simultaneous operations. Moreover, it is not possible to distinguish the type of anaesthesia from the data set, whether they are spinal or general and if there is any specific issue regarding the general anaesthesia.

5.3.1.2. Instrument preparation for revision surgeries

According to 126 total revision surgeries that were operated in 2016, which was 8.4 percent of all operations from chapter 4.5.4, instrument preparation process was done inside the OR, which shortened available operative time of the OR. Each instruments preparation process takes approximately one hour for complicated order. It means that approximately 126 hours are spent in the OR to proceed non-surgical task, which shorten available operative time.

5.3.1.3. OR emergence time

After the operation is finished, the patient needs to be recovered from anaesthesia before the patient is moved to post-op centre, which can be called anaesthesia emergence. This time also includes the time after anaesthesia stops until patient is moved outside the OR as the time patient leaves the OR is shortly after anaesthesia stops. The average OR emergence time for OR2, OR3 and OR4 during 2016 are 12.3, 17.2 and 16.8 respectively as shown in Figure 16.

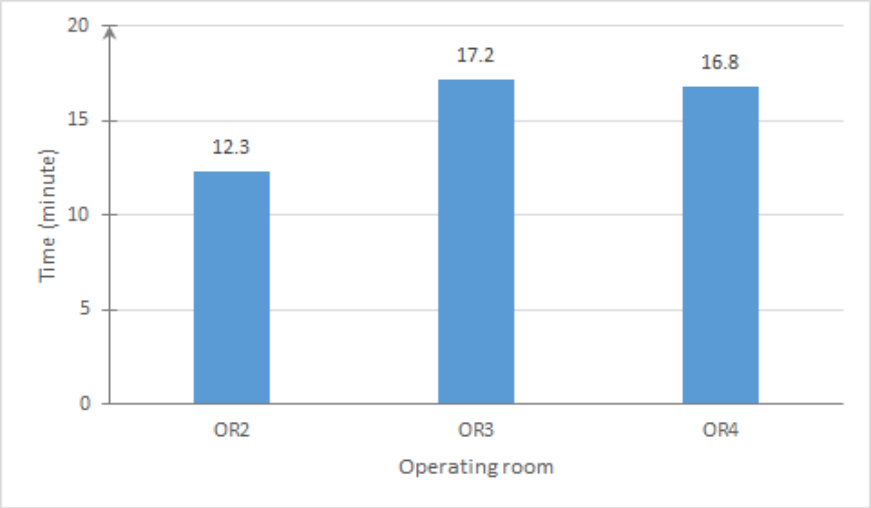

Figure 16. The average OR emergence time during 2016

OR emergence time= [Anaesthesia stop time- Operation finishing time]

This calculation is based on 1,371 operations, which are all types of surgeries that are operated in OR2, OR3, and OR4.

It takes longer time for patient to be recovered for general anaesthesia. Quantitative data that has been obtained from the department cannot identify the type of anaesthesia for each operation, therefore, the analysis is based on each OR instead, in that OR2 differs from the two other ORs in term of speed, number of cases performed, assigned personnel and not being used for educational purposes. Moreover, the average OR emergence time of OR2 is less than the other two ORs because most operations are spinal anaesthesia that takes shorter time for the patient to be recovered. For OR3 and OR4, it takes longer time because general anaesthesia is proceeded more in these two ORs as patient needs to be waken up from sleep before he/she can be moved to post-op centre.

5.3.1.4. Changeover time

Changeover is defined as the time from which a patient leaves the OR to time when the next patient goes to that OR. Average changeover time of OR2, OR3 and OR4 in 2016 are 28.7, 40.6, 44 minutes respectively as shown in Figure 17.

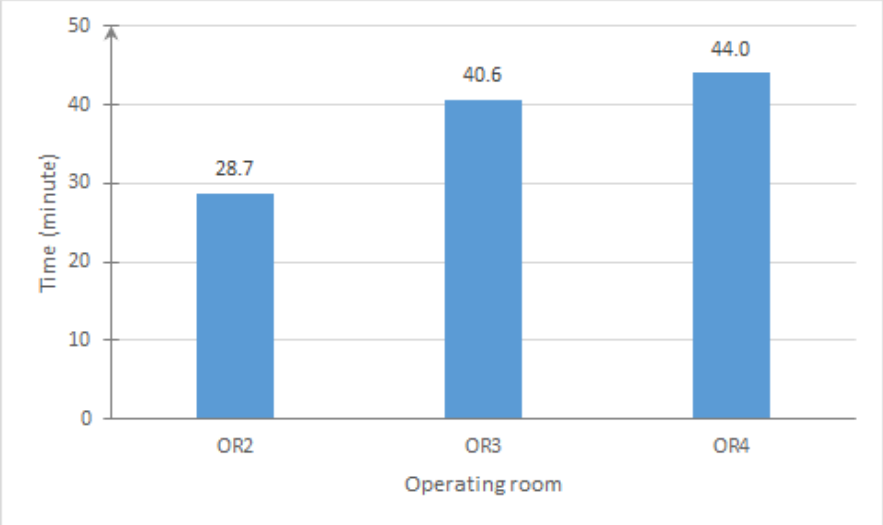

Figure 17. The average changeover time during 2016

Changeover time= [The time when next patient enters the OR- Anaesthesia stop time of current operation in the same OR]

This calculation is based on 1,371 operations, which includes all types of surgeries performed in OR2, OR3, and OR4.

The changeover time can be divided into two parts: 1. Before the room is cleaned and ready to be used, and 2. After the OR is cleaned and ready to be used (when the OR is available). By dividing into these two-time intervals, it is possible to see time intervals when the OR is unavailable and available but unused. However, summation of average cleaning time and average unused OR available time is not equal to average changeover time because changeover time and unused OR available time consider between the two operations that are operated next to each other, while cleaning time includes all the operations.

