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LOG950 Logistics

Flexibility in Operation Theatres

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Preface

This master thesis is the final part of the Master of Science in Logistics Program at Molde University College. The research has been conducted between December 2016 and May 2017, in order to finish the program and obtain an MSc degree in Logistics.

We would like to thank our supervisor, Berit I. Helgheim. You introduced us to the interesting field of health logistics, and lead us in the right direction with your first hand experience and valuable feedback. We would also like to thank Lars Magnus Hvattum, for his valuable discussions and feedback, especially in regards to modelling and simulation. We would like to thank Birgithe E. Sandbæk for providing us with essential knowledge, and for being available for questions. Appreciations goes to St. Olavs Hospital for providing us with the necessary data to complete our research.

We would also like to thank the programming wizard, Oskar A. Garshol. You truly are a genius.

Molde, May 2017

Torkil Rasmussen & Francisca Johnsen

Summary

The healthcare sector is a growing industry, and the demand is rising in line with the increasing and aging population. In addition, the demand for customised solutions are also rising. To deal with the impending development of the healthcare business, it is important that there are logistical solutions to support it. Logistical solutions will be ever more important for healthcare providers in the future in regards to increased productivity, flexibility, and efficiency.

This thesis presents a paper that addresses the possibility of increasing flexibility and efficiency in operation rooms (ORs) in hospitals. To increase the flexibility, the paper presents a new OR allocation. The allocation policy works to allocate patients to ORs based on the length of their surgeries and the patient status. The most current allocation policies are either to dedicate ORs between elective (planned) and non-elective (unplanned) patients, or to have undedicated ORs, which allows the use of both patient groups. By allocating all patients, except for high urgency non-elective patients, by their operation length, the results show that there is a significant decrease of both waiting time and overtime. In addition, the results show a heightened flexibility, as non-elective patients are efficiently provided with care, without disrupting the planned elective schedule excessively.

The simulation and associated results that are presented in the paper are empirical, and derived from data collected from St. Olavs Hospital in Trondheim. However, it is reasonable to believe that other similar institutions could achieve similar results by applying the same allocation policy. However, due to hospitals and ORs being complex and intricate systems, further research on the subject is advised.

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1.0 Introduction

Healthcare is an important growing industry. The growth is to be heavily sustained by not only an increasing population, but also an aging population (Cardoen, Demeulemeester and Beliën 2009). However, medical advances are also a factor of the growing industry. Provided health services are becoming increasingly customised, creating an uplift in patient care, providing critical impacts to patients' safety and wellbeing (Dobrzykowski, et al. 2013). To deal with the impending development of the healthcare business, it is important that there are logistical solutions to support it. Logistical solutions will be ever more important for healthcare providers in the future in regards to increased flexibility, productivity, and efficiency.

This thesis focus on the potential to increase the flexibility and efficiency in operating rooms (ORs). In this thesis, the term "flexibility" implies the opportunity to provide an effective response to non-elective patients that arrive at the hospital, whilst minimising the risk of compromising planned care for elective patients (Ward, et al. 2014). Flexibility is considered a tool to optimise throughput in the ORs, whilst reducing risk of cancellations and re-scheduling by several days. The term "OR efficiency" relates to the maximisation of utilisation, whilst minimising overtime and waiting time for patients. "Elective patients" refer to those patients who have had their operation scheduled ahead of time, whilst "non-elective patients" are patients that find themselves in urgent need to healthcare. Non-elective patients can be grouped according to their degree of urgency: U1, need treatment within 4 hours, U2, need treatment within 24 hours, and U3, need treatment within 48 hours.

Following the introduction of this thesis, a paper will follow. The paper is based on operation data collected from St. Olavs Hospital in Trondheim, from both general surgery and orthopaedic department. The paper investigates the impact a new OR allocation policy will have on OR efficiency and flexibility, in terms of waiting time and overtime.

2.0 Healthcare

Between 2015 and 2050, the world population aging 60 years and up will have nearly doubled, from 12% to 22% (WHO 2015). This is equivalent of 2 billion people. Though the population is aging, there is little research proving that the older population today is experiencing better health compared to their ancestors (WHO 2015). With age comes also a great deal of ailments and diseases, such as loss of hearing, cardio vascular diseases, and osteoarthritis.

Cardio vascular diseases are known to be connected to unhealthy lifestyles. In Norway, the proportion of the population that smokes daily has reduced by more than 50% from 1990 to 2014 (WHO 2015). Despite of having healthier lungs, the livers are suffering more as the percentage of the population that consumes alcohol has increased from 11 to 19% within a 15-year period (WHO 2015). The consumption of alcohol and high-fats and sugar foods have also caused an enormous increase of weight in the population. More than half of the grown-up population within 17 OECD countries are overweight (WHO 2015). Although Norway is one of the 17 countries with the lowest percentage, 1 out of 3 Norwegians are considered overweight (WHO 2015).

Unhealthy lifestyles and aging is a bad combination, and creates a pressure point on public healthcare facilities. In 2016, Norway spent a total of 326 billion NOK on national health services (Statistisk Sentralbyrå 2017). This equals 10% of Norway's GDP, which is slightly higher than the OECD average of 9% (Statistisk Sentralbyrå 2017). 139 338 million were spent nationally on specialist health services, and 61% of this, a sum of 85 000 million, was in 2016 spent on somatic health services, such as those provided by hospitals (Statistisk Sentralbyrå 2017).

Four out of ten Norwegian inhabitants were treated at a hospital in 2015 (Statistisk Sentralbyrå 2017). This is an equivalent of 1 752 000 individuals, who between them spent over 3 600 000 nights in Norwegian public hospitals (Statistisk sentralbyrå 2015). Considering the large number of patients in need of surgery, as well as the ORs position in the hospital budgets, it is necessary to plan and schedule to uphold the efficiency and utilisation of the ORs. However, to be able to deal with incoming non-elective patients, it is important that ORs are scheduled to show flexibility, and are not over utilised.

3.0 Healthcare logistics

Though logistics has been used within the health industry for many years, healthcare logistics is still a relatively new area in the field of logistics. There has been an increase of publications in this area since 1982; however, it remains to a large degree unexplored, considering both supply chain management and operations management (Dobrzykowski, et al. 2013).

The top five topics of healthcare logistic research were stated by Dobrzykowski et al. (2013) to be: Information technology and services, strategy and objectives of operations in services, delivery system selection and design, strategic quality issues in services, and capacity planning, scheduling and control.

Information technology is developing rapidly, and is a popular tool to increase efficiency and information flow in many businesses (Angst, et al. 2011). Businesses often has different information systems in different areas of the business, sometimes divided by activities. In healthcare, it has been found in empirical research that an integration between systems, if done correctly, can improve the quality of care, the cooperation between departments, and at the same time reduce costs (Angst, et al. 2011).

To improve their performance, many healthcare providers try to adapt theoretical strategies that has been created and implemented in manufacture settings (McDermott og Stock 2011). Such strategies include management models such as the fishbone diagram and quality control charts, and are applied in the attempt of increasing the cost, quality and financial performance (Li, Benton og Keong Leong 2002). However, to implement such a strategy, adaptions must be made. For instance, a focused strategy would not go well for a hospital if it meant they would have to reduce their medical services, but by focusing on restricting task variation in a hospital, the cost performance may improve significantly (McDermott og Stock 2011).

Other concepts and techniques from manufacturing that has been implemented in healthcare is Just-in-time, lean operations and six sigma (Pieters, van Oirschot og Akkermans 2010). However, for the system to be beneficial, the system design must be designed to be functional and valuable throughout the organisation. If not, it could lead to localised optimisation within sub-groups, and short lived results (Cochran, Kinard og Bi 2016).

The same goes for quality. To achieve high quality throughout the organisation, it is important to have quality controls at all levels. In healthcare, many of the quality issues that arise are related to patient safety. However, some also measure quality in healthcare by numbers of patients, where a high number of patients in a hospital equals bad quality, and the patients should be transferred to specialised hospitals dealing with their illnesses (Dobrzykowski, et al. 2013).

Capacity planning, scheduling and control is rather important for a hospital. Lives can be lost if there are not enough resources such as doctors, ORs, and medicine available. In a hospital, ORs are the facilities that contributes most to profit, and more importantly, to cost (Cardoen, Demeulemeester and Beliën 2009). Low and underutilisation, inefficiency, of ORs may give hospitals unnecessary idle costs and cancellations (Solmaz Azari-Rad 2013). However, overutilisation can give the hospital large costs due to overtime, cancellations, and long patient waiting times (Cardoen, Demeulemeester and Beliën 2009).

4.0 Operational Management in healthcare

Within healthcare, many logistical aspects are in need of optimisation and streamlining, such as staff rotas, minimisation of resource consumption, capacity planning, and OR scheduling. There is an extensive assortment of problem solving techniques within Operational Management (OM) that can be applied to solve these problems, making healthcare providers more effective and efficient. Such techniques include mathematical programming, queuing theory, heuristics, and model simulations. Dobrzykowski, et al. (2013) and May, et al. (2011) provide in their respective articles a review and overview of several OM articles that has applied OM techniques to solve problems in regards to OR and their functionality and efficiency.

To improve efficiency, it is important to identify weak links and voulnerable features such as bottlenecks, in order to take appropriate actions to coordinate and balance activities in the organisation (Sandbæk 2016). When an area of improvement has bee discovered, there are several phases to implement the required measures of change. A solution must be thourhoughly designed, tested, and then redesigned if necessary, before implementation takes place. Following implementation, it is important to monitor and measure the results to see if the systems performes as planned (Sandbæk 2016).

4.1 Optimisation in healthcare

There have been several studies within healthcare using optimisation. These studies typically use exact optimisation or a heuristic approach. The optimisations in healthcare often look at cost-minimisation, which consider costs related to the hospital in general, patients, ORs, and overtime, while trying to maximise the overall quality and patient satisfaction. Constraints are then connected to the use of resources such as budget, surgical staff, and more. The most common techniques in optimisation are mathematical programming, simulation, and improvement heuristics. In the later years computer programming has evolved and become more common to solve larger optimisation problems, especially when solving scenario analysis (Cardoen, Demeulemeester and Beliën 2009).

In 2007 Wullink et al. used discrete-event simulation when examining the OR policies dedicated opposed to extra capacity. Their results showed that extra capacity were performing better with their set of indicators and constraints (G. Wullink 2007). Marcon and Dexter examined sequencing rules in their scheduling in 2007, where they looked into shortest case first or longest case in mix sequencing, and how it affected the number of patients in the Postanesthesia Care Unit (PACU). The results showed that the sequencing did not have any effect reducing the peak of PACU patients (E. Macron 2007). This shows that it is possible to apply optimisation in health care.

5.0 Literature

Although healthcare is a young branch within logistics, there has been a steady increase of both SCM and OM publications within the field. Dobrzykowski et al. (2013) found in *A structured analysis of operations and supply chain management research in healthcare (1982-2011)* that the number of high quality publications almost tripled in the fifteen-year period following 1990, and the numbers are expected to increase even further as the research within healthcare logistics is in a steady, increasing demand.

Capacity planning, scheduling and control was one amongst the five most frequent topics within healthcare logistic research in 2014 (Dobrzykowski, et al. 2013), and there is no sign of it becoming less popular. According to van Veen-Berkx et al. (2016) there are two major approaches to OR scheduling research; adding capacity for non-elective surgeries to all ORs, or to dedicate ORs to elective and non-elective surgeries. In previous years, the literature has been focusing mostly on dedicated ORs, but only a few attempts of implementation have been made. This makes it difficult to check if the solution is feasible in reality (van Veen-Berkx, et al. 2016).

However, at the hospital Erasmus MC in the Netherlands, there has been conducted two studies related to this topic, both providing different conclusions. Wullink et al. conducted a study in 2007, looking at the effects of adding extra capacity in elective ORs. The results displayed an increased utilisation of the ORs and a simultaneous decrease of overtime by 20% (G. Wullink 2007). In 2016 van Veen Berkx et al. took a different approach, and studied the effects of changing the dedicated ORs at Erasmus MC to undedicated, whilst comparing to two control hospitals. The results showed a slight increase of utilisation, but in addition, there was also an increase of overtime. The two control hospitals, where dedicated ORs were implemented, experienced a higher increase of utilisation, along with a decrease in overtime and cancellations.

The mean of cancellations were 20.96% and 10.33% for the control hospitals with dedicated ORs, and 33.74% for Erasmus MC. van Veen Berkx et al. (2016) commented the results: "This study shows that in daily practice a dedicated OR for emergency cases is preferred over a approach of evenly reserving capacity for emergency surgery in all elective ORs, in performance terms regarding raw utilization (%), overtime, and the number of ORs running late".

The statement of van Veen Berkx et al. (2016) is supported by the study conducted by Sandbaek et al. in 2014. They measured the impact of a new allocation strategy, patient classification, and bookings of ORs for the hospital St. Olavs Hospital in Trondheim. The hospital went from having a undedicated strategy, where all the 17 elective ORs had extra capacity to take care of the non-elective surgeries, to having dedicated ORs, 14 elective and 3 non-elective. Even though the number of elective cases increased by 4.3%, overtime went down by 26%. For non-elective, the number of cases in the daytime increased by 48%, and in the night decreased by 24%. This was one of the major reasons that the hospital went from 55 nights without surgery, to 112. Utilisation went from 56% to 60% (elective) and 62% (non-elective) (Sandbaek, et al. 2014).

Ferrand, Magazine and Rao (2010) received similar results from their studies. By separating and dedicating ORs, they found that the utilisation of elective ORs to increase by 30%. Although the dedicating ORs reduced the capacity for elective cases, from 20 to 15 ORs, the utilisation increased due to the absent disturbances from non-elective cases coming in. The non-elective cases on the other hand, experienced an increased wait time with this dedicated OR allocation. Having only 5 ORs available for non-elective cases, the wait time increased to almost 5 minutes, compared to 0,28 minutes using the undedicated allocation strategy. The flexibility in a undedicated strategy gives non-elective cases the opportunity to utilise the first available of all ORs, while the dedicated strategy reduces this opportunity.

This was further supported in 2014, when Ferrand, Magazine and Rao investigated a new approach of partially flexible ORs. The authors found that by combining the use of both flexible and dedicated ORs, the average wait time for non-elective patients were reduced by up to 70%, depending on the number of flexible ORs, without drastically affecting the overtime. Benefits were found in both high and low partial flexibility policies, however, the authors recommended a high flexibility policy as it generally performs better than a low one, providing a much lower non-elective wait time, and small reductions in the elective wait time, total overtime and OR utilisation.

6.0 Simulation

When wishing to use a stochastic model to explain a real life phenomenon, simulation is often the best choice (Ross 2006). Simulation is a computer based experiment, and cheap tool, that can be used to discover improvement possibilities that are available to a system. Simulations are used to find improving factors that otherwise would be hard and costly, considering both time and money, to discover in real settings.

