Integral planning of operating rooms and wards

Tactical allocation of beds to reduce fluctuations in bed utilization for Medisch Spectrum Twente

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Management samenvatting

Aanleiding en doel van het onderzoek

Medisch Spectrum Twente (MST) wil zorg bieden die efficiënt georganiseerd is en waarin de patiënt centraal staat. De afdeling capaciteitsmanagement heeft daarom zich als doel gesteld de efficiëntie van de zorg te verbeteren binnen het MST. MST is bezig met de nieuwbouw van een ziekenhuis. Daarom heeft de afdeling capaciteitsmanagement als taak een brug te slaan tussen het oude en nieuwe ziekenhuis. Een deel van deze brug bestaat uit het verbeteren van patiënten planning, want de huidige manier van patiënten planning past niet in het nieuwe ziekenhuis door een afname in het aantal bedden. Desondanks moet het nieuwe ziekenhuis hetzelfde aantal patiënten kunnen behandelen als dat ze nu doen.

De hoofdoorzaak van de hierboven genoemde problemen ligt in de electieve patiëntenstroom. De electieve patiëntenstroom zorgt voor fluctuaties in bedbezetting en in hollen en stilstaan van verpleegkundigen doordat de patiëntenplanning voor operaties van verschillende specialismen niet op elkaar is afgestemd. In dit onderzoek richten we ons daarom op de tactische capaciteitsplanning van electieve patiënten om afstemming tussen electieve patiëntenstromen van verschillende specialismen te realiseren en een constantere bezetting van verpleegafdelingen te creëren. Hiervoor gebruiken we de volgende doelstellingen:

"Het opzetten van een interventie die de variabiliteit in bedbezetting verlaagt en het creëren van een methode voor de implementatie van deze interventie binnen het MST."

Methode

Als eerste is een context analyse uitgevoerd om patiëntstromen in kaart te brengen, om ervaringen van verpleegkundigen te verzamelen en om de huidige prestaties rondom operatiekamers (OKs) en verpleegafdelingen van het MST te analyseren. Vervolgens is een literatuur onderzoek gedaan naar de oorzaken van fluctuaties in bedbezetting, het creëren van OK roosters en methodes om bedbezetting efficiënt te kunnen organiseren. Door deze analyses naast elkaar te leggen is een interventie geselecteerd die voldoet aan de wensen van het MST. Deze interventie is uitgewerkt en uitgevoerd om de mogelijke verbeteringen in kaart te brengen. Vervolgens hebben we een simulatiemodel gemaakt om de invloed van veranderingen in parameters te analyseren. Voorgaande onderdelen hebben als doel het geven van richtlijnen voor het plannen van patiënten en een stappenplan voor de implementatie van de interventie binnen het MST.

Interventie

Glerum (2014) heeft een Quadratic Assignment Problem (QAP) model ontworpen. Dit model geeft een planadvies aan opnameplanners door middel van een optimale mix van patiënten, gebaseerd op ligduur, binnen een bestaand OK rooster. Hiervoor wordt een deterministische operatieduur en een stochastische ligduurverdeling gebruikt. Wij hebben ervoor gekozen dit model ook te gebruiken voor het MST, omdat het model volgens de resultaten van Glerum (2014) een groot verbeterpotentieel heeft, een goede mogelijkheid biedt om in de praktijk te realiseren en het ziekenhuis vergelijkbaar is.

Resultaten en conclusie

QAP-model: Het hoofddoel van het QAP model is het verminderen van de variabiliteit in bedbezetting. De resultaten laten zien dat de fluctuaties sterk verminderd zijn en dat het maximum aantal benodigde bedden met 29,4% is afgenomen vergeleken met de gerealiseerde situatie van 2014. Het nadeel van het model is dat er meer variatie ontstaat in de OK bezetting.

Simulatiemodel: Het simulatiemodel verhoogt de variatie in bedbezetting vergeleken met het QAP model, maar is wel lager dan de gerealiseerde situatie in 2014. Dit komt waarschijnlijk doordat de ligduur van patiënten in de simulatie meer dan het maximale aantal van 28 dagen uit het QAP model kan zijn. Ook is er meer variatie in de bezetting van OKs dan in 2014. Het maximaal aantal benodigde bedden is met 14,1% afgenomen.

Gevoeligheidsanalyse

Een gevoeligheidsanalyse is uitgevoerd om de invloed van veranderingen in parameters in kaart te kunnen brengen. De volgende veranderingen hebben wij geanalyseerd:

- Invloed van seizoenen: We hebben de invloed van de grootte van de patiëntenpopulatie in de winter en zomer geanalyseerd. De populatie in de winter is groter, maar het verschil in resultaten van het QAP-model is klein. Door een kleinere populatie in de zomer is het nodig het OK rooster te herzien.
- Invloed van veranderingen in de patiëntenpopulatie: Het MST verwacht de komende jaren meer dagbehandelingspatiënten. Dit zal resulteren in een verandering van het OK schema. Deze patiëntengroep is relatief goed te plannen door voorspelbaarheid in ligduur, maar daar is een goede afstemming tussen specialismen voor nodig.
- Invloed van veranderingen in de patiënten mix: Het verplaatsen van langverblijvers (LV) naar de eerste helft van de week of verplaatsen van kortverblijvers (KV) naar de tweede helft van de week resulteert in toenemende fluctuaties in bedbezetting en heeft een negatieve invloed op OK bezetting.
- Invloed van het sluiten van OKs: Het sluiten van OKs lijkt een kleine invloed te hebben op OKs en verpleegafdelingen, maar we hebben alleen de OKs gesloten waarin één of twee patiënten gepland stonden. Het sluiten van andere OKs kan betere resultaten opleveren.
- Het verlagen van OK-capaciteit in QAP model: Het verlagen van de OK-capaciteit in het QAP model reduceert variatie in OK-bezetting en verhoogt OK-bezetting. Invloed op bedbezetting is klein.

Implementatie

We hebben per specialisme regels opgesteld voor het planen van patiënten. De algemene regels zijn:

- Dagbehandelingspatiënten moeten worden verdeeld over de week (ongeveer 16 per dag)
- KV (ligduur <= 1,5 dag) moeten in de eerste helft van de week worden gepland
- LV (ligduur > 1,5 dag) moeten in de tweede helft van de week worden gepland

Vervolgens hebben we aan de hand van literatuur een zeven stappen plan opgesteld voor het implementeren van de interventie.

Overige aanbevelingen

Aan de hand van dit onderzoek zijn de volgende aanbevelingen naar voren gekomen:

- OK analyses laten vaak onderbezetting zien van OKs. We raden het MST aan om onderzoek te doen naar de OK roosters, omdat specialismen misschien te veel OK tijd toegewezen hebben gekregen dan daadwerkelijk nodig is.
- Wij raden de opnameplanning aan de planningsregels te volgen. Dit is alleen mogelijk wanneer de wachtlijsten voldoende patiënten van het juiste type bevatten. Daarom raden wij aan onderzoek te doen naar de relatie tussen wachtlijsten en patiënten mixen.
- Wij raden het MST aan om voor het plannen van patiënten een extra datatype aan te maken. Zodat de opnameplanning kan zien of het om een dagbehandelingspatiënt, korte ligger of lange ligger gaat.

Management summary

Background and scope

Medisch Spectrum Twente (MST) strives for the most efficiently organized care with a centralized position for the patient. Therefore, efficiency improvement is one of the main goals of the MST's capacity department. Additionally, this department creates a bridge between the old and new building to make the reallocation successful. This implies the improvement of patient scheduling, because current processes do not fit in the new building due to a decreased number of beds. Nevertheless, the new building should accommodate at least as many patients as the old building.

MST's main challenge regards the elective patient flow. Elective patient flow causes fluctuations in bed utilization and in workload for nurses, because of insufficient alignment between specialties in surgery related patient scheduling. Therefore, this research focuses on the tactical capacity planning in operating rooms (OR) and wards. It aims to improve the alignment between elective patient flows of different specialties and to reduce fluctuations in bed utilization. Therefore, the research objective is:

"To propose an intervention that reduces variability in bed utilization and to determine the necessary steps for implementing this concept in the organization."

Method

First, we perform a context analysis to describe patient flows, evaluate staff experiences in wards, and to analyze current OR and ward performances in MST. Then we perform a literature research into causes of fluctuations in ward utilization, organization of OR scheduling, and methods for leveling of bed utilization. We select the most appropriate method that fits the requirement of MST based on the context analysis and the literature research. Thereafter, we describe the intervention and do experiments to analyze the improvement potential of this intervention. We expand this intervention with a simulation study to vary experimental settings and to analyze the influence of changes in parameter settings. Finally, we give guidelines for patient scheduling and advise MST about the implementation of the intervention in the organization.