Right after the anaesthesia stops, the patient should be moved out of the OR. Then, the cleaning personnel will clean the OR. The time between the patient leaves the OR and OR is ready to be used for the next operation is 27 minutes on average, and for each OR is as follows: 25 minutes for OR2, 28.4 minutes for OR3 and OR4 as shown in Figure 18. The cleaning process, during which the cleaning personnel are inside the OR, usually takes 10-15 minutes based on the observations and interviews. However, according to the historical data, the time that is named here as cleaning time (from anaesthesia stop till the room is ready for the next operation) does not only account for cleaning time; actually, during this time interval, there may be other activities in addition to the cleaning and sterilising done inside the OR, such as, the OR team put the used instruments back to their basket and move the instrument table out of the OR, organise the used accessories and equipment, move the implant racks to the storage room and clean the devices and accessories inside the OR, enter all the necessary information into the system

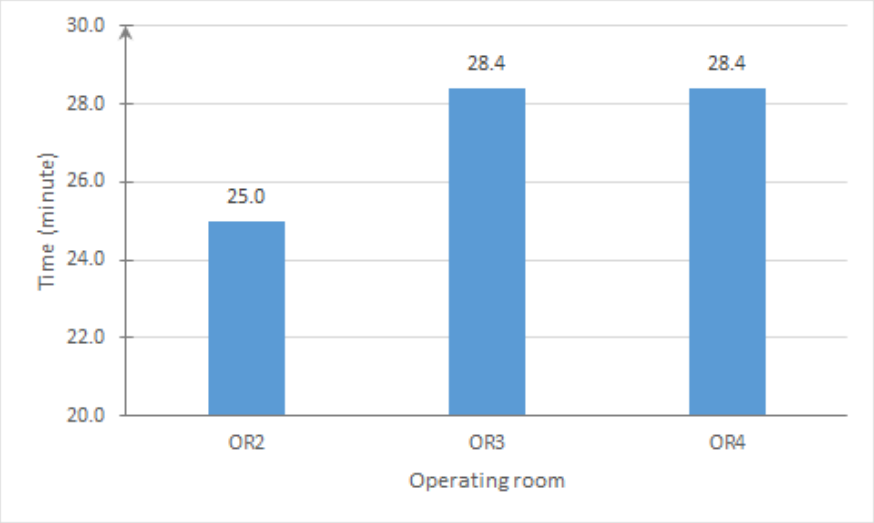

Figure 18. The average cleaning time during 2016

Cleaning time= [The time when OR is cleaned and ready for next operation- Anaesthesia stop time of current operation]

This calculation is based on 1,371 operations, which are all types of surgeries that are operated in OR2, OR3, and OR4.

Cleaning personnel usually takes 10 to 15 minutes to clean the OR after the patient exits the OR. However, the time interval between anaesthesia stops until the OR is ready to be used for the next operation takes approximately 27 minutes on average as shown in Figure 18. It means that 12 minutes on average after each operation is wasted. Considering 1,371 operations per year, 274 hours are not used effectively.

There is a duration of time after the OR is cleaned and ready for the next operation while the patient cannot enter the OR, so OR remains available until the next patient is moved inside. This length of time is a part of OR available operative time that is not used unless for fetching the implants required for the upcoming surgery.

Unused OR available operative time= [The time when next patient is moved to OR- The time when OR is cleaned from previous operation and ready for next operation]

The unused OR available operative time is calculated based on the above formula, for each OR during 2016. Calculations show that the average unused OR available time for each OR during 2016 is significantly different for OR2, which is 10.4 minutes, but the difference for OR3 and OR4 is not considerably different as they are 18.6 and 21.3 respectively as illustrated in Figure 19.

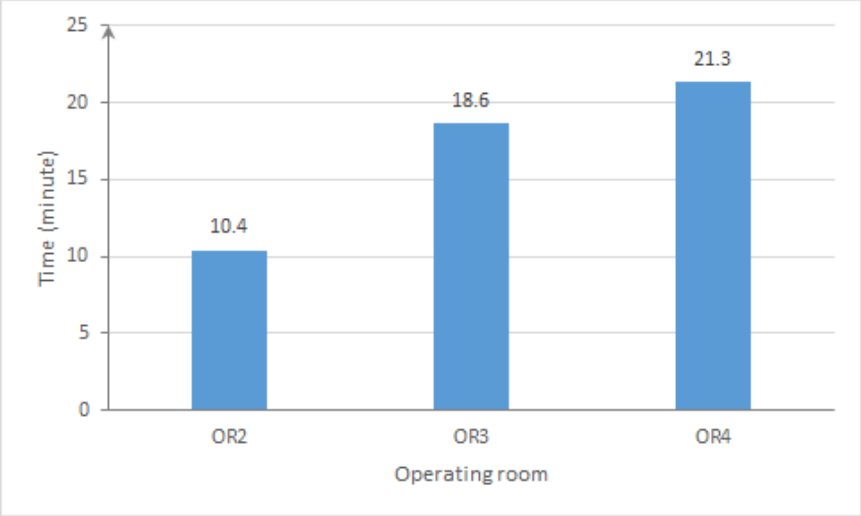

Figure 19. The average unused OR available operative time between operations during 2016

This calculation is based on the 1,371 operations, which are all types of the surgeries that are operated in OR2, OR3, and OR4.

According to Figure 19, OR2 operates with the fast pace, thus, it has shorter unused available operative time, which is 10.4 minutes between the operations on average. However, for OR3 and OR4, they have 18.6 and 21.3 minutes respectively, meaning that they can be more efficient in term of time. For OR2, for one day when they perform the primary surgeries, there is approximately 30 minutes of unused available operative time in total (there would be four operations and three changeover times). For OR3 and OR4, this time, during a day when they perform the primary surgeries, would be 40 minutes in total, as there are three operations and two changeover times per day; and this means that they are not efficiently making use of available operative time and there is space for them to work more efficiently. However, it can be inferred that OR2 is more efficient than the other ORs as it has lower unused available operative time.