Discrete Event Simulation is used when you want to investigate the impact certain events has on variables over time (Ross 2006). In addition, discrete event simulations are able to run and provide desired output from a model that many other numeric programs would not be able to solve (Insua, Ruggeri and Wiper 2012). By providing estimates and appropriate parameters, discrete event simulations are able to forecast performance evaluations of large systems (Insua, Ruggeri and Wiper 2012). When a system is not fully functional or not operating at a desired level, simulation becomes a key tool to discover the improvement possibilities available. Discrete event simulation is frequently used to simulate systems that stochastically evolve in time (Insua, Ruggeri and Wiper 2012). Discrete event simulations can also describe the flow of network queues that are lined up for a series of services, and how certain attributes factor in on their path (Lim, et al. 2012). An important aspect that makes discrete event simulation a suitable choice for such modelling is the time keeping conducted in the model, that allows one to see what happens at certain times, as well as the possibility to determine the starting and ending points of events that takes place (Lim, et al. 2012). Computer simulations creates the possibility to make small or substantial changes to a system and analyse what the effects a system would experience if the changes were set out in real life. Discrete event simulation is, according to Cardoen et al. (2009), one of the most used solution techniques in operational management research papers regarding OR planning and scheduling.

6.1 Simulation in healthcare

Simulation modelling can be a powerful tool used to inform and affect policy makers in the health care sector (van Veen-Berkx, et al. 2016). There are many activities in a hospital that takes place every day. Many of the activities have the potential of improvement, but it would be hard to make drastic changes without creating a large disruption. This is why many problems concerning healthcare are simulated by the use of computer programs. Problems concerning ORs are especially popular. Many are related to the dedication of ORs, scheduling of OR staff, influential factors of utilisation, efficiency, overtime and cancellations. Though the elective demand can be predicted, the demand for non-elective services is highly stochastic and must be planned for respectively. The most used simulations methods used in healthcare operational management are discrete event simulation, Monte-Carlo and constructive heuristics.

7.0 Summary

The demand for healthcare services is on a steady rise, and the need for more customised services is inevitable. People are living to be older, but not necessary healthier. This, in addition to an increasingly aging population, is causing higher pressure on the available healthcare services. Health care services need to increase utilisation and efficiency to deal with the impending rise of demand. Healthcare logistics is an important area to look into in regards to efficiency improvement. Operational management within healthcare logistics can be used to find areas of improvement in the health sector, by using optimising, mathematical programming, queuing theory, heuristics, and model simulations. The areas that are often covered by operational management research is cost-minimization, capacity planning in regard to patients, minimisation of resource consumption, OR scheduling, and overtime. Due to its low cost, and the opportunity to examine possible changes and their outcomes before they are implemented, simulation is a popular tool to inspect the possible improvements in the health sector.

The next section will present the research paper.

8.0 Paper: Flexibility in Operation Theatres

9.0 Abstract

Background: To increase operating room (OR) efficiency and flexibility, we used simulation to investigate how a new allocation policy would affect the ORs, considering waiting time and overtime. The new allocation involves separating ORs and patients according to the length of surgery and the patient classification.

Methodology: We conducted a retrospective study using two sets of OR data, one for orthopaedic and one for general surgery. The data in total covers 8241 operations that took place in during a dayshift in 2016, excluding public holidays and weekends.

Results: The Short/Long allocation policy resulted in a 49.7% reduction in non-elective (unplanned) wait time for the surgery department and an 86.6% reduction in the orthopaedic department. For the surgical U1 group (patients who need treatment within 4 hours) in the surgical department that had an original average 234 minutes waiting time, decreased their waiting time to an average of 130 minutes, where the median reduced from 126 to 31 minutes. The orthopaedic department had an average waiting of 353 minutes for the original U1 group, but this was reduced to 251 minutes, and the median decreased from 300 to 155 minutes. In addition, the number of children who has to wait longer than 12.00 PM to start their surgeries has decreased from 25.7% and 29.3% to less than 2.5%. The overtime was reduced by 57% in the surgical department, but increased by 29% in the orthopaedic department. This can be explained by constraints set in the model which may not give an exact replication of natural behaviour and realistic limits.

Conclusions: The simulation results prove that the new allocation policy a beneficial policy that should be further researched. The new policy provides increased efficiency, and a flexible and reactive use of ORs considering high urgency patients. Although both departments have decreased waiting times, the same cannot be said in terms of overtime. Limitations and constraints must be review before further implementation.

Keywords: Flexibility; Operating room efficiency; OR scheduling; Waiting time; Overtime

10.0 Background

There is a steady demand for healthcare services that correlates to the increasing population. Although the demand for health services is limitless, healthcare providers are not always able to accommodate all of the demand sufficiently. It therefore becomes extremely important to plan and schedule beforehand. This is especially important for hospitals who need to make sufficient arrangements to be able to care for both elective and non-elective patients simultaneously. "Elective patients" refer to those patients who have had their operation scheduled ahead of time, whilst "non-elective patients" are patients that find themselves in urgent need to healthcare. Non-elective patients can be grouped according to their degree of urgency: U1, need treatment within 4 hours, U2, need treatment within 24 hours, and U3, need treatment within 48 hours.

To care satisfactorily for all patients it is essential that hospitals increase the efficiency and flexibility of their hospitals, especially in their operating rooms (ORs). The term "OR efficiency" in this paper relates to the maximisation of utilisation, whilst minimising overtime and waiting time for patients, whilst the term "flexibility" implies the opportunity to provide an effective response to non-elective patients that arrive at the hospital, whilst minimising the risk of compromising planned care for elective patients (Ward, et al. 2014). Flexibility is considered a tool to optimise throughput in the ORs, whilst reducing risk of cancellations and re-scheduling by several days.

This paper focus on the potential to increase the flexibility and efficiency in ORs. The organisation of the paper is as follows. Firstly, a literature review will present some significant research done on the subject. Secondly, a thorough problem description will follow, before a description of the data is presented. Next, the used methodology will follow, ahead of the results and analytical discussion. Lastly, a conclusion will be given.

11.0 Literature

Although healthcare is a young branch within logistics, there has been a steady increase of both supply chain management and operation management (OM) publications within the field. Capacity planning, scheduling and control was one amongst the five most frequent topics within healthcare logistic research in 2014 (Dobrzykowski, et al. 2013), and there is no sign of it becoming less popular. According to van Veen-Berkx et al. (2016) there are two major approaches to OR scheduling research; adding capacity for non-elective surgeries to all ORs (undedicated), or to dedicate ORs to elective and non-elective surgeries. Previous literature has focused mainly on dedicated ORs, however, few attempts of implementation has made it hard to measure the realistic feasibility (van Veen-Berkx, et al. 2016).

One of the implementations that was made took place at the hospital Erasmus MC in the Netherlands. Wullink et al. (2007) looked at the effects of adding extra capacity in the elective ORs. The results displayed an increased utilisation of the ORs and a simultaneous decrease of overtime by 20%. However, van Veen Berkx et al. (2016) took another look at this study, and studied the effects of changing the dedicated ORs at Erasmus MC to undedicated, whilst comparing to two control hospitals with dedicated ORs. The results contradicted those of Wullink et al. as the control hospitals with dedicated ORs performed better than Erasmus MC's undedicated ORs.

Studies conducted by Sandbaek et al. (2014) and Ferrand, Magazine and Rao (2010) support the conclusion made by van Veen Berkx et al. (2016). Both studies conducted a change in hospitals, from undedicated ORs to dedicated ORs. Sandbaek et al. (2014) found that elective cases increased by 4.3%, overtime went down by 26%, and utilisation went from 56% to 60% (elective) and 62% (non-elective). Ferrand, Magazine and Rao (2010) found that the utilisation of elective ORs did increased by 30%, but at the expense of the non-elective's wait time, as it increased from 0,28 to almost 5 minutes.

To resolve this issue, Ferrand, Magazine and Rao investigated a new approach of partially flexible ORs. The authors found that by combining the use of both flexible and dedicated ORs the average wait time for non-elective patients were reduced by up to 70%, depending on the number of flexible ORs, without drastically affecting the overtime.

12.0 Problem description

There is an ongoing discussion whether it is more beneficial for a hospital to have dedicated ORs, separating elective and non-elective operations, or undedicated ORs where elective and non-elective operations are performed one after the other. The dedicated approach has been highly advocated and recognised to be the better solution in several research papers (Sandbaek, et al. 2014). Although having dedicated ORs have proven to increase the efficiency and throughput of surgeries (Sandbaek, et al. 2014), there is cause to believe that by dedicating the ORs in a different manner, we can increase and utilise a flexibility that is currently unaccounted for, to increase the efficiency and throughput.

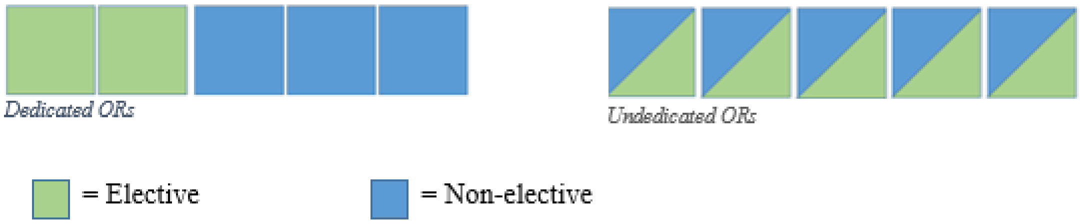

Figure 1 OR allocation policies

Our hypothesis is: by scheduling ORs by operation length, grouping by short and long durations, there will be an increased flexibility that allows for a higher throughput compared to dedicating between elective and non-elective. In this paper, a short operation is limited to a length of 90 minutes or less, whilst a long operation has a duration of more than 90 minutes. In our simulations, long elective operations, will share the Long ORs with long U2 and U3 operations. The Short ORs will accommodate the short elective operations, short U2 and U3 operations and U1 - regardless of length.

In this scenario, incoming non-elective patients will influence operations in both Short and Long ORs. However, as U2 and U3 patients have the opportunity to wait between 24-48 hours, these operations have the possibility to wait until a suitable OR is available, instead of interrupting the pre-planned schedule. The short elective surgeries are at a much higher risk of having to be rescheduled in case of incoming U1 non-elective patients coming in. However, as the elective surgeries are short of duration, it will be easier to reschedule them within the same day or the next. It is easier to find overtime for a 30-minute surgery than a surgery planned to last 4 hours.

In current OR management, when a non-elective U1 case is booked in, an OR is immediately cleared to be awaiting the incoming patient. However, in some cases, it can take up to an hour before the patient is brought in to the hospital, and at arrival, the patient is rushed off to do a series of tests. This means that the OR has been cleared, available and idly waiting for a patient for up to several hours before the surgery takes place. By dedicating ORs considering long and short durations, short surgeries can take place in the OR, until the moment it is required by a non-elective surgery.

In order to display results that reflect regular demand and use of ORs, this paper is focused on dayshifts between Monday to Friday, not including weekends, school and public holidays. This provides the opportunity to present results that are more realistic.

13.0 Data

The data contain a year's worth of records of surgeries performed at the St. Olavs Hospital in Trondheim. The collections, one surgical and one orthopaedic, holds information about all the surgeries that occurred during 2016 in St. Olavs Hospital's ORs: information such as time used in the OR, which OR was used, time spent by the surgeon, the anaesthetics used, and contamination risk. In the original datasets, there were 8340 surgeries in the general surgery department (SURG) and 6699 the orthopaedic department (ORT), which was respectively reduced to 3994 and 4247 operations.

In addition, the number of days were reduced from 365 days to 192 days for both departments. This was due to our criterion and constraints, such as looking at dayshifts, with core hours between 07:30 to 15:30, from Monday to Friday. As well as applying limitations on non-elective waiting time, and latest start-up time for children. Some extreme outliers were also eliminated from the data sets. Some of the outliers were exceptional deviations that would artificially influence the results, whilst some were the results of human errors.

Out of the 3994 patients in general surgery, there were 3496 elective, 233 U1, 217 U2, and 48 U3. In orthopaedic there were 2844 elective, 82 U1, 665 U2, and 656 U3, out of the 4247 patients.

When trying to reduce the waiting time for non-elective patients, it is not only the total and average waiting time that needs to be reduced. The maximum minutes of waiting from booking time to the start of the surgeries for non-elective patients for both departments also needs to be reduced.

Original Surg ***/ Non Elective***	**U1**	**U2**	**U3**
Total	54 456	250 687	133 939
Average	234	1155	2790
Maximum	1548	4393	5722
Median	126	1121	2960
Standard deviation	286	827	1616

Table 1 Waiting time for non-elective SURG

*Original Ort/ **Non Elective***	U1	U2	U3
Total	28 946	2 013 432	4 763 853
Average	353	3028	7262
Maximum	1257	20 636	26 412
Median	300	1849	6504
Standard deviation	290	3217	4484

Table 2 Waiting time for non-elective ORT

The number of ORs used in the two departments are 12 for general surgery and 10 for orthopaedic, which are the total numbers of ORs used in each department throughout this paper. For the sake of dividing ORs by length, an analysis of the original data showed that up-to and including 90 minutes would be the best choice for defining short operations. Short ORs therefore accommodate operations up to 90 minutes (and U1), whilst Long ORs covers those longer than 90 minutes.

To find an indication of the number of ORs that should be dedicated as Short and Long for both general surgery and orthopaedic departments, we looked at the percentage of operations and operation time within the definitions of short and long operations. For general surgery, the percentage of short operations were 35%, but they only added up for 18.2 % of the operation time.

For the orthopaedic department, the percentage of short operations were 27.4%, however they only used 13.3% of the total operation time. To keep the flexibility, both the percentage of operations and the time usage were considered together. For general surgery, an indication of 3 out of 12 should be Short ORs, 25%, and for orthopaedic 2 out of 10 should be Short ORs, 20%. Other combinations were explored, but found not feasible due to lack of OR resources and time constraints.

14.0 Methodology

14.1 Use of method

There are many analyses and techniques that can be used to approach scheduling problems, mathematical programming, heuristics, analytical procedures or simulations are some of them. However, as ORs are part of a large system, where multiple operations take place every single day, it would be hard to make drastic changes without creating a large disruption. It would take a long time before the aftermath of the changes would subside and things would return to normal. Measuring the effect of the changes might therefore prove difficult. Using a computer simulation, however, creates the possibility to make small or substantial changes to a system and analyse what the effects a system would experience if the changes were set out in real life. Discrete event simulation is, according to Cardoen et al. (2009), one of the most used solution techniques in operational management research papers regarding OR planning and scheduling.