Intervention

Glerum (2014) proposed a Quadratic Assignment Problem (QAP) model for determining the optimal mix of patients for OR scheduling, based on Length-of-Stay (LoS), within an existing master surgery schedule (MSS). The model uses deterministic surgery duration and a stochastic LoS. We decide to use this model for MST as well, because it balances improvement potential and feasibility, and hospital conditions are similar. We prospectively asses this approach with a simulation model that uses the optimal patient mix as input to calculate possible outcomes for MST.

Results

QAP model: The main goal of the QAP model is to reduce variability in bed utilization. Results show a reduction of fluctuations in ward utilization and a reduction in maximum bed requirements of 29.4% compared to 2014. The disadvantage of the model is an increase in variation of OR utilization.

Simulation model: The variation in bed utilization increases when comparing the simulation model to the QAP model, whereas it decreases in comparison to the realized situation in 2014. The variation in

OR utilization increases as well compared to 2014. However, the maximum bed requirement decreases with 14.1% compared to quarter one of 2014.

Sensitivity analysis

We do a sensitivity analysis to test the influence of changes in parameters. The following tests are executed:

- Effect of seasonality: We analyze the influence of the patient population in winter and summer. The population in winter is larger, though differences in outcomes of the QAP model are relatively small. OR schedules need revision due to a decreasing patient population in summer.
- Influence of changes in patient population: MST expects more day treatment (DT) patient in the upcoming years creating a need for revision of the OR schedule. Additionally, this patient group is relatively easy to schedule, although a good alignment between specialties is necessary.
- Influence of changes in case mix: Reallocation of long-stay (LS) patients to the first half of the week or reallocation of short-stay (SS) patients to the second half of the week leads to fluctuations in ward utilization. OR utilization and its variation increase as well.
- Influence of closing ORs: Closing ORs has a small influence on ORs and wards, but we only consider to close ORs in which one or two patients are scheduled. Closing other ORs will probably have more effect.
- Reduction of OR capacity in QAP model: Reducing OR capacity in the QAP model decreases variation in OR utilization and increases OR utilization.

Implementation

We create planning decision rules per specialty for planning of elective patients. These rules will be guidelines for admissions planners. General rules are:

- Spread DT patients over the week (about 16 a day)
- Plan SS (LoS <= 1.5 days) patients in the first half of the week
- Plan LS (LoS > 1.5 days) patients in the second half of the week

Additionally, we create a seven-step approach for the implementation of the intervention. This approach consists of communication, documentation, pilot, pilot evaluation, total rollout, rollout evaluation, and maintenance.

Further research

Recommendations to MST are:

- OR analysis reveals frequent underutilization of ORs. We recommend revision of the OR schedule, because some specialties probably need less surgery time than scheduled.
- Admission planners should follow the planning decision rules whenever there are enough patients available on the waiting lists. We advise MST to analyze waiting lists in relation to the case mix.
- An extra data type is necessary for data storage, since we cannot make a division in patient types out of the current data. Each patient should have a classification of DT, SS, or LS. In this way, admission planners can easily schedule patients according to our guidelines.

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List of abbreviations and terminology

Abbreviations

- BZH Special dental care (in Dutch: Bijzondere tandheelkunde)
- CHI General surgery (in Dutch: Algemene chirurgie)
- DES Discrete Event Simulation
- DT/M10 Day treatment (in Dutch: Dagbehandeling)
- GYN Gynecology (in Dutch: Gynaecologie)
- KCH/OMS Oral and maxillofacial surgery (in Dutch: Kaakchirurgie)
- KNO Ear-nose-throat (ENT) (in Dutch: Keel-neus-oor)
- LoS Length-of-Stay (in Dutch: Ligduur)
- LS Long-stay, LoS > 1.5 days (in Dutch: langverblijvers, ligduur > 1,5 dagen)
- MSS Master surgical schedule
- MST Medisch Spectrum Twente
- NCH Neurosurgery (in Dutch: Neuro chirurgie)
- OOG Ophthalmology (in Dutch: Oogheelkunde)
- OR Operating room (in Dutch: Operatiekamer)
- ORT Orthopedics (in Dutch: Orthopedie)
- PCH Plastic surgery (in Dutch: Plastische chirurgie)
- QAP Quadratic Assignment Problem
- SS Short-stay, LoS <= 1.5 days (in Dutch: kortverblijvers, ligduur <= 1,5 dagen)
- URO Urology (in Dutch: Urologie)

Terminology

BLOKplan	OR planning tool for specialists/specialties
Boarding	Assigning a patient to a bed on a different ward than the intended ward for this patient group
Leveling	Smooth recourse occupancies without peaks
ORsuite	Surgery scheduling tool
Utilization	The amount of time a resource is used against the amount of time a resource is available
Xcare	Admission scheduling tool

Preface

In November 2014, I started my master thesis assignment at MST Enschede, and now, eight months later, this assignment marks the end of my eight years of study. During the first five years of the bachelor Biomedical Engineering I concluded that it was not the study what I was hoping for, although I liked the health care sector. Therefore, I switched to the master of Industrial Engineering & Management with specialization Health Care Technology & Management. In this way, I kept focus on the health care sector. It was quickly clear that I made the right decision. When it was time to search an internship for my master thesis, this research project in Enschede was proposed to me. I had the choice to focus on resource logistics or on patient flows in MST. This was an easy choice, because I have always been more interested in patient flows and I definitely made the right decision.

I believe I am now ready for the next step. I hope my report will have a similar effect for MST, in that it will provide a guideline for the next step in planning for MST. I hope it provides insight in the current situation and the possibilities for tactical planning.

For the past eight months, I really enjoyed working on this research project. Therefore, I would like to thank the people of MST to give me the opportunity to do the thesis. Special thanks to Irma and Thijs, who have answered all my questions to them and have been great supervisors throughout this project. I hope you are pleased with the results. I also would like to thank Judith who gave me all the data.

I also would like to thank Erwin for all the feedback and support. I always came out of our meetings way happier than I went in. Additionally, I would like to thank Gréanne for being a "last minute" stand-in in my committee, rapid answers on emails, and useful feedback.

Not only within the project but also at home, I received support. Therefore, I like to thank Sophie, for motivating me and calming me down when needed. Moreover, I thank Jesper for being my English corrector. And last but definitely not least, I would like to thank my parents, for making it possible for me to study carefree and for supporting me all the way.

I hope you will enjoy reading this report and I am very curious for the achieved results.

Frank Smit

Enschede, July 2015

1 Introduction

Medisch Spectrum Twente (MST) wants to improve their care processes and financial results in 2014 (MST, 2013). For the capacity management department these improvements are related to increased efficiency and quality. In the past decade, the health care sector has had a strong focus on these aspects as well.

High efficiency is desired in operating rooms (OR), because they are the most expensive part of a hospital. However, not improving ward related processes leads to a decrease in efficiency and therefore a decrease in quality. For example, overutilized wards possibly lead to surgery cancellations. A more efficient patient flow and leveled workload can be obtained when ward utilization is included. This results in a higher quality of care. The focus in this research is on leveling of bed utilization and OR scheduling. It is consistent with the vision of the capacity management department: *delivering of efficient organized care with focus on patient processes*. Improvement of OR planning and bed leveling is a small part of the patient process.

This chapter gives a short introduction and motivation for this research. Section 1.1 provides the reader with an overview of developments in the health care sector that forces MST to improve their processes, as well as an introduction to MST. This is followed by the problem description with the core problem in Section 1.2. Section 1.3 describes the objective and scope of the research. Finally, Section 1.4 gives the underlying research questions.

1.1 Context

This section gives the context of the research. First, current developments in the health care sector are described followed by an introduction and characteristics of MST.

1.1.1 Developments in the health care sector

Nowadays, health care expenditures increase every year due to several factors. According to the national government of the Netherlands more care, higher quality, insufficient efficiency of health care, changing epidemiology, and ageing population are jointly responsible (Ministerie van Volksgezondheid, 2012). In 2012, the Netherlands spend 12.4% of the GDP on health care which is relative high compared to the world wide expenditures of 10.1% (WHO, 2012a, 2012b).

Efficiency and quality of care are closely related to each other and also the most common goals to change. A more efficient organized care leads to an improved quality of care. Hospitals should improve efficiency and quality related aspects. However, many improvements are already made in the past decade. Professor Bakker, of Academisch Medisch Centrum Amsterdam, has mentioned in 2009 that hospitals are function oriented whereas they should be more process oriented (Te Lindert, 2009). Additionally, the communication within a hospital is insufficient. A specialty in a hospital can be efficient at its own, whereas the hospital can be inefficient as a whole when a lack of communication between specialties occurs.

Diagnose treatment combinations (in Dutch: DBC) are introduced in 2005 and the intent changes over the years. A DBC is a standardized price for a care path of a patient. Hospitals negotiate with insurance companies before they can treat patients. These negotiations lead to a contract with prices and volumes for treatments. Insurance companies prefer volumes with a good price/quality ratio. Therefore, a hospital should deliver work in an efficient way to increase interests, since higher interests lead to an increased turnover. This creates a cycle, starting with high expenditures for health care and a possible reduction of these expenditures at the end (see Figure 1). DBC focus on efficiency which on its turn improves the quality of care.