5.3.2. Assessment on impact of wastes on available operative time

The wastes that lead to shortening the available operative time are quantified or assessed. However, some wastes that cannot be quantified would be qualitatively assessed instead. As some wastes do not have quantitative historical data that can be used to quantify such as quantification of instruments unavailability that affect available operative time. The assessment in the Table 9 is done based on the level of impact, comprehended through both quantitative and qualitative analysis, and is given as zero for those wastes without any impact on available operative time and +++ for those with the highest impact.

Table 9. Assessment on impact of wastes on available operative time

[0 = No impact, + = Low impact, ++ = Moderate impact, +++ = High impact, -/-[1]= Different impacts according to different conditions that would be explained in the comments]

Type of waste	Waste	Impact on available operative time	Mechanism of impact	Comment
Over processing	Redoing processes in medication preparation	0/+	Increasing the anaesthesia induction time and subsequently, it might continue during available operative time.	If need of redoing process become known very late or redoing takes long time, it can extend anaesthesia induction process and make available operative time unused, and might shorten it as well. In this case, the impact is low. Otherwise, there is no impact.
	Redoing processes in instrument preparation	0/+	Increasing the instrument preparation process time and subsequently, it might continue during available operative time.	For total revision surgeries when instrument preparation is done inside the OR, it automatically takes available operative time. Otherwise, there is no impact, if the preparation process is finished before the next surgery begins as this process is performed in parallel with the current surgery.
Transportation	Excess transportation	0	Increasing the length of time on the related	Mostly excessive transport happens for fetching instruments

[1] -/- means that it has different impact on different occasions; for instance, 0/+ means in the waste either has no impact on the available operative time or have low impact depending on different occasions. It is more explained in the comment column.

Type of waste	Waste	Impact on available operative time	Mechanism of impact	Comment
			activity. It has indirect impact and does not directly shorten available operative time.	and supplies from storage rooms and this activity is done in parallel with the current operation.
Unnecessary movement	Unnecessary movement	0	Increasing the length of time for the related activities. It has indirect impact and does not directly shorten available operative time.	Mostly during findings instruments, documents and other supplies.
Waiting	Instruments unavailability	0/+	Increasing the length of time for the related activities and subsequently, it might continue during available operative time	Waiting for instruments or finding those that can be replaced can create delays according to Figure 11. Otherwise, when instruments are available before next surgery begins, there would be no impact.
	Delayed anaesthesia	++	Take available operative time	Delayed anaesthesia is the highest delay according to Figure 10 and 11.
	Patient preparation	++	Take available operative time if the whole process is performed in the OR	Especially for the elbow and shoulder surgeries, it takes longer time
	Anaesthesia induction in the OR	+++	Take available operative time as it is done in the OR during its	58.8 minutes takes for induction of anaesthesia inside the OR, while 35.6

Type of waste	Waste	Impact on available operative time	Mechanism of impact	Comment
			availability.	minutes takes for anaesthesia induction outside the OR
	Preparing instruments inside the OR	+++	Take available operative time as it is done in the OR during its availability.	Mostly for total revision surgeries when instrument preparation is done inside the OR
	Late OR emergence	+	Although it is not avoidable, when it lasts longer, it increases non-operative time and reduces available operative time.	Take longer time for general anaesthesia. 12 minutes in OR2, and 17 minutes in OR3 and OR4.
	Cleaning time	++	Take available operative time	27 minutes on average after each operation
	Unused OR available time between operations	+	Take available operative time. During this time OR is idle and should waits for the next operation	Approximately 10-20 minutes between two operations
Defects	Instrument contamination	0/+	Increasing the instrument preparation process time and subsequently, it might continue during available operative time.	This can decrease available operative time, if instruments cannot be replaced before the time that the next surgery should begin. Otherwise, there is no impact.

Late cancellations, which create overproduction, are not included in this assessment, as there was not complete information regarding cancellation, whether they were replaced by other operations or not. However, during the interviews, it was indicated that if cancelled operation is replaced with another one, it is mostly trauma operation and not prosthetic.

6. Discussion

This chapter discusses the study results by considering previous studies and researches done in the same field both in a qualitative and quantitative forms. The main implication of the study results would be expressed, minor changes that can contribute to increasing the available operative time would be proposed, reflections of the study on how limitations affect our study and further practices that can be done.

In order to validate the study results from the previous chapter, this chapter is divided to two subchapters. The subchapter 6.1 is related to three time intervals: non-operative time before surgery, non-operative time after surgery, and changeover time. It includes comparison of the results with previous studies done by other researchers to see to what extend they are convergent or contradictory. The subchapter 6.2 considers limitation of the study and explains the factors that can affect available operative time but not considered in this study.

Non-surgical activities that are performed during OR available operative time either inside or outside the OR, such as the anaesthesia induction, OR emergence, cannot be considered as activities that can be eliminated from the process, or the duration can be reduced. However, they may be performed in a way that they shorten the available operative time when they last longer or performed inside the OR. In addition, the cleaning, and instrument preparation process in the OR are considered as the non-surgical tasks performed in the OR that reduce the OR available operative time. In order to contribute to increasing available operative time, the non-surgical activities should be performed outside the OR, in parallel with the current operation, and delays should be mitigated (Harders et al., 2006).

6.1. Activities during knife-out to knife-in

Activities between knife-out of previous operation and knife-in of the next operation are comprised of the OR emergence, cleaning, setting up OR for the next operation, anaesthesia process, and surgical preparation.