14.2 Discrete event simulation

Discrete Event Simulation is a computer based experiment, and cheap tool, that can be used to discover improvement possibilities that are available to a system. Discrete event simulations are used to find improving factors that otherwise would be hard and costly (considering both time and money) to discover in real settings. In addition, discrete event simulations are able to run and provide desired output from a model that many other numeric programs would not be able to solve (Insua, Ruggeri and Wiper 2012). By providing estimates and appropriate parameters, discrete event simulations are able to forecast performance evaluations of large systems (Insua, Ruggeri and Wiper 2012). When a system is not fully functional or not operating at a desired level, simulation becomes a key tool to discover the improvement possibilities available. Discrete event simulation is frequently used to simulate systems that stochastically evolve in time (Insua, Ruggeri and Wiper 2012). Discrete event simulations can also describe the flow of network queues that are lined up for a series of services, and how certain attributes factor in on their path (Lim, et al. 2012). An important aspect that makes discrete event simulation a suitable choice for such modelling is the time keeping conducted in the model, that allows one to see what happens at certain times, as well as the possibility to determine the starting and ending points of events that takes place (Lim, et al. 2012).

14.3 Organisation

Before using discrete event simulation to simulate a realistic OR schedule, it was necessary to create a benchmark. The benchmark would firstly verify that sorting operations by length would provide a feasible solution. In addition, the benchmark provided a good indication as to how many ORs it would be necessary to designate as Short and Long. As the benchmark is generated from the original data where all events are known, we can say that the benchmark provides a dream-like situation. By adding and changing some of the constraints, we are adding flexibility to the allocation policy, resulting in Simulation 1. Comparing Simulation 1 to the benchmark indicates how much more flexible the schedule is, and which benefits that comes with it.

In the generated benchmark schedule, all the operations have the same operation date as in the original data. In addition, the U1 operations are set to start and finish at the exact same time as in the original data and are placed in the schedule first to secure their timeslots. Except for the U1, the benchmark regards all operations to be elective, to be sorted by operation length, and placed thereafter, not taking into consideration the booking time of the operations in the U2 and U3 categories.

After sorting by length, the operations are sorted into their respectively assigned ORs. In the Short ORs, the operations are sorted ascendingly, and start with the shortest operations in the beginning of the day. Long ORs start their day with the longest operations, and continue in a descending order. The single queues for each of the allocations ensues that it is the shortest and the longest operations that are placed first in the new schedule. Each operation will find the first available OR that has the time capacity to accommodate it, meaning that there are no U1 surgeries that have already been placed that are blocking the necessary time slot. The benchmark creates a full schedule with as little idle time between operations as possible. An idle time gap can occur in the benchmark when there is not enough time in-between an already scheduled operation and a non-elective operation for a new operation to fit between them.

Simulation 1, on the contrary to the benchmark, start by grouping operations according to their status: elective and non-elective U1, U2 and U3, and places the electives first in the schedule. The same rules as in the benchmark, placing the operations shortest of the short first and the longest of the long first in their respective ORs, also applies here. After having placed all the electives into the schedule, the simulation handles the non-elective U-groups, in the order that they are booked at the OR. All U1 are to be conducted in the Short ORs, whilst U2 and U3 operations are divided by length into their respective ORs. The simulation thereon finds the best available space for the non-elective operation, either at an available time in an OR, or by pushing planned elective operations to a later time. The conditions provided is that a U1 needs to start within 4 hours of booking time, U2 within 24 hours, and U3 within 48 hours. However, as this paper is mainly considering dayshift operations, all non-elective operations that are booked in late on a Friday or during the weekend are pushed to be performed on the first consecutive Monday. Elective surgeries that needs to be pushed to the next day during the week, due to a non-elective operation taking precedency on the original operation date, receives a U2 status. This means that no elective operation can be pushed beyond 24 hours of their original planned starting point. For a closer understanding, see Simulation Rules in Appendix A.

In the benchmark and Simulation 1, the OR time used is defined by the total time a patient spends in the OR, including pre-operation (pre-op), surgical time and post-operation (post-op). The patients requiring anaesthetics are put under during pre-op and awoken at post-op before being transferred to a post-operation care unit.

Similar for both the benchmark and the simulation is that they only include dayshifts. Rules of the benchmark dictates that surgeries can start no earlier than 07.30 AM and no later than 15.30 PM, but allowing for overtime for ongoing surgeries exceeding this limit. Simulation 1 also does not allow operations to start before 7.30 AM, but allows operations to start in overtime hours, under certain rules (Appendix A.3). At the start of the day, for both simulations, all ORs are empty and ready for use.

In addition, we assume that all ORs are equipped to handle all types of surgeries and that the set-up time is included in the OR-time provided for each surgery. We also assume that a new patient can enter an OR at the same time as one is exiting. We do not consider the costs of the ORs in this paper, as we are focusing the logistical flexibility of this new allocation, not the economic aspect.

We measure the effects of the policy by considering the amount of overtime that is necessary with this allocation, and in addition, we look to the waiting time that is experienced by both elective patients and the non-elective patients that comes in.

14.4 Resource allocation

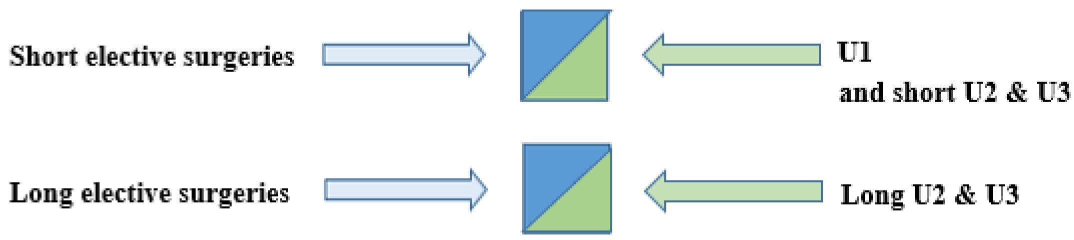

Figure 2 OR distribution

Figure 2 represents the distribution of ORs and how the patients will be allocated. All operations that comes in, except for U1, are sorted by length. Surgeries planned to take 90 minutes or less are categorised as short surgeries, whilst those above 90 minutes are categorised as long surgeries.

The Short ORs are scheduled to start the day with the shortest operations, with the operations' length increasing throughout the day. This offers non-elective surgeries the flexibility they need; ORs that are frequently finishing surgeries, creates frequent openings for a non-elective cases to come in. The non-elective surgeries will join a single queue until a flexible OR becomes available.

The Long ORs are scheduled in the opposite manner, having the longest elective surgeries at the start of the day, decreasing in length as the day progresses. However, the preliminary schedules of both the Long and Short ORs can be altered by the arrival of non-elective operations. Non-elective cases have a limited time before an operation is required to start, and these operations are not to break this limit, as far as possible. Depending on the remaining time limit, a non-elective operation will take precedence and take an earlier surgery slot, delaying an elective procedure.

This allocation bears resemblance to the partial flexibility policy investigated by Ferrand et al. in 2014, where the ORs are split between 3 groups; dedicated for electives, dedicated for non-elective, and flexible ORs that take in patients of both categories. Though the policy investigated in our paper is dedicating the ORs based on length of surgery instead of patient status, there are clear similarities.

14.5 Output measures

Both Benchmark and Simulation 1 have been created using Visual Basic for Applications (VBA) in Microsoft Access and Excel. The original data was systematically registered in Excel sheets, causing VBA to be purposely the most advantageous method for simulating.
The purpose of the benchmark is to prove the increased flexibility that occurs when dividing operations by length. Although still performed on the same date, only non-elective cases of U1 status has their original operation times, whilst the rest are sorted by length of surgery time. This will indicate if the new policy works and how well the policy will work on an average day-to-day basis, as well as an indication of the benefits of such a sorting solution will provide.

The simulation is more advanced. The simulation works in two steps, first creating a preliminary schedule, consisting only of elective operations, which is then altered by arriving non-elective cases. The alteration follows certain rules, restricting all operations to be performed during the week (Mon-Fri), eliminating overtime as far as possible, yet upholding the time limits set for each non-elective group.

The results from the simulation will show how the new Short/Long policy will affect OR utilisation, operation overtime and waiting time for both elective and non-elective. We will measure the results in relation to overtime and waiting time.

15.0 Results

After running the simulations and comparing them to the benchmarks and the original data, we were able to calculate results that play a large significance when evaluating the allocation policy. The results are shown below in table 3.

Simulations:	No. of op overtime %	No. of min overtime %	Waiting U1,U2,U3 (avg.)	Waiting U1	Waiting children
Original Surgical Data	14.7% 587 operations	5.9% (36 824 of 619 466)	439 082 min 881 min avg. 498 op.	54 456 min 234 min in avg. 233 op.	25.7% 11 742 avg. 71 min after 12:00. (165 of 642)
Original Orthopaedic Data	14.2% 604 operations	6.2% (39 872 of 648 694)	6 806 231 min 4851 min avg. 1403 op.	28 946 min 353 min avg. 82 op.	29.3% 11 348 Avg. 77 min after 12:00. (147 of 502)
Benchmark - Surgical (3-9)	3.9% 157 operations	2.0% (12 328 of 619 466)		54 456 min 234 min in avg. 233 op.	3.9% 2601 min avg. 104 min after 12:00. (25 of 642)
Benchmark - Orthopaedic (2-8)	6.6% 282 operations	2.0% (12 858 of 648 694)		28 946 min 353 min avg. 82 op.	1.6% 1040 avg. 130 min after 12:00. (8 of 502)
Simulation - Surgical (3-9)	4.6% 184 operations	2.6% (15 751 of 619 466)	220 749 min 443 min in avg. 498 op.	30 328 min 130 min in avg. 233 op.	2.5% 1680 avg. 105 min after 12:00. (16 of 642)
Simulation - Orthopaedic (2-8)	13.0% 555 operations	8.0% (51 512 of 648 694)	909 365 min 648 min in avg. 1403 op.	20 594 min 251 min in avg. 82 op.	2.4% 1224 min avg. 102 min after 12:00. (12 of 502)

Table 3 Combined results

15.1 Waiting time

15.1.1 Non-elective

As shown in table 3 in the original data, the surgical department had 439 082 minutes of waiting time divided by 498 non-elective patients, creating an average of 881 minutes, or close to 15 hours, per operation. For the 233 non-elective U1 patients, there was an average of 234 minutes of waiting before surgery could begin, giving the category a total of 54 456 minutes of waiting time. A handful of patients had zero waiting time, and entered the ORs immediately. The longest a U1 patient had to wait was 1548 minutes. Of the 233 U1 patients, 159 had a waiting time less than 4 hours.

The benchmark does not provide comparable numbers of waiting time as the non-elective groups U2 and U3 were treated as elective, pre-planned operations and are therefore not comparable. In addition, as mentioned, the U1 category patients have their operations at the same time as in the original data, and therefor has the exact same waiting time as the historical data.

Looking at the results from Simulation 1, waiting time for non-elective patients has decreased by 49.7%, from 439 082 minutes to 220 749 minutes, providing an average of 443 minutes waiting time per non-elective patient. If we look specifically at U1, this non-elective patient group had a reduction of 44%, creating an average of 130 minutes of waiting time per patient, compared to 234 minutes. 85 of the 233 patients had zero waiting time, and 192 patients had less than 4 hours waiting time. The longest a U1 patient had to wait was 1378 minutes, which is just under 23 hours.

SURG/ ***Non-Elective***	U1	U2	U3	TOTAL
Original *Total*	54 456	250 687	133 939	439 082
Original *Average*	234	1155	2790	881
Original *Maximum*	1548	4393	5722	
Original *Median*	126	1121	2960	
Original *Standard deviation*	286	827	1616	
Simulation 1 *Total*	30 328	131 625	58 796	220 749
Simulation 1 *Average*	130	606	1225	443
Simulation 1 *Maximum*	1378	3903	3952	
Simulation 1 *Median*	31	462	981	
Simulation 1 *Std. deviation*	232	675	1300	

Table 4 Waiting time in minutes for non-elective (Original and Simulation) SURG

The orthopaedic department had 1403 non-elective patients in 2016, who collectively had a staggering 6 806 231 minutes of waiting time, which gave each an average of 4851 minutes, or 3.4 days per non-elective operation. On the other hand, the U1 group, amounting to 82 operations, only had an average of 353 minutes waiting time. Four patients had the shortest wait of zero minutes; whilst the longest one patient had to wait was 1257 minutes. 37 of the 82 U1 patients had a wait time less than 4 hours.

Looking at the results from Simulation 1, waiting time has decreased from 6 806 231 minutes to 909 365 minutes, a decrease of 86.6%. The non-elective group of U1 patients have also a decreased their average waiting time, 251 minutes compared to an original 353 minutes. 19 of the U1 patients had a wait time of zero; whilst the longest one patient had to wait was 875 minutes, almost 15 hours. Of the 82 U1 patients, 48 of them had a wait time shorter than 4 hours.

ORT / ***Non-Elective***	**U1**	**U2**	**U3**	**TOTAL**
Original *Total*	28 946	2 013 432	4 763 853	6 806 231
Original *Average*	353	3028	7262	4851
Original *Maximum*	1257	20 636	26 412	
Original *Median*	300	1849	6504	
Original *Std.deviation*	290	3217	4484	
Simulation 1 *Total*	20 594	428 189	460 582	909 365
Simulation 1 *Average*	251	644	702	651
Simulation 1 *Maximum*	875	4072	4528	
Simulation 1 *Median*	147	584	450	
Simulation 1 *Std.deviation*	253	723	929	

Table 5 Waiting time in minutes for non-elective (Original and Simulation) ORT

15.1.2Elective

Simulation 1 allows elective operations to be moved later the same day or onto the following day, in case of non-elective operations with a high urgency occupying the ORs. As shown in Table 6, this resulted in 30 operations in the surgical department to be moved. They had a total of 10 175 minutes of waiting time, meaning that each operation on average had to wait 340 minutes beyond their original operation start times. The smallest move was 85 minutes, whilst the largest was a move of 595 minutes, just under 10 hours. Out of the 30 patients that had their operations moved, 22 of them had to wait longer than 4 hours, as shown in figure 3.

Simulation 1	No. of moved elective	% Of moved elective	Average min moved	Total min of waiting
Surg(3-9)	30	0.75%	340 min	10 175
Ort (2-8)	64	1.5%	249 min	15 922

Table 6 Reallocation of elective patients, in minutes

In the orthopaedic department 64 operations were moved, on average by 249 minutes, giving a total of 15 922 minutes. The smallest move in this department was by 1 minute, whilst the longest was 1555 minutes, just under 26 hours. Of the 64 moved operations, 29 had a wait longer than 4 hours, as shown in figure 4.