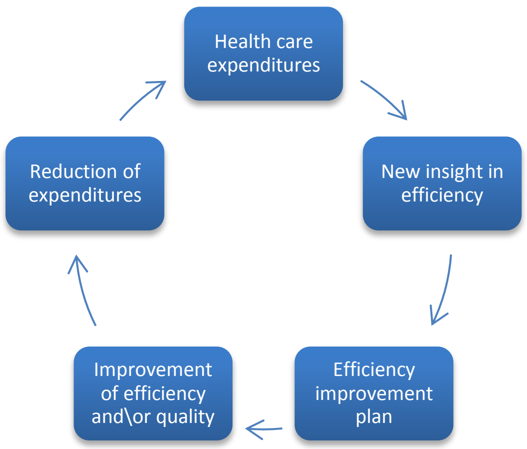

Figure 1: Circle of expenditures reduction by improving efficiency/quality.

1.1.2 Medisch Spectrum Twente

MST will open their new hospital building in Enschede in 2016 and will then be one of the largest non-academic hospitals in the Netherlands. MST consists of four different locations, namely the hospital locations in Enschede and Oldenzaal and outpatient clinics in Haaksbergen and Losser. It has a service area of approximately 264.000 people. Location Enschede focuses not only on the basic facilities, but also on the top-clinical facilities. The organization consists of approximately 2.900 employees, among which 230 medical specialists. In addition, there are 468.000 outpatient visits, 33.000 day-care treatments and 31.000 admissions each year (MST, 2014). The new MST has 670 beds available against 702 in the old situation.

In 2012 MST started with a new project for continuous improvement in the quality of care called “3S” (Samen Slimmer Systeem). This project evaluates the process of employees through the eyes of the patient. In this way, quality is monitored and the patient is in a more centered position. In addition, MST pays extra attention to patient satisfaction by extending opening hours, shortening waiting lists, and providing better information and aftercare (MST, 2013). Over the next few years, MST will provide patients with more information about the quality of care in terms of quality indicators.

Finally, the focus for the upcoming one/two years will be on the relocation to the new hospital building. Employees should be well prepared and some processes have to be improved, for example logistics, to increase the quality of care (MST, 2013). Therefore, the capacity management department plays an important role. The aim of the department is to match the demand and supply of care in the interest of mainly patients, as well as for MST itself and employees.

1.2 Problem description

In the current situation, about 60% of the patients visiting an outpatient clinic are referred to the OR. The planning of the particular patient starts when a patient is sent to the OR. A patient does not get a date for surgery immediately, because of waiting lists and unpredictability in health care. Nowadays, a lot of information is available, such as waiting times. Therefore, patients decide which hospital is most suitable for them. This results in a “shopping” culture.

If the predictability of OR schedules improves, the quality of care increases and the chance of losing patients decreases. This sounds easy in theory, but a patient is very complex in terms of predictability. No patient is the same and this leads to differences in surgery duration and Length-of-Stay (LoS). Scheduling further in advance introduces other problems. The chance of disturbances increases when the period between the moment of scheduling and the actual time of surgery increases. This research intends to find a compromise between short-term and long-term scheduling.

To cope with unpredictability, it is necessary to have knowledge about treatment pathways in terms of historical data. In the tactical planning phase, allocation of capacity over specialties takes place. Forecasting of OR schedules improves if all available knowledge is used in this phase, which might lead to a reduction of variability in bed utilization. In addition, managing utilization is easier when there is more flexibility in capacity allocation. This allocation can be successful if the communication between departments is sufficient and if the OR planners anticipate to a changed situation. The alignment between and control of OR and bed utilization is insufficient in MST. A nurse of pediatrics experiences situations as *"all or nothing"*.

In this research we focus on the tactical level of OR planning and especially on bed utilization at location Enschede. MST has to deal with variability in bed utilization. These fluctuations lead to differences in workload for employees. If the peak utilization is high, the possibility of an admission stop increases, as well as surgery cancellation rates. To match the aim of the hospital and the vision for the new hospital, it is necessary to level bed utilization. We describe the core problem as follows:

The core problem of this research is:
The alignment between and the control of bed utilization is insufficient. Therefore, the elective patient flow increases variability in bed utilization.

1.3 Research objective and scope

The OR is the most expensive department in a hospital. However, only considering OR planning without optimizing bed utilization leads to possible problems in the OR as well, because an admission stop can arise and thereby surgery cancellations might occur. Therefore, it is necessary to take in consideration the OR planning and ward planning to level variability in bed utilization. Especially since the new MST has a decreased number of hospital beds. The research objective is as follows:

The objective of this research is:
To propose an intervention that reduces variability in bed utilization and to determine the necessary steps for implementing this concept in the organization.

This research focuses on elective patient flows from the admission department to the OR and finally to the ward of MST location Enschede. To achieve the objectives the tactical part of resource capacity planning in the framework for health care planning and control is used (see Table 1). Emergency patients are excluded, because they cannot be planned in advance. Non-surgical patients are excluded as well, since they are not part of the surgical process. The interventions are obtained by comparing the current situation with the literature. Section 1.4 provides an outline of the research.

Table 1: Framework of health care planning and control (Hans, Van Houdenhoven, & Hulshof, 2012).

	Medical planning	Resource capacity planning	Materials planning	Financial planning	
Strategic	Research, development of medical protocols	Case mix planning, capacity dimensioning, workforce planning	Supply chain and warehouse design	Investments plans contracting with insurance companies	↑ Hierarchical decomposition ↓
Tactical	Treatment selection	Block planning, staffing, admission planning	Supply selection, tendering	Budget and cost allocation	
Offline operational	Diagnosis and planning of an individual treatment	Appointment scheduling, workforce scheduling	Materials purchasing, determining order sizes	DRG billing, cash flow analysis	
Online operational	Triage, diagnosing emergencies and complications	Monitoring, emergency coordination	Rush ordering, inventory replenishing	Billing complications and chance	
	← Managerial areas →				

1.4 Research questions

To achieve the research objective we formulate several research questions. Each question corresponds to a chapter. This part gives the outline of the report. Each chapter answers corresponding sub-questions. The main questions are answered in the final conclusion.

Chapter 2: Context analysis

Chapter 2 gives an overview of the current situation. The main question for this chapter is formulated as follows:

How can the current OR and ward planning be described and what is the current performance?

Necessary information regarding this question is obtained by meetings with employees. This leads to an up to date description about the current situation at MST. To find an answer on the main question, Section 2.1 describes the key-figures of the planning process and organization of OR/ward planning. Section 2.2 summarizes meetings with the heads of the wards. In Section 2.3, you will find performance indicators, which is followed by the performance analysis in Section 2.4. Section 2.5 describes the core problem. Chapter 2 answers the following sub-questions:

- 2.1 Which key-figures can be identified in the planning process and how is OR and ward planning currently organized?
- 2.2 How do wards experience current performances?
- 2.3 What performance indicators can be identified?
- 2.4 What is the current performance?
- 2.5 What is the core problem, what are the consequences, and what factors influence the problem?

Chapter 3: Literature Research

Chapter 3 describes the relevant literature. This literature is based on the following question:

What concepts are mentioned in the literature to organize the core problem(s)?

Section 3.1 starts with causes of fluctuations in bed utilization according to the literature. In Section 3.2, you will find possible concepts for leveling of utilization. Finally, Section 3.3 gives the best intervention for our situation. The following sub-questions are used:

3.1 What causes high fluctuations in bed utilization?
3.2 How can OR planning on a tactical level be organized to level bed utilization?
3.3 What improvement concept is applicable for the situation at MST?

Chapter 4: Intervention

Chapter 4 is used for the intervention. The following question supports the process behind the intervention:

How can the current organization be improved to anticipate and reduce variability in bed utilization?

Section 4.1 is about the modeling approach. To setup an experiment we need experimental settings that can be found in Section 4.2. Finally, Section 4.3 shows the modeling output and comparison with the current situation. The following questions are applied:

4.1 How can we model the intervention?
4.2 What experiment settings do we use?
4.3 How does the model operate?

Chapter 5: Simulation study

Chapter 5 describes the simulation mode. This model is used to test the outcome of the model in Chapter 4. The following question is used:

How does the output of the model in Chapter 4 perform according to a simulation?

Chapter 5 uses the methodology of Law (2007). Each section of this chapter corresponds with one of the steps of this methodology. The following questions are used the answer the main-question:

5.1 How can we simulate the process of MST by using the output of the intervention?
5.2 What experiment settings do we use?
5.3 How does the simulation operate?

Chapter 6: Sensitivity analysis

This chapter gives insight into the consequences of changes in parameters. We will test some changes that can occur in reality by using the following question:

What is the influence of changes in parameters on the performance of ORs and wards?

Chapter 7: Implementation

When a suitable intervention is found, the intervention has to be implemented. Chapter 7 provides MST with suggestions to organize the proposed interventions by using the following question:

How can the implementation phase be organized to implement the proposed interventions?