The reasons for longer time between knife-out and knife-in can be created from the scheduling, anaesthesia induction process, and types of surgeries. First, this can be as a result of unevenness in scheduling from the different number of surgeries in each OR during Monday to Wednesday when the primary surgeries are operated as uneven schedule can create unequal workload for the staff and overburdening of instruments, resulting in instruments shortage. Levelled schedule can be applied to mitigate the problems so that workload can be levelled and other wastes and unevenness can be eliminated (Liker, 2004). Second, the location where the anaesthesia is induced also has impact on the available operative time. In addition, the delayed anaesthesia is another important issue that needs to be taken into consideration as it consumes the available operative time of the OR. Smith et al. (2008) have pinpointed that additional anaesthetist nurse to take care of the patient after the operation would allow the other anaesthetist nurse to start with the next patient, which can be applicable and useful according to circumstances in this department. Last, shoulder

and elbow surgeries that require longer patient preparation are mostly operated in OR4 and some are operated in OR3, therefore, this can be another reason of longer time between knife-out and knife-in in these two ORs.

Further, to assess the waste activities and their impacts on the available operative time, the three subchapters considers three time intervals as can be seen in Figure 20 separately: 1) Non-operative time before the surgery, 2) Non-operative time after the surgery and 3) Changeover time.

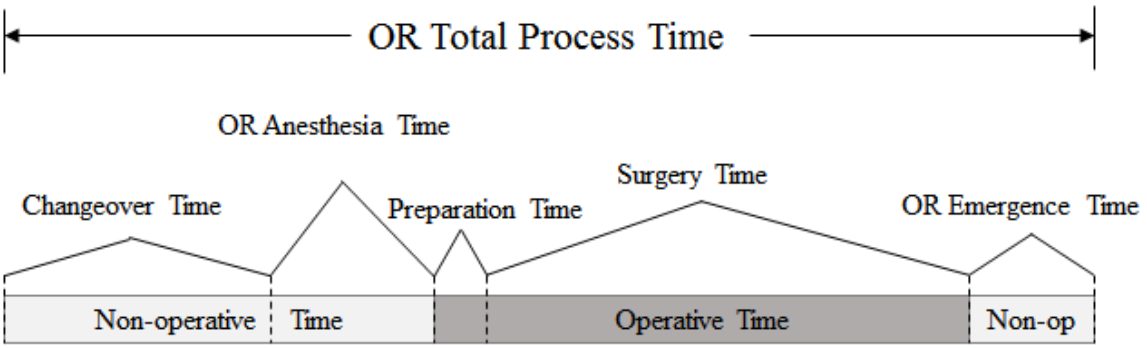

Figure 20. Different time intervals in OR total process time

6.1.1. Non-operative time before surgery

In order to understand the differences between performing anaesthesia process inside the OR and inside the anaesthesia induction room and how this process can lead to reduction in available operative time, the time that is taken for non-surgical activities inside the OR in both cases are compared with each other. Activities that are related to the pre-operative processes, in the two cases include: moving the patient into the OR, anaesthesia process (only for those operations done inside the OR), washing and sterilisation process, and patient positioning etc.

Considering the operations in which anaesthesia process is done inside the OR, we have calculated the portion of OR available time that is used for non-surgical activities before surgery starts as mentioned in subchapter 5.3.1.1.

It should be mentioned that this time consists of the anaesthesia induction time, yet it is not only this time duration as it comprises the patient preparation time as well. The preparation time includes the activities that OR staff do after anaesthesia process is done, activities such as positioning, washing and sterilising patient body before knife time. All these processes are done inside the OR. Anaesthesia induction time when it is done inside the OR, means that the OR available operative time is taken for non-surgical activities. Therefore, available operative time is reduced.

For the other occasion when the anaesthesia process is done inside the anaesthesia induction room, anaesthesia induction time is not included in the time when the patient is inside the

OR, and to calculate the duration of time when non-surgical activities are done inside the OR and throughout the OR available operative time, the same formula has been used.

Harders et al. (2006) have pinpointed that doing non-surgical activities outside of the OR and more importantly in parallel with the operations can increase the efficiency by reducing the time for non-surgical tasks during available operative time. From the investigation on data from the operation department and its concomitant proves from the literature, it can be drawn to the conclusion that performing non-surgical activities such as anaesthesia induction outside the OR and in parallel with other activities, not only results in reduction in non-operative time, but also eliminates using OR available operative time for activities that are not surgical. Smith et al. (2008) have proved through process redesign that parallel processing can result in nearly 50% reduction in non-operative time and is accompanied by decreasing the operative time by 12% that let the OR staff perform additional procedures.

Time taken to do non-surgical tasks in the OR including patient preparation and anaesthesia induction cannot be separated as these two processes proceed simultaneously. Non-surgical tasks that are performed inside the OR from the time that the patient enters the OR until the patient is ready for the operation, between proceeding anaesthesia in anaesthesia induction room and inducing anaesthesia in the OR, are different. The other point is related to those occasions when the anaesthesia process is done inside the anaesthesia induction room. In these occasions, the time that it takes for the non-surgical activities do not include the time when the OR is idle during anaesthesia process. It can happen that sometimes OR is ready while the patient is not ready for the surgery due to incomplete anaesthesia process or patient is not affected. Thus, this is not a precise comparison.

For elbow and shoulder surgeries, it takes longer time for non-surgical tasks inside the OR before operation begins to prepare the patient. The reasons are due to positioning the patient on the surgery bed, which is more complicated, and the general anaesthesia, which takes longer time to perform. Moreover, sterilising the patient's operating field in shoulder surgeries requires two personnel to do it, as one needs to hold the patient's arm, while the other one is sterilising operating field. On the other hand, the other surgeries, which are knee and hip, have equipment to hold patient's body when it is sterilised. This can be one of inefficiencies that occurs in patient preparation for shoulder surgery.