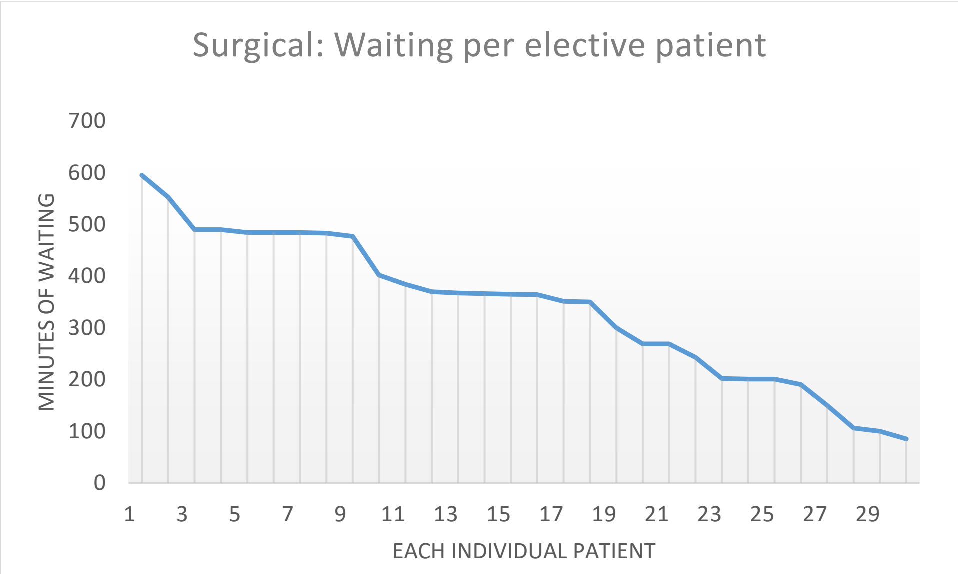

Figure 3 Waiting time per reallocated elective patient, SURG

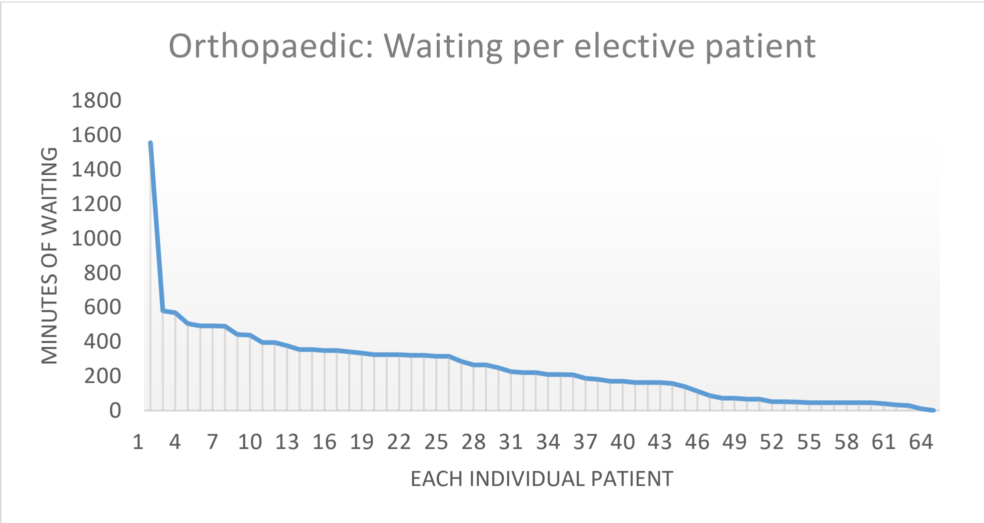

Figure 4 Waiting time per reallocated elective patient, ORT

15.1.3Children

Children between the ages 0-16 years are generally prioritised to have their operations scheduled early in the day. However, according to the original data shown in Table 3, 165 of the 642 children in the surgical department had surgeries that started later than 12.00 PM, by an average of 71 minutes. Of the 165 children, 46 were non-elective that were booked and operated on the same day. This leaves 119 elective children and children with an earlier booking time than the dayshift they were operated on to have their operations later than 12.00 PM. The latest operation start for an elective child was at 14.30 PM.

The new allocation policy used in the benchmark reduced the number of children that has an operation starting later than 12.00 PM from 165 to 25 children. All of these 25 children were in the U1 group, which means that their operation time was set by the rules of the simulation to be the same times as in the original data and could not be moved.

In Simulation 1, the number of children who started their operations later that 12.00 PM was reduced to 16. Of these children, 12 were the same is the ones in the benchmark, whilst 4, made up by 1 U1, 2 U2 and 1 elective child, have been affected by the rules of Simulation 1, and been pushed beyond the appropriate start time for a child operation, due to more pressing limitations. However, this means that out of the 25 children with a late start in the Benchmark, 12 were the same in the simulation, whilst 13 received a better suiting time for their operation in Simulation 1.

In addition, 16 children is a decrease of more than 90% compared to 165 in the original data. On the other hand, the 16 children had to wait on average 105 minutes, which in comparison to the original waiting time, 71 minutes, is an increase of almost 48%.

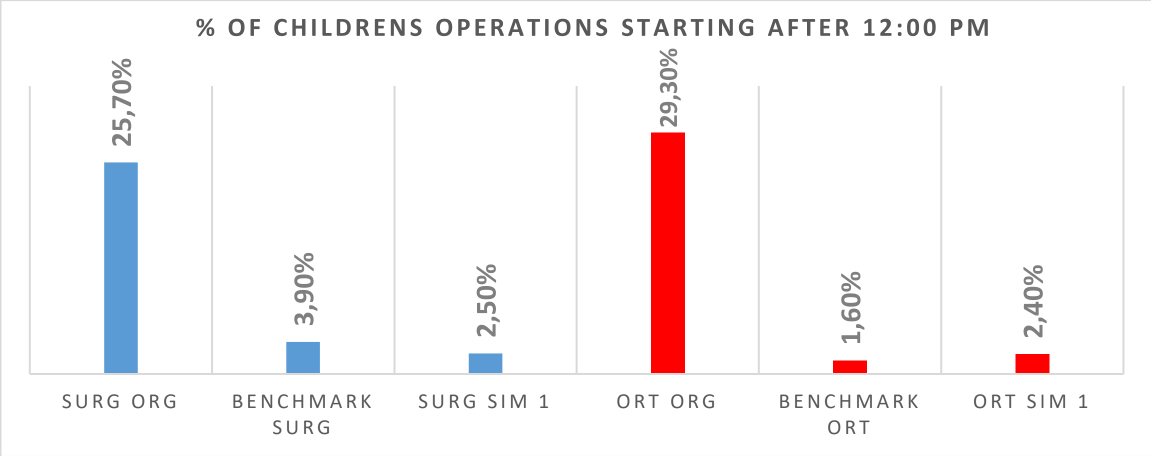

Figure 5 Children starting after 12:00 PM

Similar to the surgical department, the orthopaedic department had 147 out of 502 children in the original data who went into surgery after 12.00 PM, by an average of 77 minutes. Out of these 147, there were 101 elective, 8 U1, 27 U2, 11 U3.

The number of children in the orthopaedic department that started their operation later than 12.00 PM in the benchmark was reduced from 147 to 8 children, all of which were of the U1 non-elective patient group, with a destined later starting point.

Simulation 1 resulted in 12 children having their operations later than 12.00 PM, a clear reduction from the original data, but a step-back from the benchmark. 5 of the children are the same as those in the benchmark, whilst the rest, except for 1, are new non-elective children. The combination amounts to 5 U1, 5 U2, 1 U3 and 1 elective. In addition to the increase of children, the waiting time for these children has increased by 32.5%, from 77 to 102 minutes.

15.2 Overtime

The original data sets show that in 2016, the surgical department conducted 3994 operations, giving a total of 619 466 minutes of operating time. Looking at the number of operations that lasted longer than the normal workday, on average 14.7 % of the operations each month went into overtime. However, some of these operations were only a few minutes on overtime, whilst some were hours late. Therefore, looking at the minutes that occurred in overtime (after 15.30 PM), the result is 36 824 minutes, or on average 5.9% of total surgery time each month (Appendix B.1.1).

Looking at the results from the benchmark, we see that dedicating ORs between long and short operations has a great impact on overtime. This new allocation reduces the total minutes of overtime from 36 824 to 12 328 minutes. This is a reduction of 66.5%. In addition, the total overtime only makes up 2% of the total operating time as well as 2% in average each month, though the percentage of operations that experience overtime is a monthly average of 3.9% (Appendix B.3.1).

Simulation 1 has different set of rules and more complex constraints than the Benchmark, providing an increased realistic outcome from the simulation. Though allowing for overtime, the simulation works to eliminated it as best as possible. The overtime in the surgical department accounted to 15 751 minutes of overtime, which is a reduction of 57% in comparison to the original data (Appendix B.5.1).

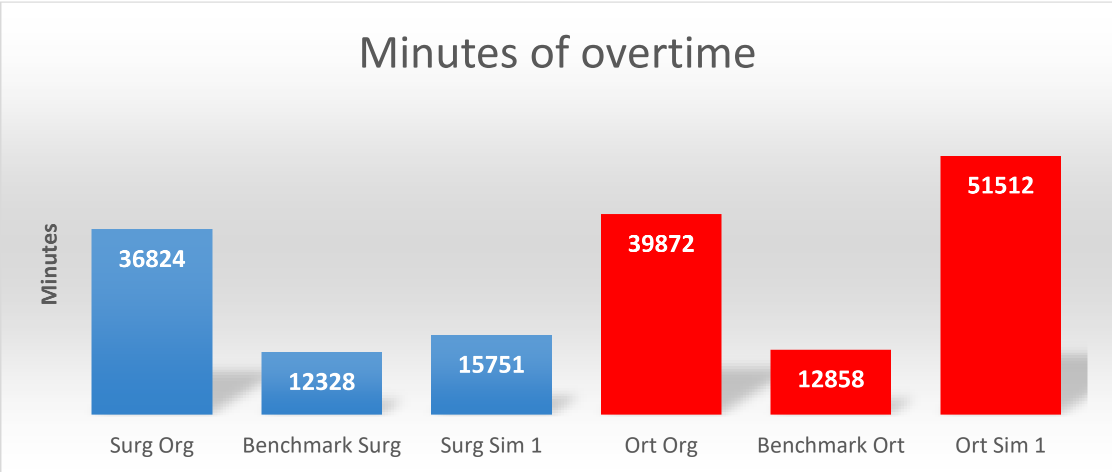

Figure 6 Total minutes of overtime

The orthopaedic department had a total of 4247 operations, amounting to 648 694 minutes of operating time in the original data. On average, 14.2% of the operations each month ran into overtime, but the 39 872 minutes of overtime they resulted in only amounts to an average of 6.2% of the total operating time each month (Appendix B.2.1).

For the orthopaedic department, the new allocation in the benchmark has reduced the total minutes of overtime from 39 872 to 12 858 minutes, a reduction of almost 68%. The total overtime makes up 2% of the total operating time, and the monthly overtime has an average of 2%. On a monthly average, 6.7% of the operations experienced some overtime (Appendix B.4.1).

Simulation 1 of the orthopaedic department provides somewhat contrasting results compared to the surgical department. The overtime has increased by 29% compared to the original data. This may be explained by the fact that the orthopaedic department is responsible for 1403 non-elective patients throughout the year, more than doubled the 498 non-elective patients in the surgical department. In addition to this, 498 of the orthopaedic non-elective patients had operations that went into overtime, either because they were booked in late in the day, or because they were placed/shifted there to make the best schedule solution.

15.3 Utilisation of ORs

Looking at figure 7 and 8 below, displaying the utilisation of ORs, we can see the distribution of operations in the ORs within each division, Short and Long. Some of the Short ORs have a lower utilisation compared to the Long ORs. This can be explained by the operations that generally comes into the different ORs. The Long ORs accommodates operations that can last a whole workday, in which the OR would have a high utilisation, whilst Short ORs could have few operations or breaks in between operations, in which case would reduce the ORs utilisation.

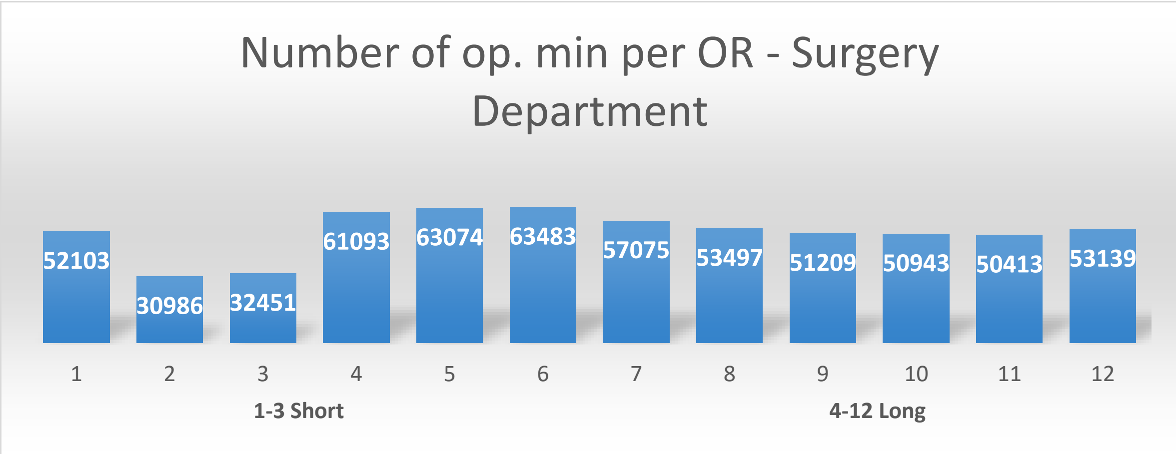

Figure 7 Total number of operations per OR, SURG

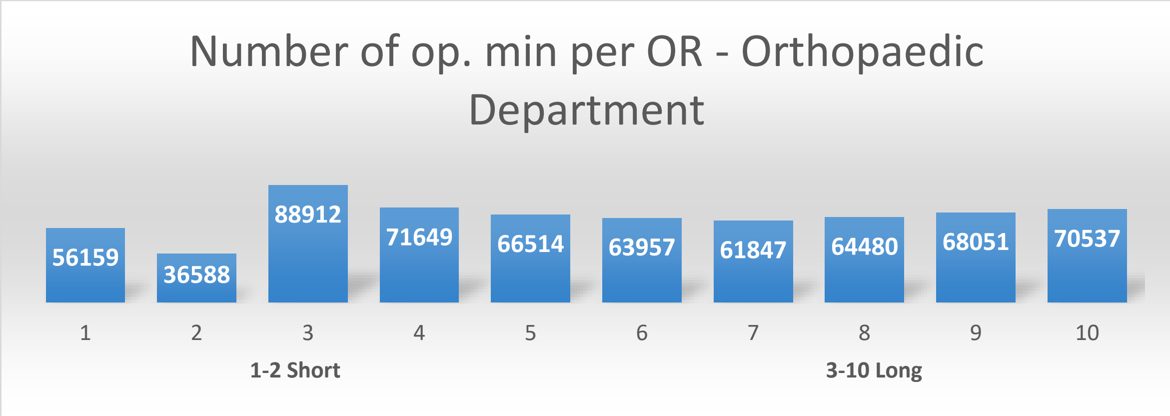

Figure 8 Total number of operations per OR, ORT

In both of the simulations, the first OR for the short operations has a higher utilisation in both minutes used in total and total amount of operations (Appendix B.5.2, Appendix B.6.2). This can be explained by the rules of the simulation, which dictates that the first OR should always be checked first, so if this OR is available at the necessary time, this is where the operation will be placed. This also explains why the first Long OR also has such a high utilisation.