Chapter 8: Conclusion and recommendations

The last chapter covers the conclusion, limitations, and suggestions for further research.

2 Context analysis

This part describes the current processes in and performances of MST. The analysis is obtained by analyzing OR and ward related processes. In this way, the problem(s) is (are) identified and input for an adequate model is created. Section 2.1 starts with the patient flow, because this determines the fluctuations in MST. The next section explains the ward related problems according to head of wards. Section 2.3 explains what performance indicators are used to evaluate the current process. Section 2.4 describes the current performance. Finally, Section 2.5 gives the core problem.

2.1 Patient flow

Different patient flows lead to difficulties in the planning process. Therefore, it is necessary to draw these flows and to describe the actors in this process. There are two main flows in the process, namely the elective and emergency flow. The elective flow enters the preoperative screening (POS) and is planned centrally or decentrally. The emergency flow directly enters a ward or OR. Figure 2 visualizes these patient flows. Each actor in process is explained in the remainder of this section.

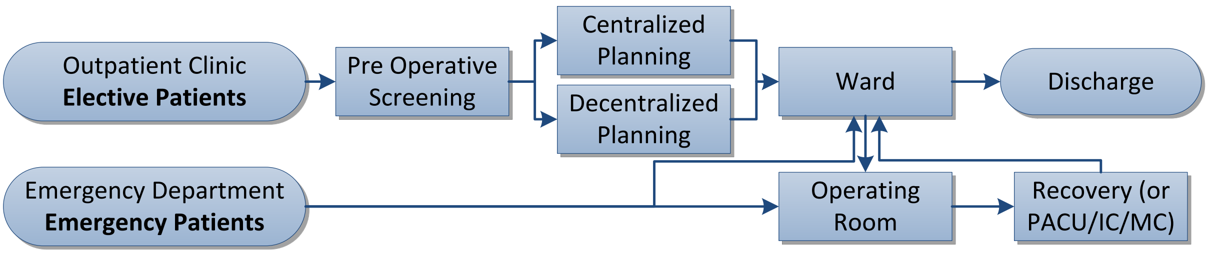

Figure 2: OR related patient flow through MST.

2.1.1 Outpatient clinic

The outpatient clinic functions as consultation for the patient with any specialist. Therefore, the clinic is the starting point of the care path of elective patients. If the patient needs surgery, he/she will be placed on the waiting list and referred to the preoperative process. In case of a medicine patient, the patient will be planned on a bed for possible further research.

2.1.2 Emergency department

The emergency department functions as starting point for emergency patients (non-elective). Thereafter, the right specialist will be assigned to the patient and, if necessary, a surgery follows. This patient stream is difficult and actually impossible to schedule in advance, but a planner schedules capacity based on historical data.

2.1.3 Preoperative Screening

The POS collects relevant information about the patient by a questionnaire and informs the patient about the surgery. Depending on the outcome of that questionnaire, the patient may need an extra consult with an anesthesia assistant and anesthetist or physician assistant. The status is set as completed when the patient meets the required surgery condition.

2.1.4 Centralized planning

Information for this and the next section (2.1.4 and 2.1.5) is obtained from Dekker and Spenkelink (2014). They gave an extensive description of the current planning process in MST.

The admission planning (in Dutch: Bureau Opname) is part of preoperative process. This department schedules surgeries for surgical specialties and the department is centrally organized. The different specialties that are planned centrally are general surgery, gynecology, ear-nose-throat (ENT) surgery, ophthalmology, orthopedics, plastic surgery, and urology.

The program ORsuite is used for scheduling of patients. This program shows which specialist operates in which OR and at what time. All these aspects are imported out of BLOKplan. The medical secretaries put the availability of a specialist in BLOKplan. With this program, the admission planning plans ahead for six weeks. Moreover, the admission planning takes into account the rules for elective patient scheduling. Examples of these rules are the amount of permitted similar operations on one day, availability of resources, availability of beds and preferences of specialists. Another factor is related to time scheduling, namely the amount of time that should be scheduled in total and the amount of time that should be scheduled for emergency patients.

Each week there is a meeting about the surgeries in the week after with the aim to finalize the OR schedule. The day coordinator of the OR decides if the schedule fits, whether there are enough beds available and whether the required resources are present. Every specialty has their own characteristics according to the scheduling process. Therefore, each specialty will be described in the upcoming sections.

General surgery

General surgery consists of three subspecialties, namely traumatology, vascular surgery, and oncology. These patients are scheduled in a short time horizon or placed on a waiting list, but this depends on the urgency. Oncology patients are always planned within five weeks, because of a heavy emotional surgery. Additionally, if a patient has been scheduled in a certain block then the date of surgery will not be changed as well. These standard blocks are fixed for carotid surgery, liver surgery, thoracotomy, lobectomy, and whipple.

Gynecology

This specialty focuses on secondary obstetric care and gynecological care. The gynecology department has an outpatient OR in VKC (Vrouw Kind Centrum), but uses the general ORs as well. This specialty has a small amount of emergencies, but all of these should be incorporated in the scheduling process. In addition, oncology patients should be scheduled within five weeks. Caesarean patients have priority as well. However, in an emergency caesarean will be scheduled for one hour at the end of the elective schedule. Empty slots in the OR schedule are filled with patients from the waiting list. There is a possibility for patients that another specialist will perform the surgery such that the waiting list decreases in size.

ENT surgery

ENT surgery performs surgeries related to ear, nose, and throat. This specialty is relatively easy to schedule, because there is a small amount of emergency patients and the entire group consists of a high amount of children. Children are in general healthy and therefore easier to treat. The specialists of this department can do almost all surgeries of another specialist within this department. Therefore, waiting lists can be leveled and it is easier to predict a surgery date for patients.

Ophthalmology
Ophthalmology surgeries focus on eye disorders. Most of the surgeries for ophthalmology are in outpatient clinics in Oldenzaal. Surgery is in Enschede if it cannot be performed by the use of drop anesthesia. Ophthalmology has an OR capacity of two days per month. Due to small OR capacity, there are long waiting lists for some surgery types. Specialists do not do each other's surgeries within this specialty, because of possible difficulties. Therefore, the opportunity to decrease waiting lists is low.

Orthopedics
Orthopedic surgeries focus on the entire musculoskeletal system. Many fluctuations in the patient flow are present, for example emergencies and seasonality. Nowadays, waiting lists for orthopedics are short and there still is OR time left. However, departments are afraid to lose their OR time permanently thus the free time will not be given to other departments. Therefore, these other specialties are not able to decrease their waiting lists using the empty slots of orthopedics.

Plastic surgery
Plastic surgery focuses on cosmetic surgery, reconstructive surgery, hand surgery, and wrist surgery. Weekly the four specialists have one OR and each of them focuses on their own patients. They seldom have patients of other specialists, because each of the four has their own capabilities. Additionally, due to clinics at different locations it is difficult to schedule plastic surgeons at another moment in time. This specialty has to deal with emergencies as well. Frequently occurring emergencies are tendon injury and have priority over elective patients.

Urology
This specialty focuses on disorders in kidneys, ureters, bladder, prostate, urethra, and male genitalia and is located in VKC. The amount of emergencies is small and is caused mainly by oncology and urinary retention. There are reserved time slots for emergency surgeries in the upcoming two to three weeks. This specialty has a relative short waiting list, because its specialists are able to do each other's surgeries. In addition, if there is OR time left, urologists can use this time to decrease their waiting list. Waiting lists for children's surgeries are relatively long, because these surgeries are performed with a specialist from another hospital.

2.1.5 Decentralized planning
Specialists who are scheduled decentrally are part of special dental care, stomatology, and neurosurgery. The medical secretary of the corresponding department schedules these patients. The role of admission planning is only to communicate the final appointment with the patient. The following sections describe characteristics of each specialty that is schedule decentrally.

Special dental care
Special dental care focuses on patients who cannot be treated by their own dentist. Oldenzaal takes care of outpatient treatments, Enschede performs clinical and outpatient treatments. All specialists have common skills, but do not take over a patient from another specialist. Therefore, some waiting lists are longer than others. Special dental care hardly any emergency or oncology patients. If there is an oncology patient, he/she will be referred to oral and maxillofacial surgery (OMS).

Oral and maxillofacial surgery

This specialty treated disorders in jaw and facial skeletal, and focuses on hard and soft tissues. Oncology patients need a treatment within five weeks. The amount of emergency patients for this specialty is low. Therefore, there is no OR time reserved for them. If an emergency patient arrives, an already scheduled elective patient will be cancelled. In addition, waiting lists for this specialty are long. The specialist notes whether another specialist will be allowed to operate the patient.

Neurosurgery

Neurosurgery is related to surgical treatment of disorders in the nervous system. MST treats patients out of the whole region Twente. Scheduling of these patients depends on the sequence on the waiting list and urgency, because emergency patients have higher priority. Due to a large amount of emergency patients, scheduling is done over a small time horizon. When patients are scheduled over a longer period, the number of cancellations increases and these cancellations are difficult to reschedule. Neurologists do not operate patients from other neurologists except for emergency patients. However, some specialists have a shared waiting list for corresponding patients. MST tries to reallocate the scheduling process of this specialty centrally.