Another point that has to be mentioned here is that in order to reach the most optimum result in increased available operative time, all the waste activities have to be eliminated and best practices should be done. Concluding that it is more efficient to perform anaesthesia process inside the anaesthesia induction room and not inside the OR, is not enough. As it mentioned previously, although the anaesthesia process as a non-surgical activity is not performed inside the OR, it does not necessarily help increasing available operative time, in fact, anaesthesia process should be done at a right time too; meaning that the surgeon who performs the surgery for current operation should let the OR team know the approximate finishing time of the operation so that the OR team can inform the team working outside to prepare the next patient for anaesthesia induction and do it in a way that patient can be ready

for the next operation, and this depends on the how accurate are surgeons in notifying the OR staff about the surgery finishing time and how accurate of estimated time in anaesthesia induction. In this way, the anaesthesia process for the next patient is performed in parallel to the current surgery, and the following activities such as removing the trashes, instruments and cleaning process can also be done in parallel to OR emergence time. Immediately after the patient is moved to the post-op centre and the OR becomes ready, the next patient can be moved to the OR and the preoperative processes can begin.

However, considering utilisation time of anaesthesia induction room. Table 7 shows that more than 50 percent of all operations have proceeded anaesthesia process in the operating room. If anaesthesia induction room is used only for OR2, which has four surgeries per day from Monday to Wednesday, then it is occupied approximately three hours out of 11.5 regular working-hours (7:00 A.M. to 6:30 P.M.) resulted in low utilisation of the anaesthesia induction room. This is because anaesthesia process and patient preparation for primary surgeries are done inside the OR for the first operation in the morning, therefore, only three operations use anaesthesia induction room. In addition, each anaesthesia process takes approximately 30 minutes to one hour in anaesthesia induction room before patient goes to the OR. Low utilisation of the anaesthesia induction room can be considered as another potential area for inefficiency in this department (Divatia & Ranganathan, 2015). Considering same number of operations done in two different OR during one working shift, regardless of any other variation between the two cases, the one that uses the anaesthesia induction room more, would have lower unused available operative time and can contribute to increasing available operative time.

6.1.2. Non-operative time after surgery

Anaesthesia recovery is another non-surgical activity that occurs in the OR after the surgery is finished and before the patient is moved out. As stated by Divatia & Ranganathan (2015) that delays in moving the patients out of the OR after recovery from anaesthesia can be considered as one inefficiency of the OR. However, considering OR emergence time in Figure 16, it cannot be identified from the data whether the patient is immediately moved out from the OR after anaesthesia stops or delays have occurred in moving the patient out of the OR. As the department does not separate the time when the patient is moved out of the OR with anaesthesia stop time because it usually happens shortly after anaesthesia stops.

6.1.3. Changeover time

Changeover time includes several activities between anaesthesia stop time of current patient in the OR till the time next patient enters the same OR. As mentioned in subchapter 5.3.1.4, 12 minutes on average is wasted after each operation, and 10, 18, and 20 minutes are considered as unused OR available operative time for OR2, OR3, and OR4 respectively. It can be seen in other studies that both the duration of changeover and the time that is wasted are similar and quite close to this study. Leslie et al. (2006) has addressed that lack of standardisation in the processes, unbalanced tasks and not precisely defined responsibilities

create inconsistency and variation in the performance. These reasons are consistent with the causes of waste identified during changeover time in this study.

Surgeon's availability during the changeover time and preparation of the patient can help reducing the changeover time and it is a kind of teamwork that create a cooperative atmosphere for all the staff. During the changeover times, especially when the staff prepare the OR and patient for the operation, activities such as positioning the patient, and placing the equipment should be in a way that suit the surgeon and provide the maximum of flexibility and comfort for the surgeon. Thus, surgeon presence during preparation with minor assistance on surgeon-related activities, would not only minimise the delays to position the patient based on surgeon's preferences, but also can be a sort of motivation and team spirit for the OR team (Meredith et al., 2011). Moreover, Harders et al. (2006) indicate that when delays of the processes are minimised, the staff and patients feel less frustrated.

Moreover, in order to increase available operative time of the OR, some non-surgical activities that are done inside the OR both before and after the surgery should be performed outside the OR instead (Harders et al., 2006). Those activities that can be moved outside the OR must not affect safety of the patient or increase the possibility of getting infection. For example, moving the patients to the surgery bed before transporting them into the OR would decrease time in positioning them, shaving patient's hair on the operating field at the pre-op centre or at the ward would decrease surgical preparation time, and preparing the instruments for the total revision surgeries outside the OR etc. Preparing instruments for the revision surgeries outside would require investment in resources in order to change the layout and have bigger space in the instrument preparation room. However, if it is possible and not harmful to prepare a part of them in the instrument preparation room and the rest in the OR, it would allow other staff to perform activities in the OR at the same time. Therefore, less available operative time would be used for the non-surgical activities (Harders et al., 2006).

Minimising changeover time between the operations can be another way to increase the available operative time as it actually takes 10-15 minutes to clean the OR, but changeover time is quite long. An example of how to reduce the changeover time is that the cleaning team be in the OR immediately after dressing is placed on the operating field and start cleaning the OR (Harders et al., 2006). Moreover, if the department could exploit the unused OR available time by having better synchronisation between the pre-operative processes for the patient and OR available operative time, it would be beneficial for them as the OR is considered to be an expensive asset of the hospital (Peltokorpi et al., 2009).

In addition, the irregular schedule can create unevenness workload for the staff (Liker, 2004). As can be seen in this case, the department needs more staff during Monday to Wednesday when they operate primary surgery because of higher number of surgeries and staffs who work for OR2 also need to work in faster pace. As stated by Liker (2004), unevenness is the cause of overburdening people and equipment.

6.2. Limitations of the study

The trauma section has high influence on the prosthetic section as two sections share resources including staff, pre-op centre, post-op centre, corridor, storage area. For example, the nurses can work in both sections depending on schedule on each day. When number of staff in the trauma section is inadequate due to either sickness of the personnel or other reasons, staff who are assigned to the prosthetic section in that day need to support and help the trauma section. This also applies in the other way around. Excluding the trauma section from the scope might hinder us from considering some related issues and discovering something beyond what we have included in this study.