Looking at figure 9, we see that the number of operations performed in the beginning of the week was generally higher than in the end of the week. This behaviour is reinforced by the simulation.

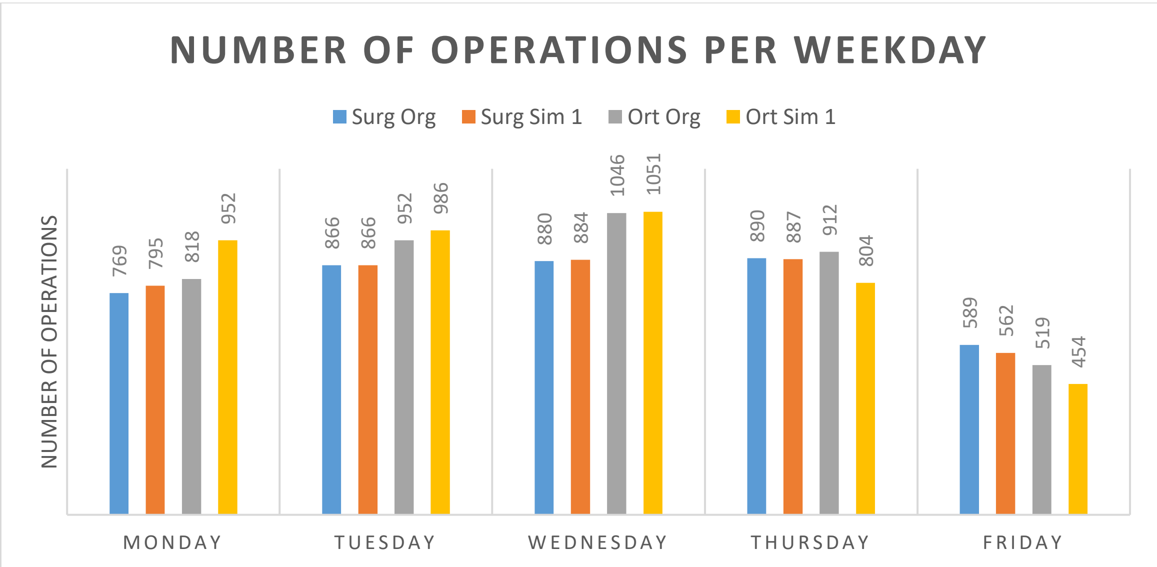

Figure 9 Amount of operations per weekday

16.0 Discussion

16.1 How does the new policy affect waiting time?

16.1.1 Non-elective

Looking at Table 3, we see that each of the non-elective-groups have an average that lies well within their own limit of waiting time. The median for all U-groups are close to, but lower, than each group's average. However, due to the constraints concerning the weekend, all U-groups have maximum waiting times that exceed their limitations. It is important that surgery takes place within the estimated time limit, and that unnecessary waiting is avoided. The surgical department experienced a 44% decrease in waiting time in the U1 patient group. As shown in Appendix B.1.2 and B.5.3, the spread of U1 patients waiting time has been reduced, but there is still some outliers. For U2 and U3 patients, Appendix B.1.3, B.5.4, and B.1.4, B.5.5, the spread is still highly diversified. However the average, median and the range between max and min have been greatly reduced, as shown in Table 3.

The orthopaedic department experienced an even higher reduction of waiting time, astonishing 86.6%. Looking at table 4, the median is well below the average presented for each non-elective group. The U2 and U3 group both have averages below the waiting limitations, but the U1 group has an average that is 11 minutes above the limit of four hours. However, the average is still lower in the simulation compared to the original data. The orthopaedic department have an outlier for U1 at 1257 minutes in the original data, which made the maximum waiting time for U1 artificially large. After the simulation, the maximum was reduced to 875 minutes.

However, what is important to mention, is that non-elective patients that are booked in do not always need treatment within the time limits that we have set in this paper. On one hand, some fractures, such as femoral fractures, are essential to treat within a short time, as this injury has large impacts on the remaining health of a patient. A long wait before treatment on a femoral fracture has been linked to a heightened risk of mental disorders and dementia in older patients (Ponomareva, Kalyn and Gavrilova 2015). On the other hand, injuries with large swellings around the fracture, requires patients to wait up to several weeks before it is possible to treat the damage that has occurred.

Many patients are booked in as soon as it becomes apparent that there is a need for surgery, even though a patient should not be booked in for surgery before being cleared. At the point of realising that surgery is necessary, the patient may not have been properly diagnosed, and may still be need other treatments before being cleared for surgery. For instance, severe ankle fractures that are not treated within 6 hours have to wait between 6-12 days before it is safe to perform open surgery to reduce the risk of soft tissue damage (Lavini, et al. 2014). The patient can then either wait in the hospital or in the comfort of their own home. However, by booking a patient in for surgery when it becomes apparent that it is necessary, guarantees that the patient will not be forgotten. This indicates that some of the waiting times in the original data is artificially prolonged. Had this not been done, the results from the simulation might have been less extensive.

The limitations used on waiting time for non-elective patients in this paper do not comply with the current limits of St. Olavs Hospital, which currently have limits of 6, 24 and 72 hours. The choice to reduce these limits was made in accordance to advice from healthcare personnel, so to reduce the wait time collectively for all non-elective patients.

16.1.2 Elective

In total 94 out of 8241 elective patients needed to be moved. This makes up for 1.2% of the elective patients. Only 1 out of the 94 patients required rescheduling to the next day. Without knowing the number of moved elective patients in the original data, it is hard to make a comparison. However, knowing that only 30 out of 2844 elective patients were moved, it is fair to say that the simulation provides positive results.

Moving patients within the day instead of the upcoming day or days could also make it less stressful for the patients, considering surgical preparations, and the psychological impact of being operated or being delayed due to incoming non-elective patients. In addition, a small number of affected operations could increase both patient and hospital staff satisfaction.

16.1.3Children

The number of children that has their surgery later than 12.00 PM is reduced drastically, comparing the original data to the results from the simulation. The benchmark in the orthopaedic department provide somewhat better result than the simulation. This can be explained by the fact that all but one of them were non-elective children. The non-elective children have to a large degree been operated on the same day they were booked, and many of them were booked later than 12.00 PM. The elective child that had a late start, had to be moved to accommodate a more pressing surgery.

Going into surgery can be a frightful ordeal for any person, but more so for a child, as they often do not fully understand the situation. Making sure that the children go into operation early in the day will reduce the hours of dreading and psychological stress a child might experience.

16.2 How does the new policy affect overtime?

Figure 10 display how the overtime is distributed during the week. Due to the constraints of non-elective patients that are booked in during the weekend, overtime is higher in the beginning of the week than in the end. The rules dictate that all non-elective patients that are booked in after the end of overtime on a Friday night and before 07.30AM Monday morning will receive a new time limit that starts on Monday morning. U1 will have 4 hours, whilst U2 and U3 will have 8 hours, unless their original allowed waiting time exceeds this limit.

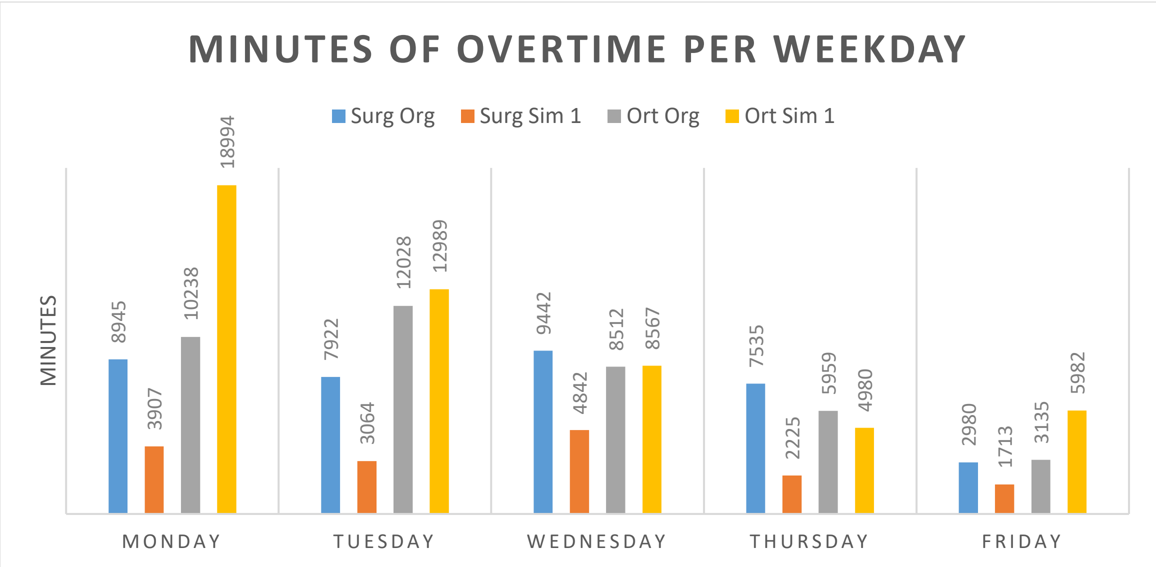

Figure 10 Amount of overtime per weekday

The simulation is retrospective, and we know that all surgeries that were booked after 15.30PM on Fridays and during weekends were performed in the beginning of the consecutive week. An explanation for this is that some patients that come in as a U1, are later downgraded to a U2 or a U3, or because the operation was booked before the patients was fully diagnosed and cleared for surgery.

This is believed to be the main reason for the orthopaedic department to have an increase of overtime, by 29%. Having more than doubled non-elective patients compared to general surgery, the orthopaedic department have a larger amount of patients that are booked in during the weekend and need treatment on the consecutive Monday or Tuesday. Looking at Figure 9, we can tell that these are some of the busiest days in this department. By increasing the limitations for the non-elective patients to those currently in use at the hospital, 6, 24, 72 hours, maybe the operations would be more evenly spread out during the week, reducing the overtime.

For general surgery, the new policy reduces their overtime by 57% compared to the original data. This is a great improvement and could help to reduce the number of nurses getting a burnout and dissatisfied and leave their job, which nurses working long shifts has 250% more likelihood of getting (Stimpfel, Sloane and Aiken 2012).

Looking at the cost of overtime, the 29% overtime in the orthopaedic department is equal to 194 hours of paid overtime The cost for keeping a surgical team available during this time would be 331 481.33 NOK, which includes the hourly rate for two surgeons and three nurses (Statistisk Sentralbyrå 2015). This cost does not include any overtime costs in Norwegian context. Hospitals are always looking to ways to save money, and cutting overtime is definitely a big cost saver. Although the orthopaedic department has an increase of 194 hours of overtime, the reduction in the surgical department is by 351 hours, which in total still leaves the hospital with a total reduction of 157 hours of overtime. Although, these combined savings are problematic, as each department in the hospital have individual budgets.

16.3 How does the new policy affect utilization?

Looking back to figure 9, we see that the number of operations conducted on each day of the week stays fairly stable when comparing the result from Simulation 1 with the original data. For both surgical and orthopaedic departments, Simulation 1 has increased the number of operations conducted in the beginning of the week, which in turn reduces the number at the end of the week. However, if the operations had been more equally distributed throughout the week, this could have positive impact on wait time and overtime.

16.4 Limitations of the new policy

There are several limitations to the research presented in this paper. First off, the data that our simulations are built on originate from a single hospital. The results that appear in this paper may therefore not be applicable to other institutions, due to different functional compositions of hospital facilities, such as number of ORs, both in total and between different departments. In addition, the simulations are retrospective, conducted using known data instead of randomised, which makes it difficult to ascertain whether the results would be similar or vastly different. However, it is reasonable to believe that hospitals with similar prerequisites will experience similar results with the new Short/Long OR policy.

On the other hand, there may have been other factors influencing waiting time and overtime which are not included in this research. Using other parameters in the simulations might have changed the results. In addition, other methods of programming might have provided results that are more advantageous. It is difficult to include all of the aspects that influence ORs in a hospital, so whilst focusing on waiting time and overtime, as in this paper, other aspects such as economy and staff availability are neglected. In order to fully appreciate the results in this paper, before venturing the possibility of implementing the new policy at a hospital, more studies and research is necessary to see how the policy influences other aspects in the hospital.

17.0 Conclusion and further research

After looking at what the future holds for the healthcare sector, it has become evident that an increase of utilisation and efficiency is important to keep up with the rising demand. In order to deal with both elective and non-elective patients, efficiency and flexibility is especially important within ORs. One of the most popular allocation policies is to dedicate ORs between elective and non-elective, however, this policy bears room for improvement. By dedicating ORs according to duration of operations, short and long, the predicted results were higher efficiency and flexibility, including lower waiting time and overtime.

After cleaning and sorting the data sets from St. Olavs Hospital, a benchmark and a discrete event simulation model was constructed using VBA. The Benchmark firstly proves that the Short/Long allocation is viable, and secondly proves that there are possible benefits to collect from such an allocation. The simulation, on the other hand, shows that the allocation policy is reactive, beneficial, and realistically feasible, considering our constraints.

The new policy reduces the wait time for non-elective operations, most importantly for children and the U1 patient group. Simulation 1 shows that the ORs with this policy is equipped to handle incoming non-elective patients and provide care for them, within their set time limits, affecting only a small number of elective operations. In addition, almost 98% of the children for both departments starts their operations before 12:00 PM, a significant improvement from the original data.

The new policy provides better result in the surgical department compared to the orthopaedic department concerning overtime. The differences in overtime shows that the limitations for the non-elective waiting times may not be in accordance with reality and for the policy to be fully beneficial and operational, these limitations need to be revised.

Hospitals have different rules and constraints than those that appear in the simulation, so even though the simulations provide positive results, it is yet to be proven viable in real life. More advanced testing and simulation is necessary to prove the Short/Long allocation feasible. Further research should include similar simulations that comprises several years of data. Data from different hospitals would also indicate whether this policy is hospital specific, or adaptable throughout the healthcare industry. To make the simulations more realistic, it would be beneficial to conduct simulations with randomised data, considering either non-elective patients, or all patients. Randomised data derived from a probability distribution could make it easier to go from simulation to implementation, as it will have a closer resemblance to reality.

In addition, it would beneficial to look at all systems and activities that are connected to the ORs, considering all steps that takes place between entering and discharge. The number of available beds in the post-operative units may impact, and potentially limit, the patient flow through the ORs. A simulation that considers turnover time and related aspects, such as contamination cleaning should also be included for a realistic time perspective in the simulations. As well as considering all connected units and departments, simulations that cover the full day might also contribute to a realistic overall picture, in regards to the constant flow of patients.

The simulation and results in this paper do not take into consideration the costs and budgets that are available. Further research on resource costs and allocations are necessary before considering the implementation of this new allocation policy. However, the results in this paper indicates that there are good chances for this allocation policy to achieve positive benefits of implementation.