2.1.6 Ward and OR

MST will start with reallocation to the new building in 2015/early 2016, which should be completely in use mid-2016. A revision of the OR schedule will be necessary in order to achieve this, because the current schedule leads to high fluctuations in bed utilization and thereby fluctuations in workload. Another option is to reallocate patients in another way without revision of OR schedule by scheduling patients based on their LoS in the current OR schedule. The current work process does not fit into the new situation due to a decreasing number of hospital beds. This section describes the structure of wards and the OR department in the old and the new situation.

Ward

Table 2 gives insight in the old and the new situation of wards. The ward of VKC is still the same in the new situation, but the general ward decreases with 80 beds. However, 11 more specific beds are available in 2016. We only focus on the surgical wards, because they are OR related.

Table 3 gives an overview of the surgical wards in the old situation.

Table 2: Number of beds in the old situation (2013), new situation (2016) and the difference between the situations.

Bed type	2013	2016	Difference
General	409	329	- 80
Specific	103	114	11
VKC	123	123	0
Day care	48	66	18
Outpatient clinic beds/chairs	19	38	19
Total	702	670	- 32

Table 3: Capacity of each ward in the old situation (2013).

Department	Specialty(s)	# of beds
General – A3	General surgery, oral and maxillofacial surgery	33
General – A5	Orthopedic surgery, trauma surgery	33
General – B4	Neurosurgery	33
General – C3	General surgery, plastic surgery	32

General – C5	Day care, short stay	33
VKC – K3	Pediatrics, ophthalmology, special dental care, urology	8
VKC – K4	Urology, ENT, gynecology	30
Total		220

The structure of wards in the new situation will change completely. There will be three floors with wards and the general intensive care (IC-A) and medium care (MC) will be located on the third floor near the ORs. Each floor will have single rooms which will be divided over different specialties. Therefore, each floor will have a spot division. Appendix A shows a map of each floor. Overlapping spots imply that a specialty is able to use capacity of another specialty, by which each department will have flexible capacity. The patient will obtain a centered position and the ward division is based on a horizontal collaboration between nurses and a vertical collaboration between specialties. Table 4 shows the location of each specialty. The available number of beds is not included, because the amount of beds is unclear yet and the capacity is flexible. VKC will continue with the same capacity at the same location.

Table 4: Location of wards in the new situation (2016).

Floor	Specialty(s)
4	Oncology
4	Genecology oncology
Unknown	Urology oncology
4	Vascular surgery
4	Orthopedics
4	Trauma surgery
5	Long oncology
6	Internal medicine
6	General surgery
6	Other surgery (eye, plastic)
6	Neurosurgery
VKC – K4	Genecology
VKC – K4	Urology, ENT
Total	

OR

The structure of the new OR complex will be comparable with the old situation. The old situation contained four ORs for thoracic surgery, whereas in the new situation one OR of thoracic surgery will be replaced by a shared OR for general and thoracic surgery. However, the idea is that day treatment surgery will be in a separate location and will stay in the old building with its own ward and ORs. This is currently in the development phase.

Table 5: Number of ORs in the old situation (2013) and new situation (2016).

OR type	# of ORs 2013	# of ORs 2016
General surgery	11	11
General surgery and thoracic surgery	-	1
Specific thoracic surgery	4	3
Outpatient surgery	1	1
Total	16	16

Currently, these ORs are scheduled according to a repetitive schedule of 4 weeks. This schedule is revised four times a year, but the changes in this schedule are minimal. As mentioned before, each week there is a meeting for the OR schedule of next week to complete the particular schedule. Nowadays, it is tried to schedule patients according to a fixed quota. This means that the number of scheduled patients should be within predefined boundaries.

2.1.7 Recovery

After surgery, the patient enters recovery. The patient is moved to the IC/MC if the patient needs intensive care. The recovery period is used to monitor the patient is able to control vital physical mechanisms. Afterwards the patient is relocated to the ward of corresponding specialty if his/her condition allows.

2.1.8 Discharge

If the physical condition is recovered to a specific level, the patient will be discharged. Depending on this condition, the patient goes home or to another location for extra medical care.

2.2 Problem identification in wards

It is necessary to identify ward related problems if we want to improve the current situation. A meeting with heads of wards was organized to identify these problems and they gave us possible solutions as well. The following sections describe the situation of each ward based on these meetings.

2.2.1 B4

Due to variety in the OR schedule (a double OR session on Monday and Thursday) the outflow of the OR is variable as well. This variability leads to fluctuations in ward utilization, but this can be dealt with by aligning the right amount of personnel. The ward planning is based on the elective patients and not on emergency patients. Moreover, the amount of pain patients leads to difficulties, because the length of stay is unclear and they need high-level care.

B4 uses 28 out of the 33 available beds. The remaining beds are used for emergency patients, because these should always be helped at B4. They can allocate patients at to the neurology department if there is lack of available resources at B4. The admission of patients is between 7:00 a.m. – 8:00 a.m. and is done by two nurses. However, all patients arrive in this period, so the waiting times often increase. Patients who are admitted on Monday will be discharged on Wednesday (if possible) and the patients who are admitted on Thursday will be discharged after the weekend. In this way, care paths of three, four or five days are created.

2.2.2 C3

C3 has to deal with variability in bed utilization and peak demand on Thursday, because of an extra OR on that day. Furthermore, many changes occur after the definitive OR schedule has been made. Another problem is related to PTA (in Dutch: Percutane Transluminale Angioplastiek) and DSA (in Dutch: Digitale Subtractie Angiografie) patients, since they have another care level. About one (PTA/DSA) patient is admitted a day. Finally, the definition of emergency patients is unclear. This causes confusion, because it is not clear if a patient needs treatment immediately or can be treated later.

C3 can handle three or four patient admissions a day, but there are about seven admissions on Thursday. An extra nurse is used to cope with this peak demand. Due to admissions, the workload in the morning is higher compared to the rest of the day.

2.2.3 C5/A3/A5

C5, A3 and A5 participated together in one meeting and discussed their wards with each other before our meeting. Difficulties arise in scheduling due to different flows from elective patients, IC, other hospitals, outpatient clinic, and acute admissions. If there is an extra OR available, the planners first consider the availability of a surgeon and second the length of a waiting list, but they do not consider the number of available beds. A fifth OR is preferred at the beginning of the week, but most of the time these wards have four ORs. Also the surgery throughput might vary over different specialists. Therefore, the outflow to wards will increase if specialists with a high throughput are scheduled at the same time.

The wards gave some preference related to scheduling of patients. First, diabetes patients should be divided over the week, because of their care level. Secondly, short stay patients of C5 have to be scheduled in the beginning of the week, since in C5 only short stay patients and day treatment patients need to bed scheduled. If the short stay patients are scheduled at the end of the week, the ward can probably not be closed on Saturday. This implies that more day treatment patients have to be scheduled at the end of the week. C5 is the day treatment ward and most of the patients have a relatively short LoS. This ward consists of 33 beds and they have about 20 new admissions a day. Additionally, A3 and A5 both have a capacity of 33 beds as well, but deal with only three or four new admissions a day.

2.2.4 K3

The main problem in K3 is the combination of different specialties (mainly pediatrics, but also ophthalmology, special dental care, and urology). It is possible that many different specialties have an OR in the beginning of the day, which increases the workload. In addition, the number of ORs differs throughout the week with peak moments on Wednesday and Thursday. A solution could be to plan less patients on Tuesday to be sure that there will be enough capacity on the next two days. However, this might lead to unoccupied beds. Additionally, the decentralized planning departments often are too late with their planning and many schedule changes are made during the week.

There are eight day treatment beds available, but the ward uses clinical beds up to a maximum of 13 beds when the demand is higher. In exceptional circumstances, C5 will be used for allocation of the older children (16/17 years).

2.2.5 K4

This ward consists of three specialties, namely ENT, gynecology and urology. Therefore, the OR schedule varies and the outflow of the OR leads to fluctuations in bed utilization. All three specialties have different care levels, which affects the workload. Moreover, there are peaks of utilization when the amount of oncology patients is high. Therefore, these patients should be divided over the week. In addition, oncology patients are patients with an extended LoS. ENT patients can be used for “filling”, because these patients have a relatively short LoS and low care level.

Gynecology and urology patients arrive at 7:00 a.m. and ENT patients arrive at 6:45 a.m. In K4 there are 30 beds available and 27/28 beds are used for elective patients. The other beds are reserved for emergencies. If there is a shortage of available resources, C5 is used as back up.

2.3 Performance indicators

Performance indicators are a useful measure to quantify the performance of ORs and wards. Cardoen et al. (2010) mentioned eight performance indicators: waiting time, throughput, utilization, leveling, makespan, patient deferrals, financial measures, and preferences. We defined indicators based on these eight indictors as well as the problem analysis above, the ORdashboard and already defined indicators of MST. We divided the indicators into two categories, namely OR and ward specific indicators.