In addition, excluding the other departments such as the ward, the department of obstetrics and gynaecology, the sterilisation department that can have influence on the processes at this department may also affect the results of this study. For instance, staff might be required to work in the obstetrics and gynaecology department and as the number of staff is reduced in the operation department, the workload for other staff would increase and it can lead to delays, increasing waiting times etc. The other example can be lack of staff at the sterilisation department and long sterilisation process time.

In order to mitigate the wastes, root causes of the wastes should be eliminated. Even though, we considered other departments when we identified causes, there can be more causes that we have not noticed, as there was no direct observation at the other departments, except one observation at the sterilisation department.

Moreover, as this study mainly focuses on staff activities and workflow and on OR efficiency, the patient's experience and satisfaction in the department have not been considered. Furthermore, the total time that patient spends in this department for a surgery from the point when he/she arrives until the point when he/she leaves the department is not included in the analysis. Not including the patient's perspective and focusing more on the OR efficiency and staff's perspective made us recognise and identify the problems based on one side, as it may be better to see and consider the problems in another view.

7. Conclusion

In this chapter, the overall conclusion would be drawn on the whole study and what can be the next step for further practices would be discussed.

In order to contribute to increase available operative time of the operating room, the OR non-operative time should be decreased. To achieve the purpose of the study, the wastes that shorten the available operative time are identified, causes of them are recognised, and then those wastes are assessed. Different activities performed by the staff related to the OR efficiency are in focus in this study. Efficiency of the operating room, operating room scheduling, lean management and root cause analysis are studied in order to answers three research questions and achieve the purpose of the study.

The answers to the research questions formulated in the purpose are explained: wastes in this department (see chapter 5.1), causes of wastes (see chapter 5.2) and assessment of wastes (see chapter 5.3).

Wastes can be appeared in several ways based on the seven wastes of lean management including overproduction, waiting, transportation, over-processing, excess inventory, unnecessary movement and defects. The wastes that have direct impact on the available operative time, are performing anaesthesia induction in the OR, preparing instruments for total revision surgery in the OR, long OR emergence time, and long changeover time between the two surgeries. However, some wastes, which are redoing instrument or medication preparation process, excess transportation of the instruments and medication, and searching for the instruments and documents, may not have direct impact on decreasing available operative time, but have possibility to shorten the available operative time, and decrease efficiency of the staffs in performing activities. If those wastes are mitigated, the staffs can have time to support other activities such as teaching, helping the OR team to have faster performance etc.

Causes of the wastes that shorten available operative time are divided into four categories: people, environment, method and equipment. One cause can be a cause of more than one wastes, while one waste can be created from several causes. The causes that are common for many wastes such as redoing processes, and excess transportation, are lack of standardisation and lack of proper communication. These causes need to be taken care of in order to mitigate many wastes. Moreover, the main causes that lead to increasing non-operative time in the OR, are due to lack of resources in this department, and insufficient patient preparation before the patient entering the OR. Lack of resources include lack of space in the instrument preparation rooms for the total revision surgery, lack of anaesthesia induction room, and inadequate number of staff.

In conclusion, the largest portion of the activities that shorten available operative time are created from the non-surgical tasks that are operated in the OR such as performing

anaesthesia induction, preparing the patient, moving the patient to the surgery bed, OR emergence, and preparing instruments inside the OR.

The next step for further study would be to mitigate and eliminate those wastes by implementing methods and techniques that can be solution to the problems in order to increase available operative time, and improve both OR and staff efficiencies. The implementation phase is required to minimise those wastes. In addition, it has to be highlighted that although this study can be a base for the further decision regarding efficiency improvement plan, the implementation phase is not included in this study. Other similar case studies in other healthcare organisations or academic literatures can be used as example and applied with this case. Moreover, developing KPIs can be helpful for the department in order to measure different performances and have better visualisation of the wastes and current situation.

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Appendix - Interview questions

1. OR Nurse

1. What is your position? Do you also work at the trauma section?
2. Could you please explain briefly how your schedule change during a week? If it is always the same time of the day or change?
3. What are your responsibilities? What is your starting point activity on your shift? How different between working in the OR or in the corridor?
    a. OR team
    b. Corridor team
    c. Do you think changing position between these two help you to work more efficiently or hinder you from getting used to your responsibility? (Like diversity make your job more excited and then you are more efficient, or repetitive responsibilities make you more efficient?)
4. Do you receive guidelines or work instructions in preparing instruments?
5. How long have you been working in this position?
6. How do you know which instruments are required? Who provide you instrument list?
7. Does it happen to you that the instruments that you should pick up are not available at the storage? What would you do next? Should you call someone to inform him/her or you know it yourself?
8. If the instruments are missing, how do you notice that? Visualisation or registered in the system? Do you notice when you need the instruments and realise that they are not ready or do you get information beforehand?
9. What kind of information you enter to the system when you pick up any instrument?
10. How long does it take to prepare the instruments?
    a. kitting the instruments on the rack
    b. transport the instruments to the preparation room
    c. prepare the instruments in the preparation room
    d. prepare the instruments in the OR
11. How many times you should go for taking the instruments from the storage for one operation?
12. Have you ever experienced that during the surgery you understand you miss any instrument? Or it should be in the container but it does not?
13. What do you have to do after the surgery? Who has responsibility to clean the OR and handle used or unused (if any) instruments?
14. Do you have to set up all the instruments before the patient coming inside the OR can you do it when the patient is in OR?
15. Have you ever waited for the patients? When the instruments are set up and the OR is ready but the patient is not ready?
16. Do you think experience of the nurse or second nurse has any effect on the duration and precision of your job?
17. Do you have any difficulties working in this position? Ex. problems, conflicts etc.?

18. What are the main problems that usually happen? Do these problems affect your performance?
19. How do you handle those problems? Can you solve them by yourself or do you need to address help from your colleague or your boss?
20. If you are asked about changing something at the department, what would you suggest working more efficiently?