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19.0 Appendices

Appendix A: Simulation rules

A.1 Simulation Rules for Benchmark

Time definitions:

1. The workweek is from Monday to Friday.
2. The work day is from 07.30AM to 15.30PM
3. Operations can go beyond 15.30PM, but they cannot start any later than 15.30.
4. No operations takes place during the weekend, Saturday and Sunday.
5. There is no slack accounted for between the operations, allowing one operations to start at the same time as one finishes, in the same OR.

Scheduling rules:

1. Divide ORs between short and long.
    - The amounts of ORs necessary to accommodate the largest number of U1 operations occurring at any one time dictates the number of short ORs.
    - There are different number of short and long ORs in each surgical department (KIR/ORT)
2. U1:
    - Operating times are the same as in the primary data.
    - Are only to be put in “short” ORs.
3. U2 and U3
    - For simulation 1, all U2 and U3 operations are considered as elective operations.
4. Short operations
    - Operations 90 minutes or less.
    - The shortest operations, in each group, are placed first, at the first available time in the first available OR. The time of short operations therefore increase throughout the day.
5. Long operations
    - Operations longer than 90 minutes.
    - The longest operations, in each group, are placed first, at the first available time in the first available OR. The time of long operations therefore decrease throughout the day.
6. Children
    - Elective children’s operations are to commence before 12.00 PM.

A.2 Simulation Coding for Benchmark

1. Define short and long ORs
    a. Short ORs - until all short surgeries have been placed.
        i. Insert all non-elective U1 into short ORs, at the exact same time as in the primary data.
        ii. Insert all short child operations.
        iii. Insert all other short operations.
        iv. In case of an idle time gap between two surgeries, (can occur when there is not enough space between last placed surgery and a U1 that is placed for a certain operation to be placed in between), the next operation being placed is being measured to empty slots on the schedule to be put in if it fits.
    b. Long ORs
        i. Insert all long child operations.
        ii. Insert all other long operations.

A.3 Simulation Rules for Simulation 1

<u>Time definitions:</u>

1. The workweek is from Monday to Friday.
2. The ordinary workday is from 07.30AM to 15.30PM
3. Overtime is from 15.30PM to 20.30 PM
4. No operations takes place during the weekend, Saturday and Sunday.
5. There is no slack accounted for between the operations, allowing one operations to start at the same time as one finishes, in the same OR.
6. An non-elective operation can start from the time they are booked in.
7. No operation can be scheduled to be performed before their original timeslot. They can only be moved later, not earlier.

<u>Scheduling rules:</u>

1. Divide ORs between short and long.
   - The amounts of ORs for each length is decided by the requirements
   - There are different number of short and long ORs in each surgical department (KIR/ORT)
2. Non-elective operations:
   - U1:
      i. Are only put in “short” ORs.
      ii. Have to be started within 4 hours AS LONG AS they have been booked in within the beginning of the work day and end of overtime (07.30AM-20.30PM)
   - U2:
      i. Divided into short and long by length.
      ii. Must be started within 24 hours after being booked in.
   - U3
      i. Divided into short and long by length.
      ii. Must be started within 48 hours after being booked in.
3. Short operations
   - Operations 90 minutes or less.
   - The shortest operations, in each group, are placed first, at the first available time in the first available OR. The time of short operations therefore increase throughout the day.
4. Long operations
   - Operations longer than 90 minutes.
   - The longest operations, in each group, are placed first, at the first available time in the first available OR. The time of long operations therefore decrease throughout the day.
5. Children
   - Elective children’s operations are to commence before 12.00 PM.
6. Weekend
   - Operations, no matter the degree of non-elective, which are booked in after the end of overtime on a Friday night and before 07.30AM Monday morning, will receive a new time limit that starts on Monday morning. U1

will have 4 hours, whilst U2 and U3 will have 8 hours, unless their original allowed waiting time exceeds this limit.

A.4 Simulation Coding for Simulation 1

1. Insert elective operations
    a. Short surgeries in short ORs until all have been placed.
        i. Insert all short child operations.
        ii. Insert all other short operations.
    b. Long surgeries in long ORs until all have been placed.
        i. Insert all long child operations.
        ii. Insert all other long operations.
2. Insert non-elective operations
    a. Non-elective operations are inserted in chronological order.
        i. Each non-elective operation checks all respective ORs to see if one is available – if available, it is inserted here.
        ii. If no available OR, check all ORs for the earliest available time. If earliest available time is within allowed waiting time – insert here.
        iii. If earliest available time is outside of the operation's allowed waiting time, all respective ORs are checked for the earliest finishing time for previous operation. If the operations that are scheduled to follow in this OR has enough allowed waiting time to be postponed later that day, the non-elective operation is inserted here. If the following operations are not able to be moved, the next OR with the earliest finishing time is checked.
        iv. U2 and U3 operations that are booked in during the overtime period are placed that day IF there is space on the schedule AND IF the booking time is earlier or no later than 30 minutes of the last planned operation.
3. Moving operations that are affected by non-elective operations.
    a. Operations that originally had both starting and ending times within the period of time that the new non-elective operation is requiring are moved to the end of the day.
    b. Operations that are partly overlapping with the new non-elective operation, i.e. supposed to start before the non-elective operation is ended, are moved to start at the time the non-elective operation finished. All the operations following this shifted operation has to move equally as much.
4. Managing overtime
    a. All operations that have a start point after the workday ends (15.30PM) are collected into a temporary file and sorted by descending length of time. The longest operation is then placed at the earliest available starting time in any respective ORs. This action is repeated until the list of overtime operations is empty.
    b. If operations exceed the overtime limit, the operation must be postponed until the next day.
5. Waiting time

a. All operations that have been postponed, either same day or a later day, receive a waiting time, number of minutes since the operation was originally meant to start until it actually starts.
b. Non-elective operations receive waiting times that indicate how long they have been waiting from when they were booked in until they started.

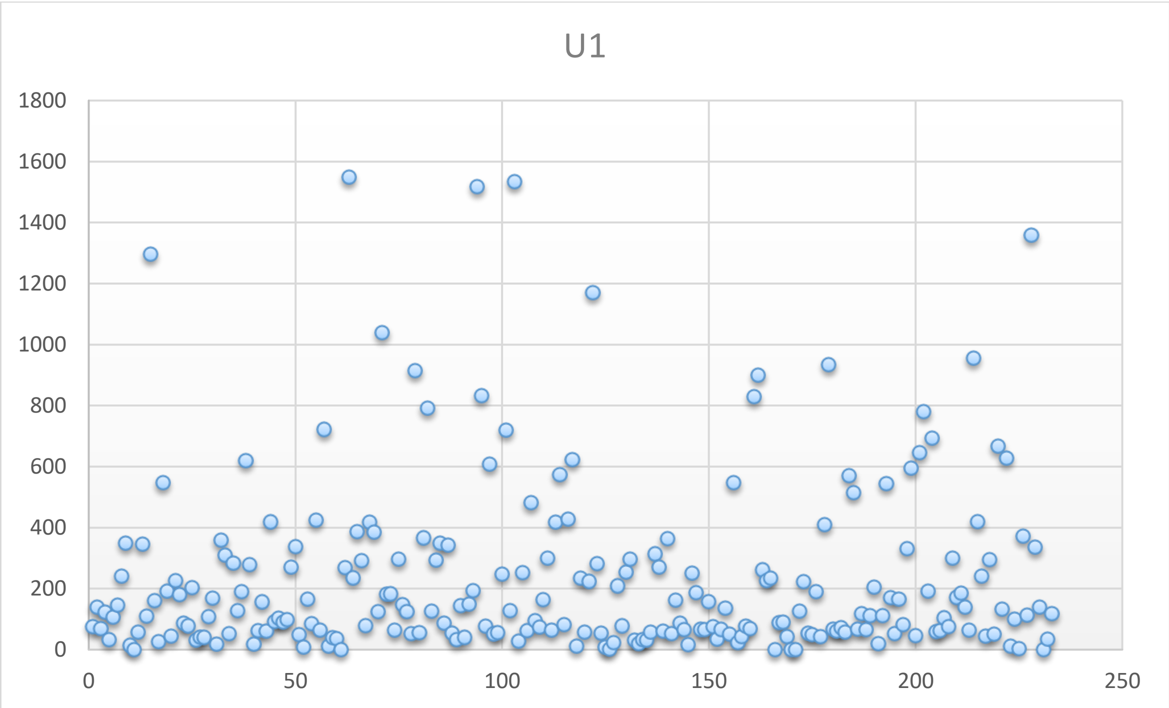
Appendix B: Graphs

B.1 General surgery – Original data

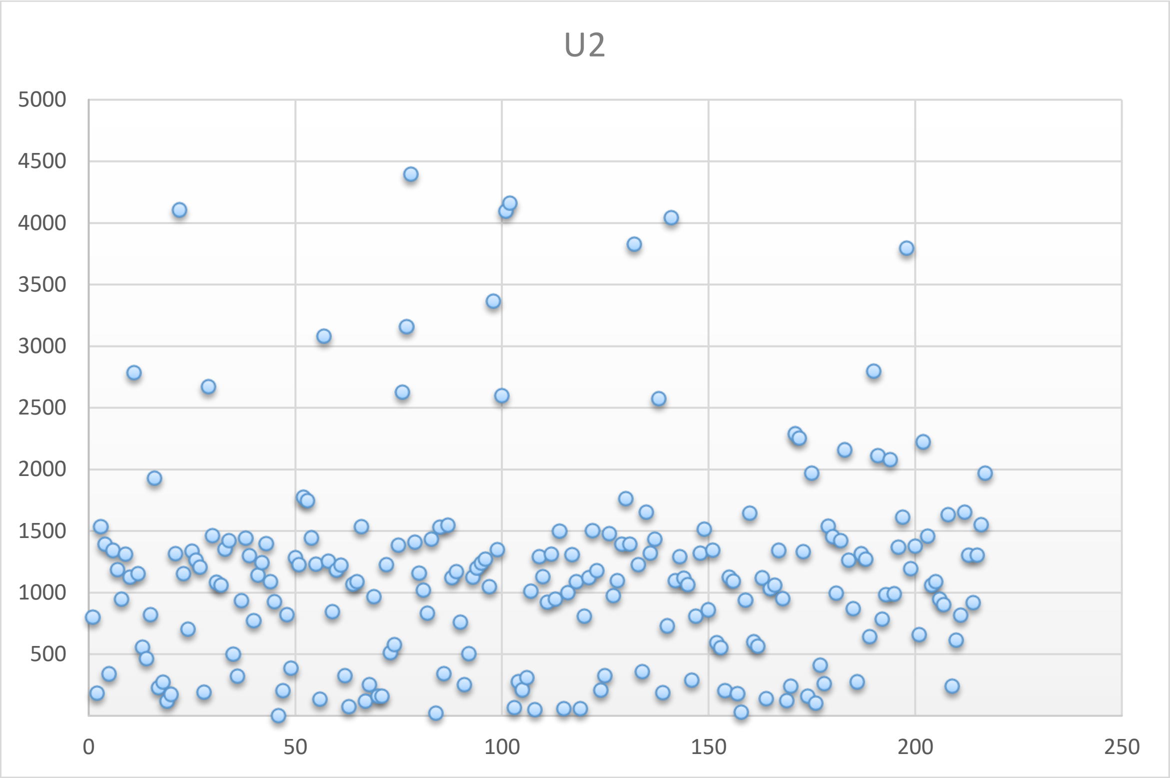
B.1.1 Overtime

Month	% of op. with overtime	No. of op. in total	% min overtime	No. of min overtime	Total min in op.
January	14,4 %	430	5,6 %	3615	64746
February	13,6 %	345	4,6 %	2418	52067
March	15,1 %	364	6,9 %	3877	56064
April	16,2 %	431	6,6 %	4466	68060
May	16,2 %	383	6,3 %	3922	61870
June	15,7 %	254	7,8 %	3245	41577
August	12,8 %	273	5,5 %	2316	42231
September	15,3 %	464	5,8 %	4074	69760
October	11,1 %	279	4,5 %	1956	43855
November	16,2 %	450	6,8 %	4827	71304
December	13,1 %	321	4,4 %	2108	47932
Total		**3994**	5,9 %	*36824*	**619466**
Average	14,5 %				

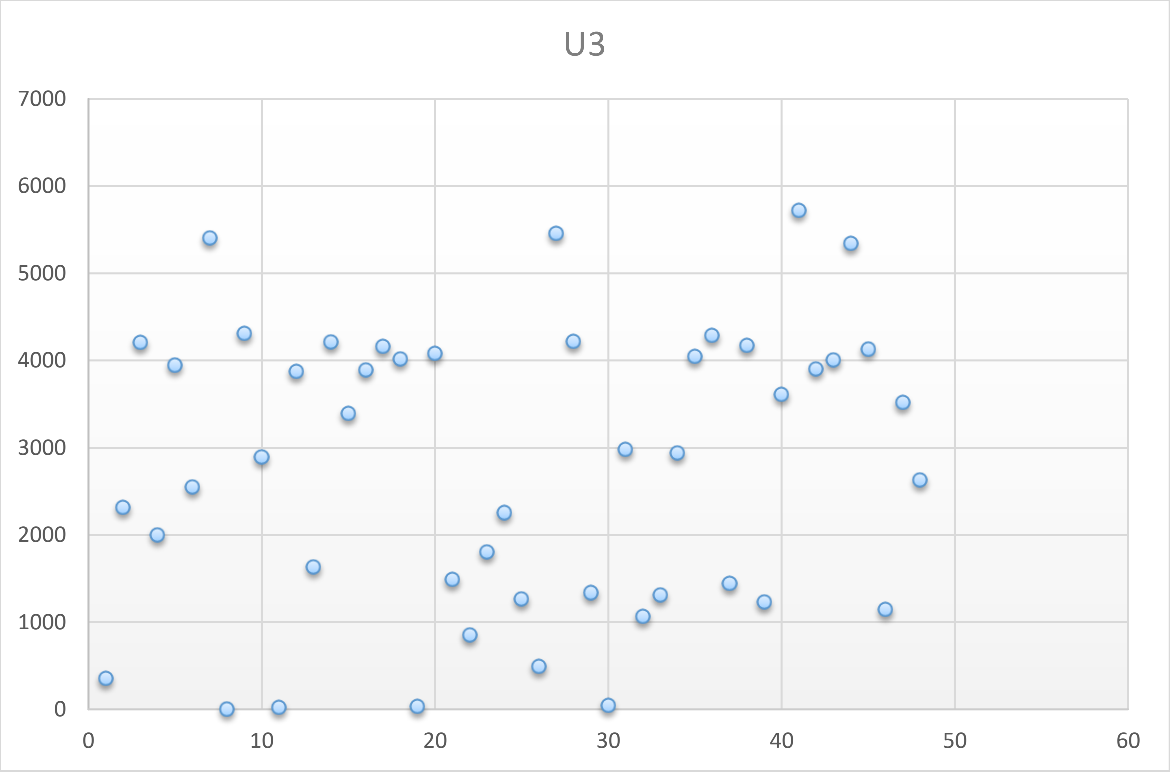
B.1.2 Distribution of waiting U1 patients