2.3.1 OR

OR related indicators give insight in the performance of ORs. Due to a performance analysis, OR staff knows if adjustment should be made and if the current process functions according to their preferences. Performance indicators for the OR are:

- *Utilization* is the amount of time a resource is used against the amount of time a resource is available (Cardoen, Demeulemeester, & Beliën, 2010). ORs can be over or underutilized. Unnecessary costs are the consequence if an OR is underutilized. However, overtime and cancellations are the consequence of fully planned ORs without buffer. We describe this indicator as percentage utilization.
- *Throughput* is the amount of treated patients per time unit (Cardoen et al., 2010). Hospitals try to have a high throughput, but not to the expense of quality. High throughput in the ORs might have negative results in wards, because the workload of nurses increases if the throughput increases. However, increasing throughput indirectly leads to shorter waiting times. We defined number of surgeries as indicator for throughput.
- *Makespan* is the time between the first entrance of a patient and exit of the last patient on one day (Cardoen et al., 2010). However, an individual patient has a makespan as well, because it is the time between admission and discharge. Hospitals try to minimize the makespan. This leads to more patient satisfaction and possible higher throughput. Length of surgery time describes the makespan.
- *Leveling* means smooth resource occupancies without peaks (Cardoen et al., 2010). This indicator is useful in wards, because fluctuations in bed utilization probably lead to admission stops or boarding and thereby surgery cancellations. It is hard to react on fluctuations in terms of resources (i.e. employees), especially when utilization varies over a day. This results in a process of all or nothing. We describe leveling as variation in utilization.

2.3.2 Ward

Ward related performance indicators are necessary for our research as well, because the main goal is to level ward utilization. The following indicators describe the performance of wards:

- *Utilization,* besides being performance indicator for ORs, describes the performance of wards as well. Therefore, percentage utilization is used again.
- LoS is the counterpart of surgery time. Therefore, we select LoS to describe the *makespan* of wards.

- The *throughput* for wards is defined as the number of admitted and discharged patients. Additionally, we use the moment of admission and discharge as performance indicator.
- *Leveling* in wards is described as the variation in utilization.

2.4 Data analysis

Different factors influence the utilization of wards and ORs. First, we will describe the division of patients over different specialties and what type of patients needs surgery. OR related factors consist of the amount of time a specialty has available and how much of that it actually uses. For example, ward performance is described by the utilization and its corresponding variation.

We use the coefficient of variation (CV) to give insight in the variability. It is given by the following formula:

$$CV = \frac{\sigma}{\mu}$$

The CV is a dimensionless quantity since the standard deviation is scaled by the mean. Therefore it is independent of the unit corresponding to the quantity we are calculating the CV for. This makes CV very useful for comparing variability of different specialties and wards, each having their own different mean. Though the disadvantage is that the CV is large for means close to or equal to zero. Therefore, we draw conclusions carefully if the mean is close to zero.

2.4.1 Patient population

12861 patients underwent surgery in the period from 01-05-2013 to 30-04-2014. The percentage of patients per specialty is given in Figure 3. General surgery has the highest amount of patients, namely 40%. However, this amount consists of a sub-division of three specialties: traumatology, vascular surgery, and oncology. Orthopedics obtains a high percentage as well (19%) and consists of orthopedic patients only.

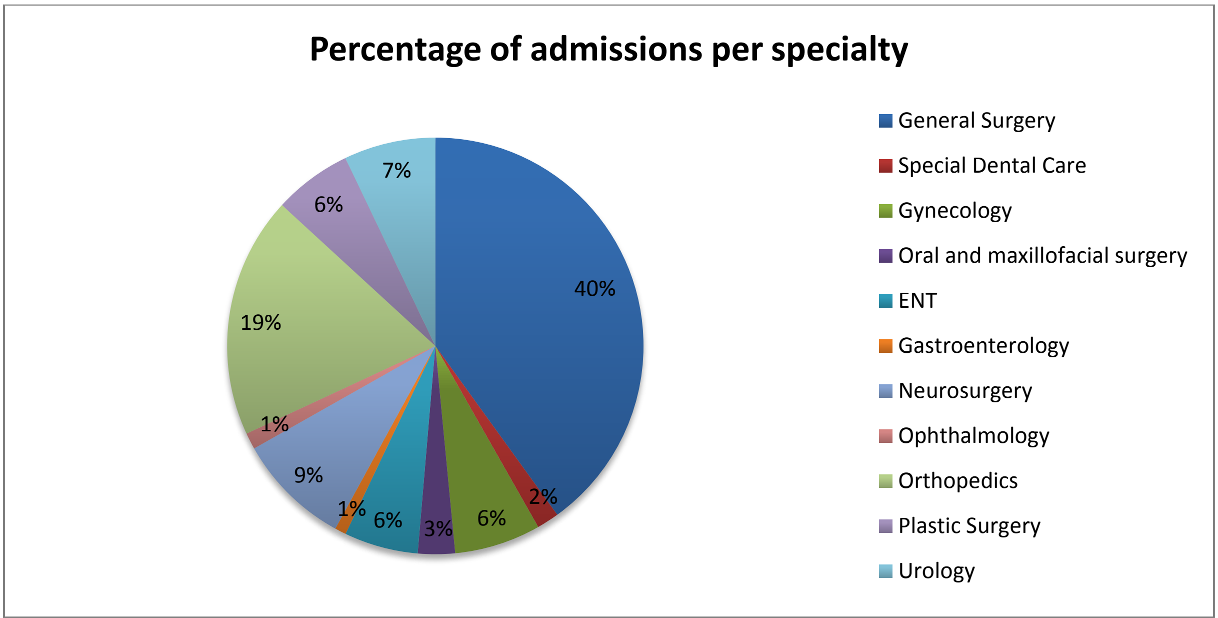

Figure 3: Percentage of admissions per specialty during 01-05-2013 to 30-04-2014, n = 12861, source: ORSuite.

Each specialty treats different patient types. We divided each specialty into elective and emergency patients. Both types are sub-divided in clinical patients and day treatment patients (M10). Figure 4 shows the percentage of patient types within each specialty. In this figure each specialty sums up all patients of that particular specialty, giving a total of 100%. Combining this with Figure 3, 100% of general surgery in Figure 4 means 40% of the total patient population. According to Figure 4 the ratio of elective M10, elective clinical, and emergency patients differ per specialty. Therefore, the OR schedule should incorporate these differences to align different specialties to each other, especially when a ward consists of different specialties.

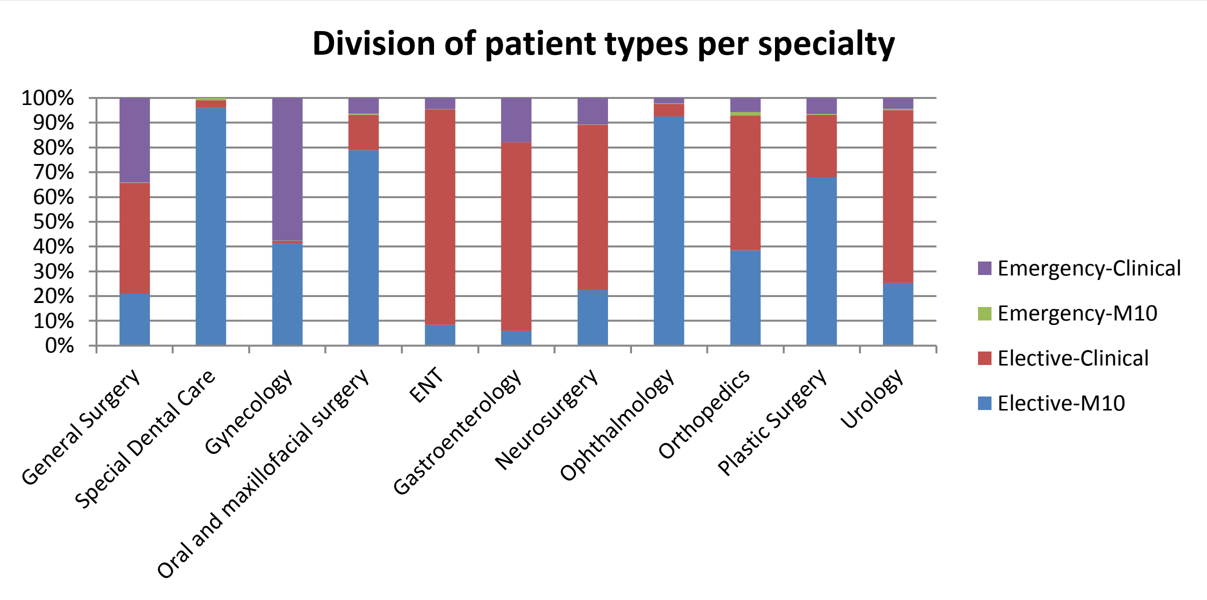

Figure 4: Percentages of patient types per specialty during 01-05-2013 to 30-04-2014, n = 12861, source: ORSuite.