2. Nurse practitioner

1. What is your position? Do you also work at the trauma section?
2. Could you please explain briefly how your schedule change during a week? If it is always the same time of the day or change?
3. What are your responsibilities? What is your starting point activity on your shift? How different between working in the OR or in the corridor?
    a. OR team
    b. Corridor team
    c. Do you think changing position between these two help you to work more efficiently or hinder you from getting used to your responsibility? (Like diversity make your job more excited and then you are more efficient, or repetitive responsibilities make you more efficient?)
4. Do you receive guidelines or work instructions in preparing the instruments?
5. How long have you been working in this position?
6. How do you know which instruments are required? Who provide you instrument list?
7. Does it happen to you that the instruments that you should pick up are not available at the storage? What would you do next? Should you call someone to inform him/her or you know it yourself?
8. If the instruments are missing, how do you notice that? Visualisation or registered in the system? Do you notice when you need the instruments and realise that they are not ready or do you get information beforehand?
9. What kind of information you enter to the system when you pick up any instrument?
10. How long does it take to prepare the instruments?
    a. kitting the instruments on the rack
    b. transport the instruments to the preparation room
    c. prepare the instruments in the preparation room
    d. prepare the instruments in the OR
11. How many times you should go for taking the instruments from the storage for one operation?
12. Have you ever experienced that during the surgery you understand you miss any instrument? Or it should be in the container but it does not?
13. What do you have to do after the surgery? Who has responsibility to clean the OR and handle used or unused (if any) instruments?
14. Do you have to set up all instruments before the patient coming inside the OR or can you do it when the patient is in the OR?

15. Have you ever waited for the patients? When the instruments are set up and the OR is ready but the patient is not ready?
16. Do you think experience of the nurse or second nurse has any effect on the duration and precision of your job?
17. Do you have any difficulties working in this position? Ex. problems, conflicts etc.?
18. What are the main problems that usually happen? Do these problems affect your performance?
19. How do you handle those problems? Can you solve them by yourself or do you need to address help from your colleague or your boss?
20. If you are asked about changing something at the department, what would you suggest to work more efficiently?

3. Anaesthetist nurse

1. What is your position? Do you also work at the trauma section?
2. Could you please explain briefly how your schedule change during a week? If it is always the same time of the day or change?
3. What are your responsibilities? What is your starting point activity on your shift? How different between working in the OR or in the corridor?
    a. OR team
    b. Corridor team:
    c. Do you think changing position between these two help you to work more efficiently or hinder you from getting used to your responsibility? (Like diversity make your job more excited and then you are more efficient, or repetitive responsibilities make you more efficient?)
4. Do you receive guidelines or work instructions in preparing the patients?
5. How long have you been working in this position?
6. If you need any instruments at pre-op or any other place, you need to pick it up from storage room? Or you have it at the pre-op or somewhere else?
7. Do you know beforehand which medications are needed for the patient? Or health conditions of the patients?
8. What is the objective of the anaesthesia induction room?
9. How long does it take for you to do spinal/general anaesthesia? How long does it take for the patient to be ready after each of these methods? Where do you usually do anaesthesia induction? Inside the OR or at the anaesthesia induction room? Do you need someone to help you do anaesthesia induction? Who?
10. What do you have to do after the surgery?
11. How often do the patients have to wait for the OR? When the OR is not ready to be used but the patient is ready?
12. How long is the waiting time for the patients at the pre-op or before?
13. Do you think experience of the nurse or second nurse has any effect on the duration and precision of your job?
14. Do you have any difficulties working in this position? Ex. problems, conflicts etc.?

15. What are the main problems that usually happen? Do these problems affect your performance?
16. How do you handle those problems? Can you solve them by yourself or do you need to address help from your colleague or your boss?
17. If you are asked about changing something at the department, what would you suggest to work more efficiently?

4. Anaesthetist doctor

1. Which department you belong to? What are your responsibilities before, during and after surgery? Do you also work at the trauma section at the same day you are working at prosthetic section?
2. What are the factors that affect the choice of different anaesthesia for a patient?
3. Do you need to meet the patient before the surgery? How do you know patient's condition and type of anaesthesia? Do you receive any information regarding those from the surgeon or from the ward? Do you decide the type of anaesthesia by yourself or surgeon?
4. How is your schedule planned? What time do you start working and finish your shift? What time do you have to start anaesthesia in the first operation in OR2, OR3, and OR4?
5. For other operations that are not the first operation in the morning, how do you know what time you should start for the anaesthesia process? Since there can be delayed or ahead of the planned time from previous operation. Who informs you?
6. Do you have to do anaesthesia for all the patients? Or just in case of problem that the anaesthetist nurse call you?
7. How many OR that you have to respond in one shift? All the patients in one OR or many ORs?
8. What kind of information you should exchange with the surgeons and nurses in the operation department? Does it work well?
9. Have you had 'lack of information of the patients' problem from the surgeon?
10. Is it possible that the surgery is cancelled due to the anaesthesia problem? If yes, how often is it?
11. How long does it take for you to do spinal/general anaesthesia? How long does it take for the patient to be ready after each of these methods?
12. Where do you usually do anaesthesia induction? Inside the OR or at the anaesthesia induction room? Do you need someone to help you do anaesthesia? Who?
13. Can you do spinal anaesthesia in the pre-op centre or do you have to do it in the preparation room inside or in the OR?
14. Do you need special instruments that are used in the anaesthesia and its availability causes delay for your operation?
15. How long does it take for the patient to be recovered after general anaesthesia? And how long he should be kept in the post-op centre?
16. Why the recovery process for general anaesthesia should be done inside the OR? And can be done somewhere else?