B.1.3 Distribution of waiting U2 patients



B.1.4 Distribution of waiting U3 patients

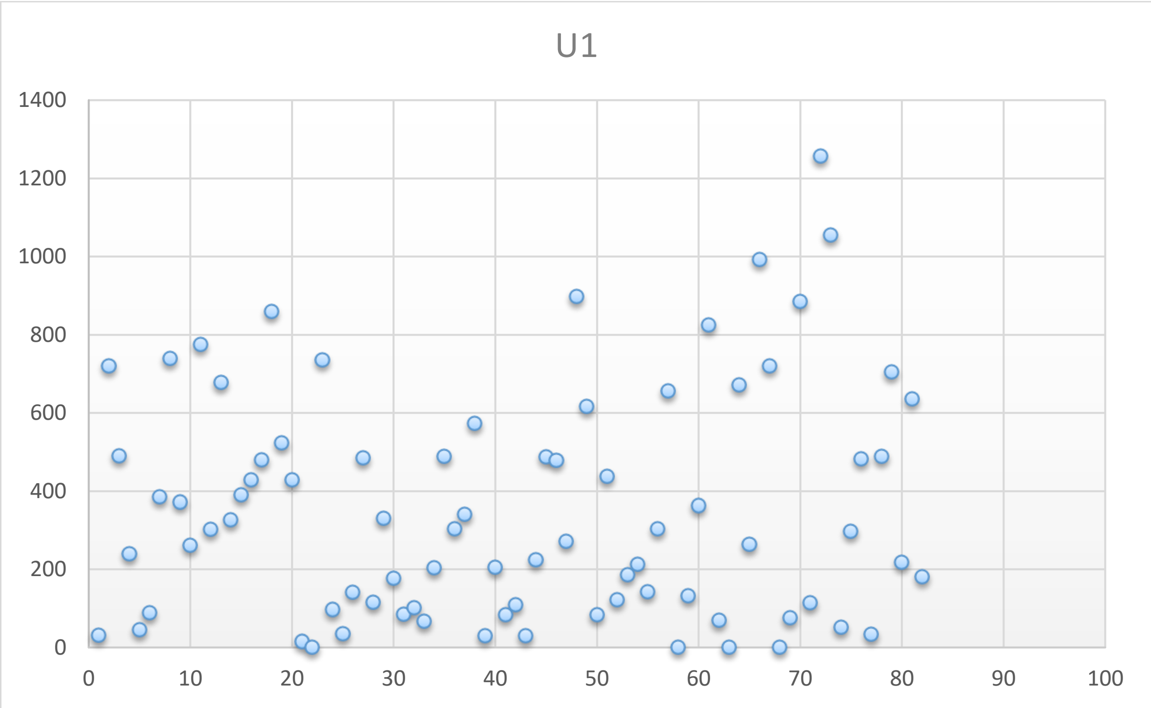


B.2 Orthopaedic – Original data

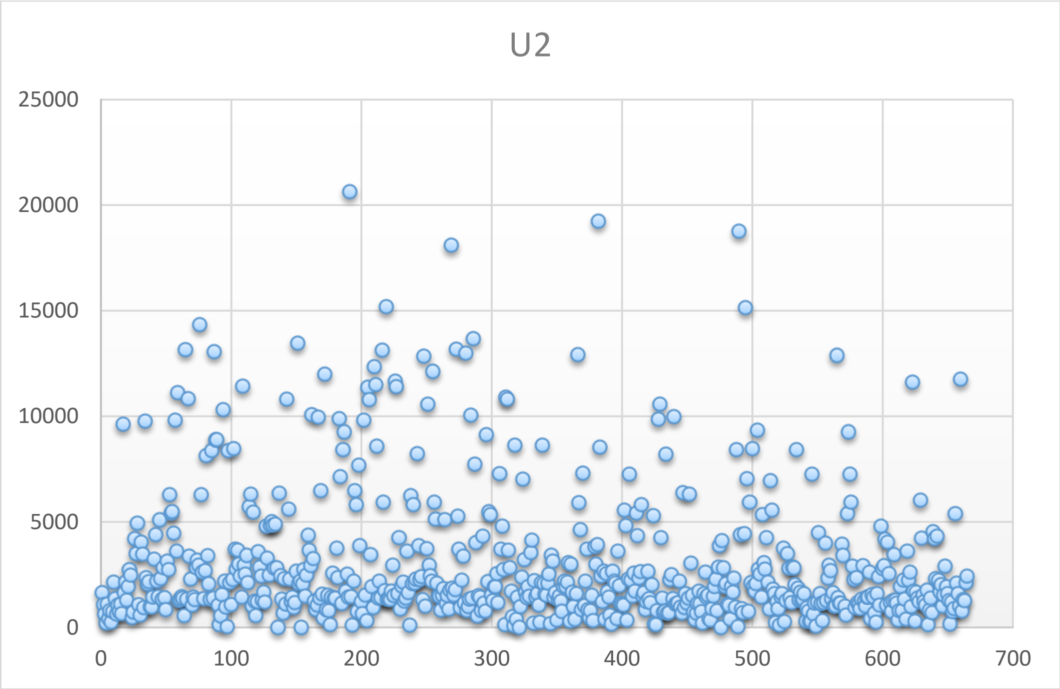
B.2.1 Overtime

MONTH	% of op. with overtime	No. of op in total	% of min overtime	No. of min overtime	Total min in op.
January	13,4 %	434	5,7 %	3729	65440
February	14,7 %	381	6,8 %	3982	58246
March	12,5 %	399	6,4 %	3906	61226
April	15,0 %	460	7,2 %	5198	72253
May	15,3 %	412	5,8 %	3690	63124
June	11,8 %	279	5,4 %	2288	42317
August	11,9 %	293	4,4 %	1815	41568
September	12,3 %	472	5,1 %	3622	70776
October	17,3 %	300	7,5 %	3604	48322
November	18,1 %	465	7,4 %	5499	74026
December	13,1 %	352	4,9 %	2539	51396
Total		4247	6,1 %	39872	**648694**
Average	14.1 %				

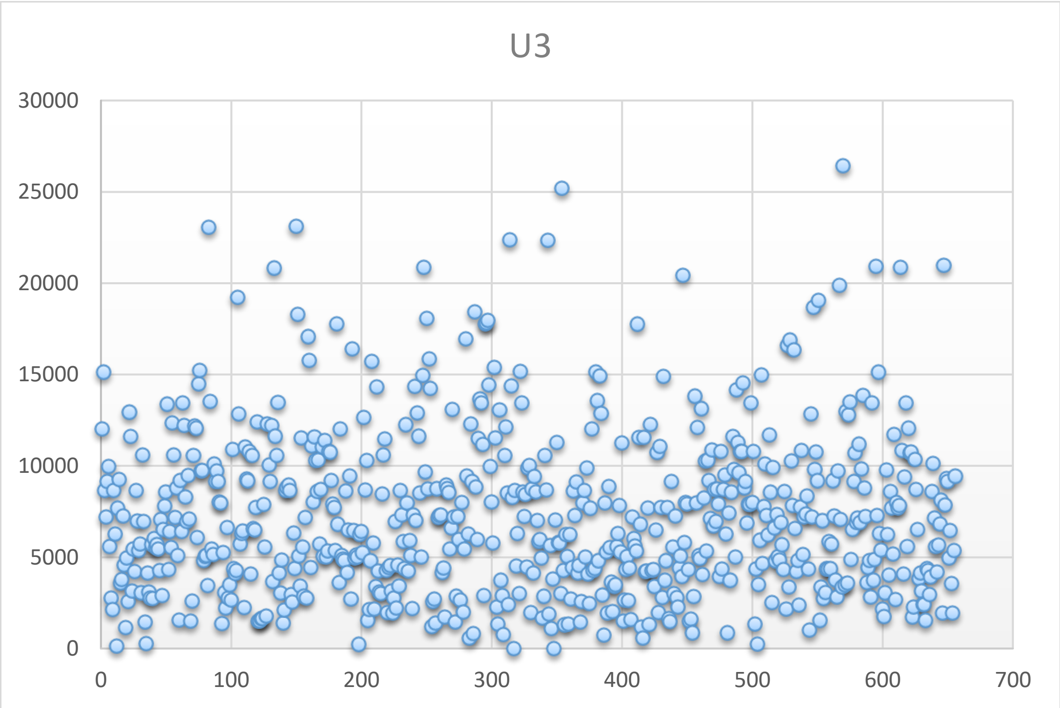
B.2.2 Distribution of waiting U1 patients



B.2.3 Distribution of waiting U2 patients



B.2.4 Distribution of waiting U3 patients



B.3 General surgery – Benchmark (3-9)

B.3.1 Overtime

Month	% of op. with overtime	No. of op. in total	% min overtime	No. of min overtime	Total min in op.
January	3,7 %	430	1,8 %	1150	64746
February	3,2 %	345	1,9 %	992	52067
March	3,8 %	366	2,4 %	1343	56203
April	5,3 %	431	2,2 %	1519	68040
May	3,4 %	383	1,8 %	1120	61924
June	4,7 %	256	2,7 %	1134	41899
August	2,9 %	273	1,8 %	753	42471
September	5,4 %	464	1,8 %	1254	69369
October	3,6 %	279	2,0 %	896	44086
November	3,1 %	450	1,6 %	1146	70982
December	3,5 %	317	2,1 %	1021	47679
Total		**3994**	2,0 %	12328	**619466**
Average	3,9 %		2,0 %	1120,7	

B.4 Orthopaedic – Benchmark (2-8)

B.4.1 Overtime

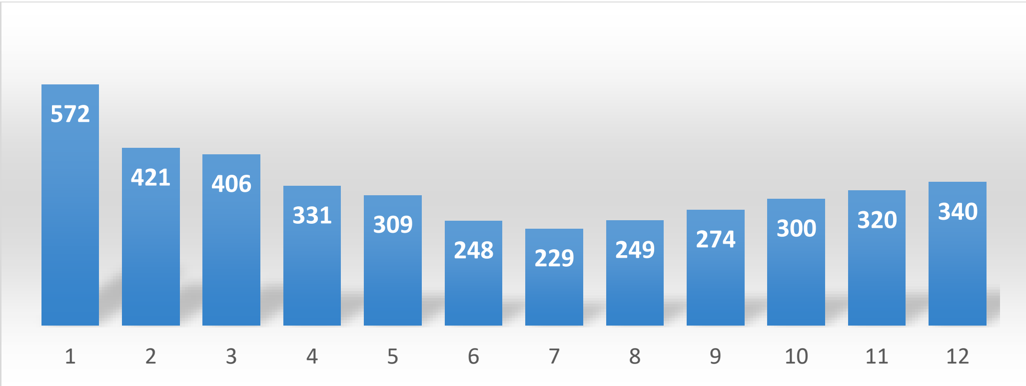
Month	% of op. with overtime	Nr of op in total	% min overtime	Nr. of min overtime	Total min in op.
January	5,5 %	**434**	1,8 %	1178	**65440**
February	5,8 %	**381**	1,0 %	580	**58246**
March	9,3 %	**399**	3,4 %	2073	**61226**
April	8,3 %	**460**	3,3 %	2405	**72253**
May	9,2 %	**412**	2,7 %	1732	**63124**
June	5,0 %	**279**	1,4 %	607	**42317**
August	5,1 %	**293**	1,3 %	521	**41568**
September	4,2 %	**472**	0,7 %	506	**70776**
October	8,7 %	**300**	2,3 %	1108	**48322**
November	8,0 %	**465**	2,4 %	1740	**74026**
December	4,3 %	**352**	0,8 %	408	**51396**
Totalt		**4247**	2,0 %	12858	**648694**
Average	6,7 %				

B.5 General surgery – Simulation 1 (3-9)

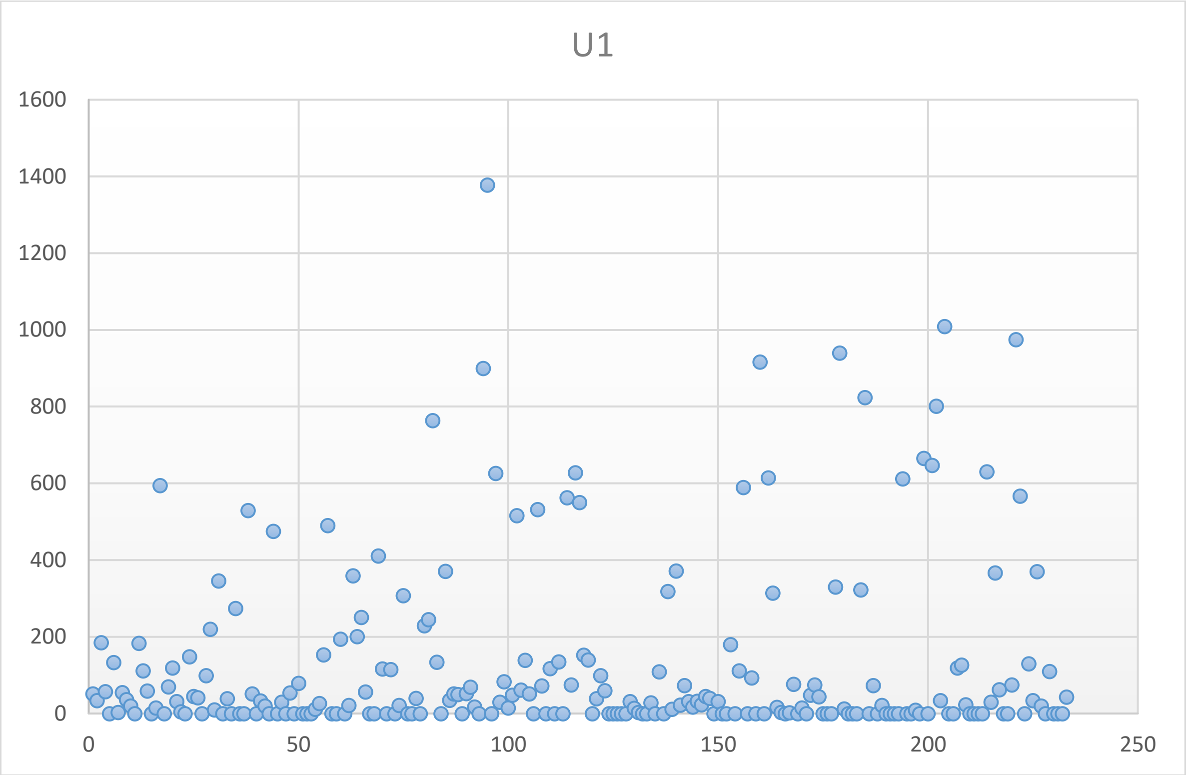
B.5.1 Overtime

Month	% of op. with overtime	No. of op. in total	% min overtime	No. of min overtime	Total min in op
January	3,7 %	430	2,0 %	1268	**64746**
February	3,8 %	345	1,8 %	942	**52067**
March	4,7 %	365	3,0 %	1689	**56191**
April	6,5 %	430	3,1 %	2124	**67933**
May	4,9 %	385	3,8 %	2340	**62377**
June	4,8 %	252	3,5 %	1425	**41070**
August	3,7 %	273	1,7 %	698	**42231**
September	5,2 %	464	2,5 %	1750	**69760**
October	2,9 %	280	1,6 %	685	**43918**
November	4,6 %	452	1,8 %	1308	**71676**
December	5,0 %	318	3,2 %	1522	**47497**
Total		**3994**	2,5 %	15751	**619466**
Average	4,5 %				