From Figure 4, it can be concluded that the amount of emergency M10 patients is close to zero. Therefore, we grouped these patients together with emergency clinical into one group of emergency patients. Table 6 gives insight into the statistics for the number of emergency patients. The number of emergency patients increases during the week and the variability is the lowest at the end of the week.

Table 6: Number of emergency patients per weekday during 01-05-2013 to 30-04-2014, n = 2217, source: ORSuite.

Day	Mean	St. dev.	CV
Ma	6,92	2,38	0,34
Di	6,65	2,27	0,34
Wo	7,74	2,78	0,36
Do	7,60	3,37	0,44
Vr	9,81	2,38	0,24

2.4.2 OR analysis

Each specialty gets their own amount of OR time based on their number of patients. Figure 5 shows the percentages of the total available OR time per specialty during one year. These percentages are comparable to the percentages of admissions in Figure 3. The differences originate for example in the surgery duration. A specialty with more complicated and longer surgeries needs more surgery time. Neurosurgery on average takes longer than surgeries of other specialties and therefore obtains a higher percentage of OR time compared to their percentage of patients.

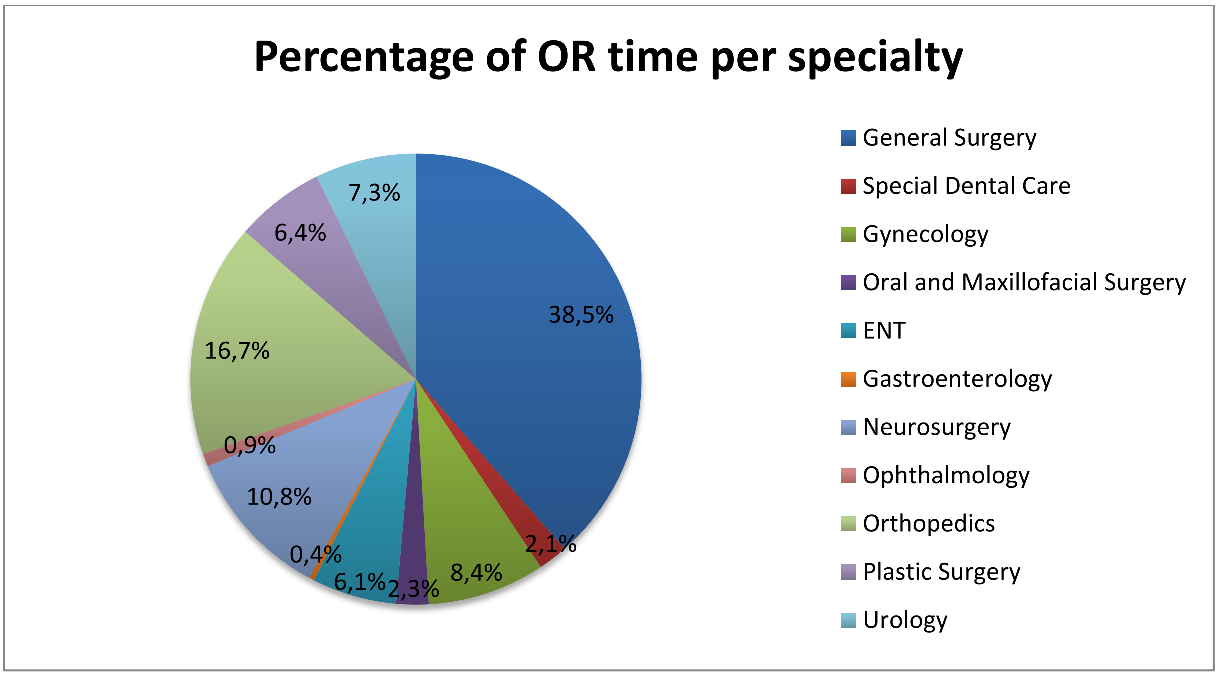

Figure 5: The amount of OR time per specialty of a total 22535 hours during 01-05-2013 to 30-04-2014, source: BLOKplan.

Specialties get their amount of OR time, but this does not mean that the total available time is used. Figure 6 shows the utilization of OR time. Utilization of many specialties is close to 90%. However, special dental care, OMS, ENT, and ophthalmology are close to 80%. A percentage of 20% of their OR time remains unused. It is remarkable that almost every specialty has about 10% or less unused OR time.

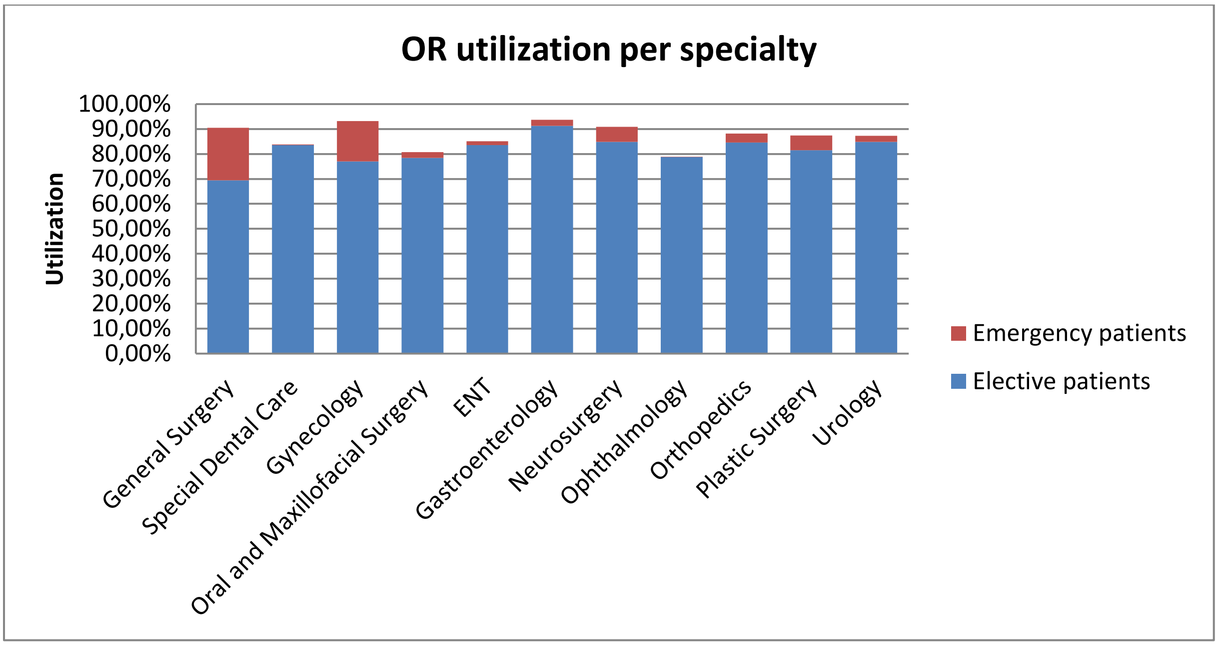

Figure 6: Average utilization of OR time during 01-05-2013 to 30-04-2014, source: ORSuite & BLOKplan.

There is variation in utilization of ORs, but the CV is low for almost all specialties. The highest variation occurs for the elective patient flow of plastic surgery. Gastroenterology has relatively high variation as well. The difference between the elective flow and the elective + emergency flow is very small. We can conclude that the emergency flow has a small influence in OR utilization. Therefore, we have to review the elective patient scheduling process if we want to change OR utilization.

Table 7: Coefficient of variation for utilization of ORs per specialty.

Specialty	CV Elective	CV Elective + Emergency
General Surgery	0,20	0,17
Special Dental Care	0,13	0,13
Gynecology	0,24	0,25
Oral and Maxillofacial Surgery	0,15	0,16
ENT	0,18	0,18
Gastroenterology	0,28	0,27
Neurosurgery	0,19	0,20
Ophthalmology	0,17	0,17
Orthopedics	0,13	0,13
Plastic Surgery	0,31	0,33
Urology	0,23	0,22

The OR utilization is mainly determined by the surgery duration. Figure 7, Figure 8 and Figure 9 give an overview of the surgery duration for all specialties. All patient types have a right-skewed graph like a lognormal distribution. Elective M10 patients have an average surgery duration of about 54 minutes and a standard deviation of 25 minutes.