17. Do the patients with spinal anaesthesia need any further care after surgery? Or they are at the stable condition after knife-out?
18. How long you should stay at the OR? Is the anaesthetist nurse able to do monitor the patient conditions?
19. Do you have any difficulties working in this position? Ex. problems, conflicts etc.?
20. What are the main problems that usually happen? Do these problems affect your performance?
21. How do you handle those problems? Can you solve them by yourself or do you need to address help from your colleague or your boss?
22. If you are asked about changing something at the department or what do you think it is inefficient, what would you suggest to work more efficiently?

5. Surgeon

1. How surgeons' employment looks like? Do you have contract with the hospital? Do you have your own office that can visit the patients with any relation to the hospital? Do you do the surgeries in another clinics or hospital?
2. What are your responsibility? Do you need to have an appointment with the outpatient or round ward with the in-patient before the surgery? Do you inform that information you receive to the other related staff in this department?
3. Do you work at both the prosthetic and trauma section?
4. How your schedule is planned? Do you yourself decide when you are available or the hospital provide you with time slot?
5. Do you make an appointment with the patients yourself?
6. How long before you receive the schedule?
7. Do you satisfy with your schedule?
8. Does it happen that you cancel the operation before the surgery due to the personal issue? How long before you should inform it that the coordinator can replace someone instead of you or postpone the surgery?
9. How often do the operations start and finish on-time? In the first and latter operations?
10. How often do you have to wait before the surgery can begin?
11. If the first operation starts late, does it affect the latter operations? Or can you manage to finish it on-time even though it starts late?
12. If the operations begin late, how often do you have to wait until the operations begin?
13. Could you please tell us what do you think is the cause that make the operations start late or finish late?
14. Who do you have to provide the instruments list to? Nurses, coordinator?
15. How long before you provide the instruments list to the nurses or coordinator before the surgeries?
16. How often do you get informed that instruments are not ready to be used? How long before the surgery begins?
17. How do you react if you find out that the instruments are not ready? Do you change the surgery method? Have you ever cancelled the operations due to unavailable instruments?

18. How often do the nurses, or other staff call you to ask you specific information? What is the reason?
19. What do you think is inefficient in this department? What is your suggestion?

6. Instrument coordinator (Prosthetic section leader)

1. What is the objective of the anaesthesia induction room?
2. Preparing the instruments for the revision surgery inside the OR, if they do it before the surgery or during the surgery?
3. How long do you keep the patients in the post-op centre? Any difference between the primary and revision surgeries? Does it create any inefficiency?
4. How many revision surgeries in the OR.2 /3 /4?
5. If there is a delay to receive instruments from sterilisation department, is there any considerable difference between revisions waiting time and primary waiting time for instruments?
6. How many revision surgeries on Thursday and Friday?
7. Do you have clear goals and guidelines? Everyone is aware of their responsibilities? Or it might happen to them that they are not sure what should they do?
8. Can you explain the mechanism of your inventory control at the department? How you understand you get out of some instruments? Do you know in advance when the instruments are missing? Or when they are not sterilised yet?
9. Do the containers contain specific set of instruments? And they should be brought to the OR with same instruments each time?
10. Do the person who take out the instruments from the storage room should enter the information of the taken instruments in the system? Can you check these information at your system? What about the instruments that come from the sterilisation department? How do you know when you need them?
11. If they do not use the anaesthesia induction room, will they do those activities inside the OR?
12. Do you share some personnel between the trauma and prosthetic section?
13. When does the sterilisation department receive the instruments from your department? And when they start washing them? How long does it take for washing the instruments?
14. How often do you need to request the instruments from other hospital?
15. What data are essential for the staff at different positions? And when these data should be available to them?
16. Do you share same storage room for the trauma and prosthetic section?
17. Which type of instruments you usually run out of stock? Are the same instruments between other departments? Like eyes surgery? Do you have to share all type of instruments with the other department?
18. How was it looking like when you previously had sterilisation at your department? Where and how big it was?
19. Are these surgeries free of charge for the patients? Do you have any competition with other hospitals in Göteborg to have more surgery?

20. Do you think the workload at the trauma section (the number of the patients that they have in a day affect the lack of instruments and the personnel at the prosthetic section? If so, in what part of the year they have more patients, and you have more patients?
21. What is the problem with doing revision surgeries during Mondays to Wednesdays? Is keeping them in the hospital is the problem?
22. What is the difference between the trauma and emergency surgeries? How fast an emergency operation should be done?
23. How long before you plan a surgery for the patient at the prosthetic section?

7. Department Manager

1. What is your responsibility?
2. How do you evaluate the performance of the personnel in time aspect? What kind of data you use?
3. Are you measuring the delays?
4. What is the operative time? From the patient going inside the OR or when the doctor start cutting them (knife-time)?
5. How accurate is your estimation of knife-time?

8. Orthopaedic coordinator

1. How is the admission process of the patient?
2. How long before you plan a surgery for the patient at the prosthetic section?
3. Could you please tell us what do you have to do when planning the schedule? Ex. talk with the involved staff etc.
4. How often do you have to revise the schedule?
5. What data is needed to plan the schedule? Where do you receive those data?
6. How long do you receive those data before planning the schedule?
7. What do you have to consider when planning the schedule? Ex. instruments availability, patient's condition etc.
8. Do you have the list of instruments when you plan the schedule for each OR?
9. Do you have any system that everyone has access to that and you all share the patients' information? If so, what data are entered?
10. Do you think the workload at the trauma section (the number of patients that they have in a day affect the lack of instruments and personnel at the prosthetic section? If so, in what part of the year they have more patients, and you have more patients?
11. Do the surgeons work at both prosthetic and trauma section?
12. How often you have cancellation from the patients for the prosthetic surgeries? What do you do for that time?
13. How often you are forced to cancel a surgery for the patient? What is the reason? And how the schedule will change?
14. Are these surgeries free of charge for patients? Do you have any competition with other hospitals in Göteborg to have more surgery?
15. What is the problem with doing revisions during Mondays to Wednesdays? Is keeping them in the hospital a problem?