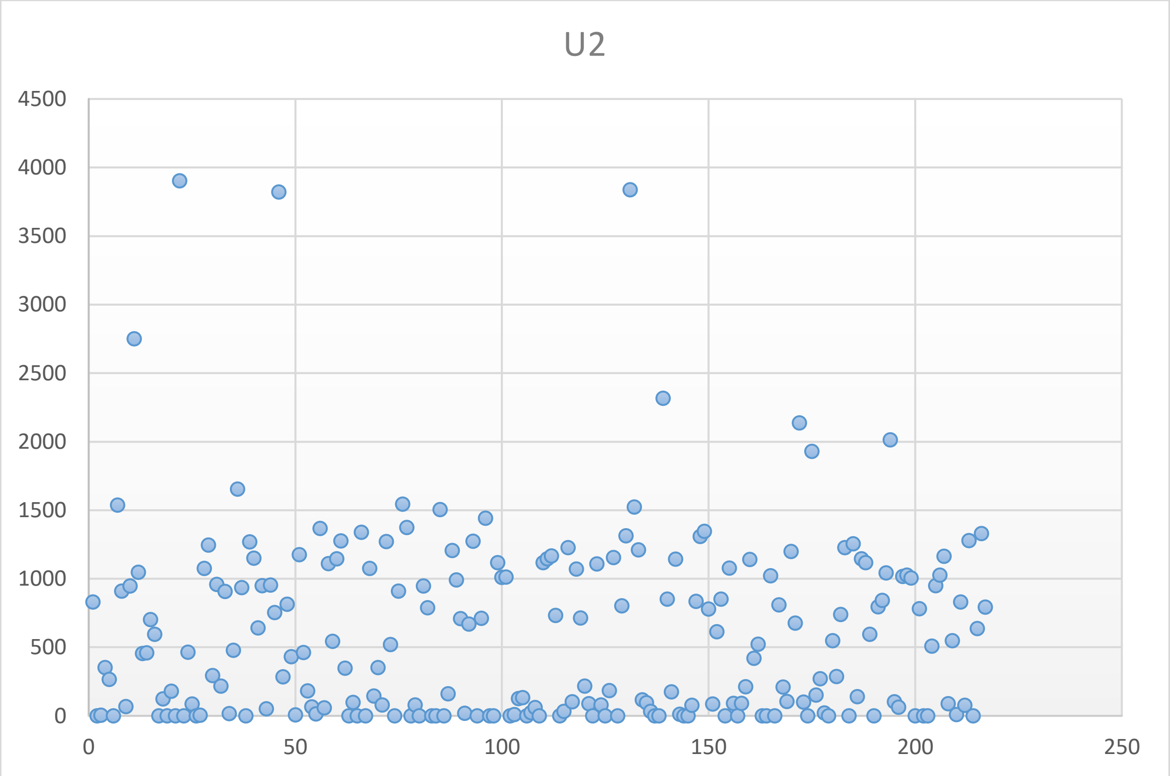
B.5.2 Number of operations per OR (1-3 Short, 4-12 Long)



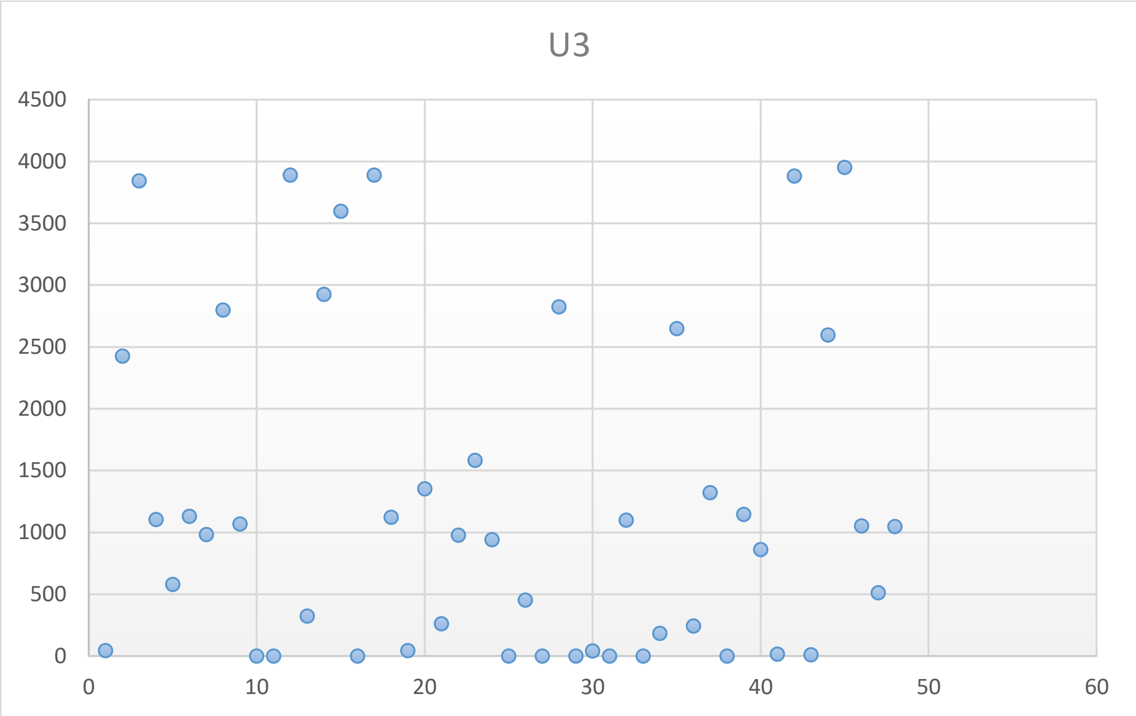
B.5.3 Distribution of waiting U1 patients



B.5.4 Distribution of waiting U2 patients



B.5.5 Distribution of waiting U3 patients

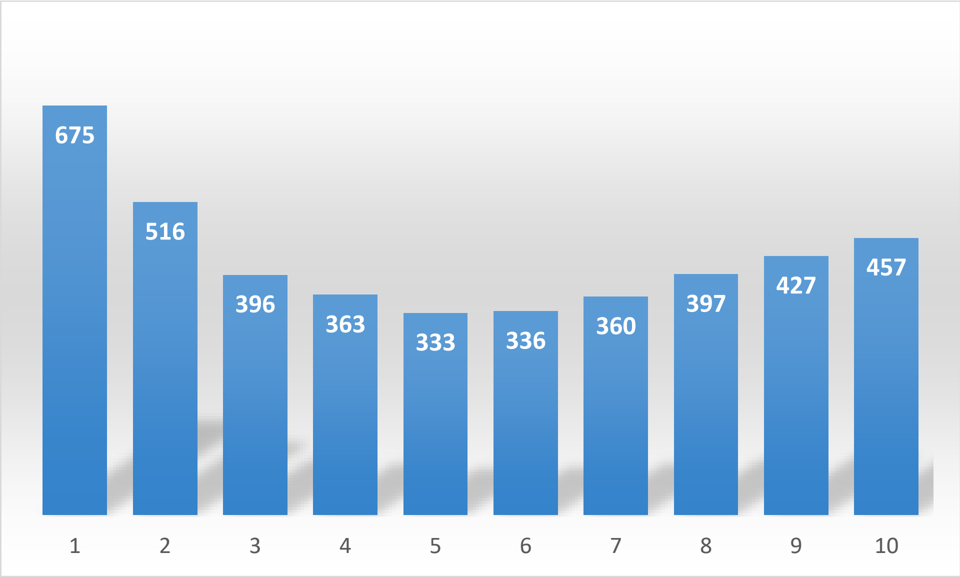


B.6 Orthopaedic – Simulation 1 (2-8)

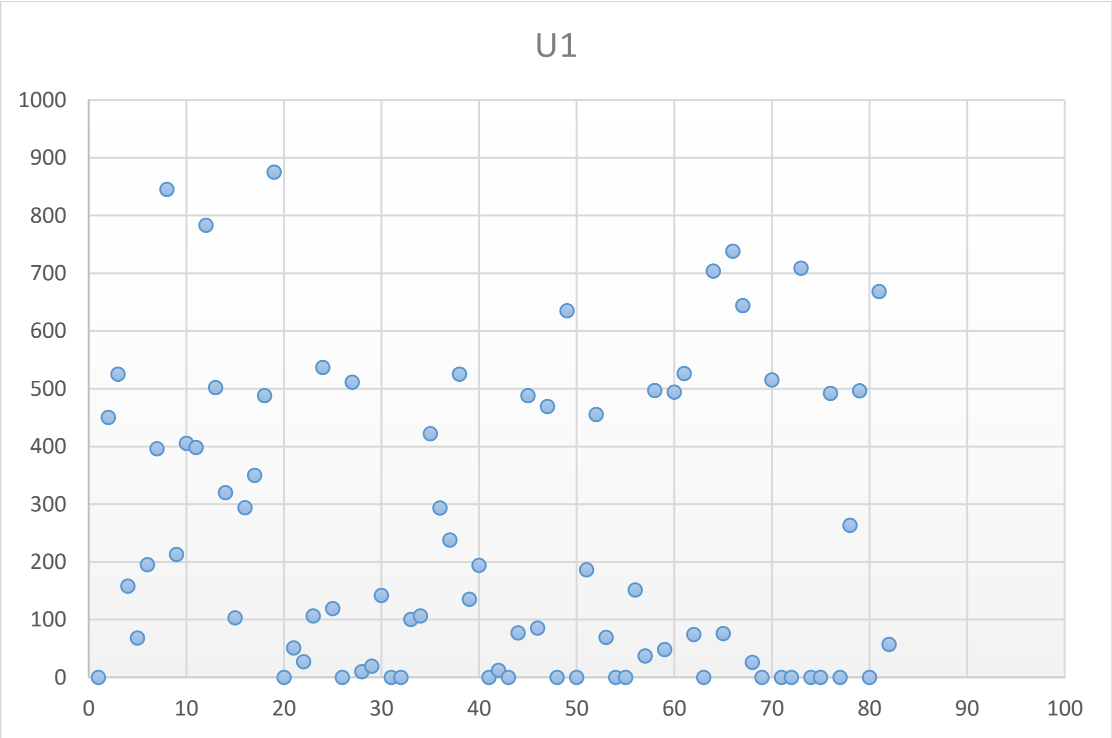
B.6.1 Overtime

MONTH	% of op. with overtime	No. of op. in total	% of min overtime	No. of min overtime	Total min in op.
dec.15				184	1724
January	13,1 %	436	7,6 %	4961	65687
February	15,6 %	391	12,0 %	7318	61153
March	17,3 %	400	9,0 %	5427	60278
April	13,8 %	456	9,3 %	6662	71924
May	12,0 %	399	8,6 %	5260	61510
June	12,5 %	271	6,4 %	2558	40220
August	10,1 %	306	6,9 %	3034	43879
September	11,6 %	475	5,6 %	3997	71138
October	14,2 %	303	6,0 %	2917	48512
November	13,3 %	460	8,6 %	6277	72968
December	9,1 %	339	5,9 %	2917	49701
Total		**4247**	**7,9 %**	**51512**	**648694**
Average	13%				

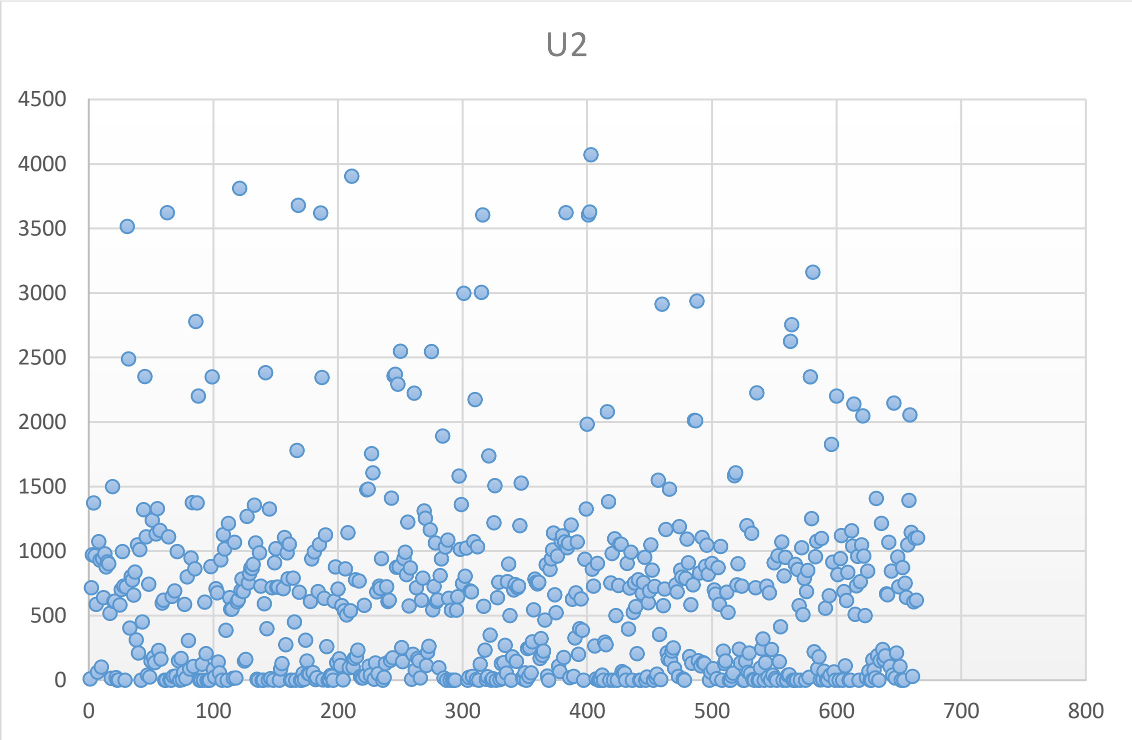
B.6.2 Number of operations per OR (1-2 Short, 3-10 Long)



B.6.3 Distribution of waiting U1 patients



B.6.4 Distribution of waiting U2 patients



B.6.5 Distribution of waiting U3 patients