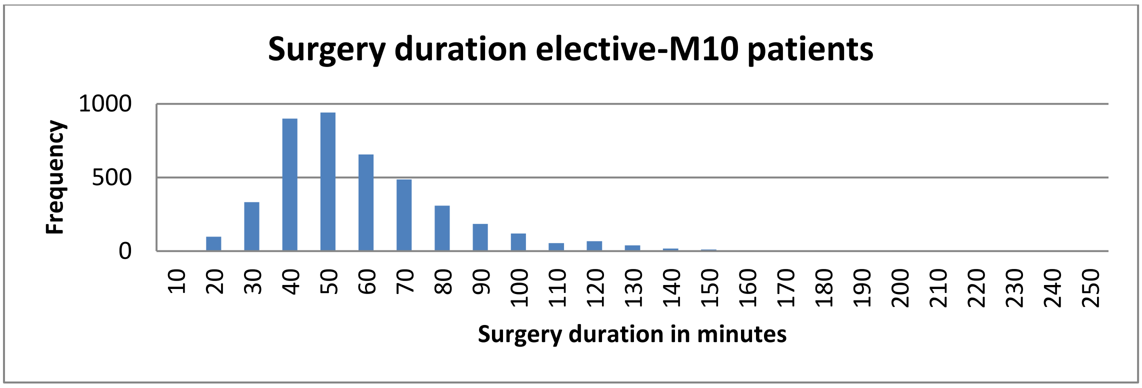

Figure 7: Surgery duration for elective-M10 patients of all specialties during 01-05-2013 to 30-04-2014, n = 4251, source: ORSuite.

The frequency of elective clinical patients is more spread out. The average duration is about 108 minutes with a standard deviation of 68 minutes. These people have probably a higher care level due to longer surgery durations.

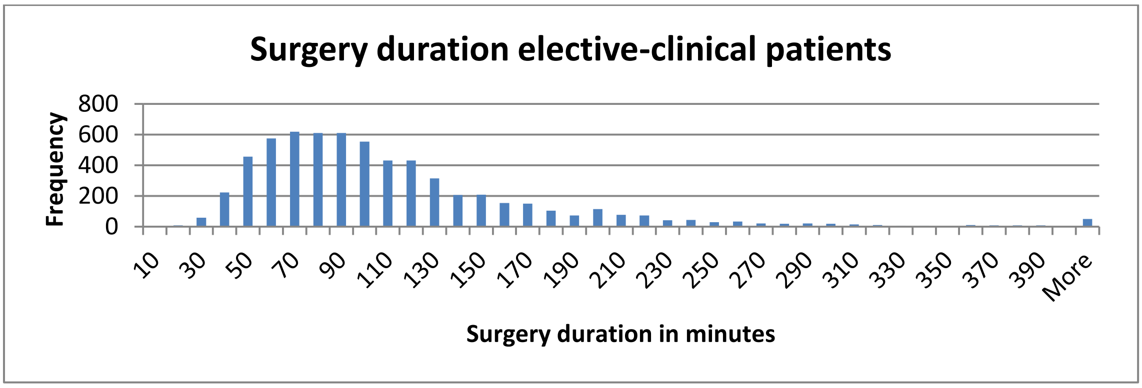

Figure 8: Surgery duration for elective-clinical patients of all specialties during 01-05-2013 to 30-04-2014, n = 6393, source: ORSuite.

The distribution of Figure 9 is comparable with Figure 7, but the frequency is higher for longer surgery durations. Emergency patients have an average surgery duration of 79 minutes and a standard deviation of 48 minutes. M10 patients often have a lower care level than clinical or emergency patients. Therefore, it is plausible that the surgery duration is lower as well.

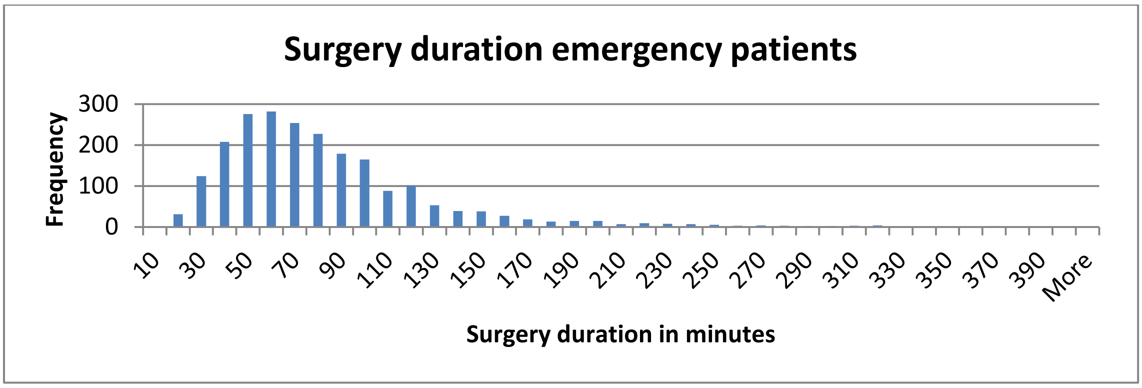

Figure 9: Surgery duration for emergency patients of all specialties during 01-05-2013 to 30-04-2014, n = 2217, source: ORSuite.

2.4.3 Ward analysis

Ward utilization starts with admission of patients and ends with discharge. We made these moments insightful by analyzing the data of elective patients over one year. Figure 10 shows a peak of admission at 8:00 p.m. and a peak of discharge at 12 p.m. and 15 p.m.

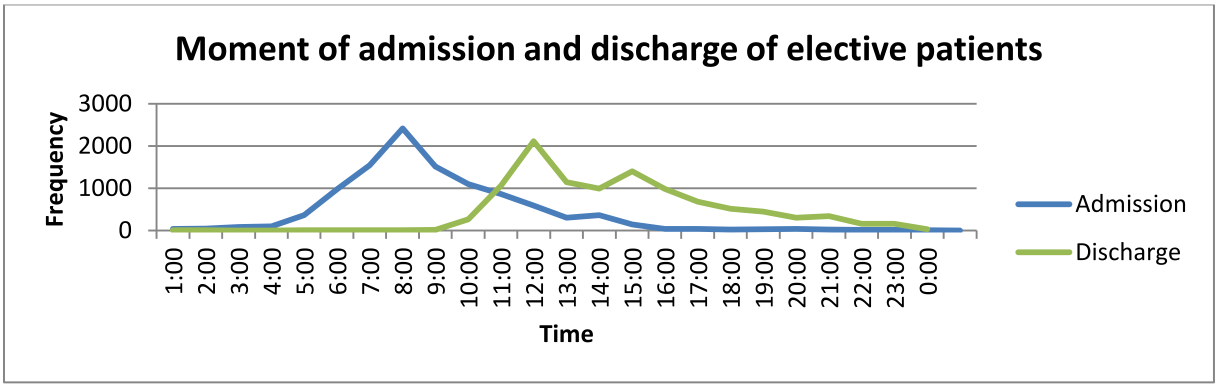

Figure 10: Frequency of admission and discharge at each hour of all elective patients during 01-05-2013 to 30-04-2014, n=10642, source: Xcare.

The emergency flow is hard to regulate, because of its unpredictability. In Figure 11, you can see that the admission of emergency patients is leveled over the day. This flow does not fluctuate the workload of nurses that much, because of evenly distributed admissions.

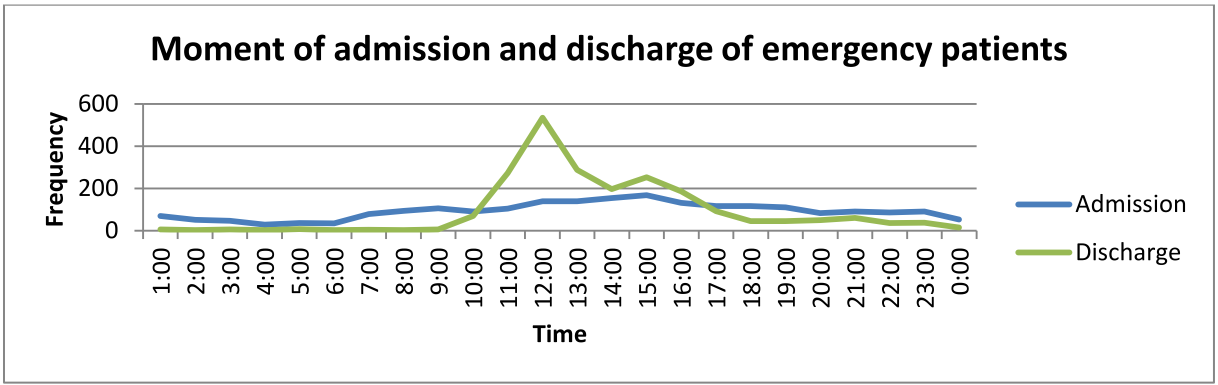

Figure 11: Frequency of admission and discharge at each hour of all emergency patients during 01-05-2013 to 30-04-2014, n = 2219, source: Xcare.

We have to analyze the variation in wards in more detail to create an intervention that fits the requirements of MST. Figure 12 shows the utilization of wards. You can see that the variation of C5 (day treatments) is the highest. C5 and K3 are the only wards that exceed their maximum capacity of 33 and 8 beds. However, we did not consider the reuse of beds on the same day, which is probably the fact in C5. C5, K3, and K4 consist of different specialties and have a relatively large dispersion in utilization. Therefore, the alignment between specialties is probably insufficient.

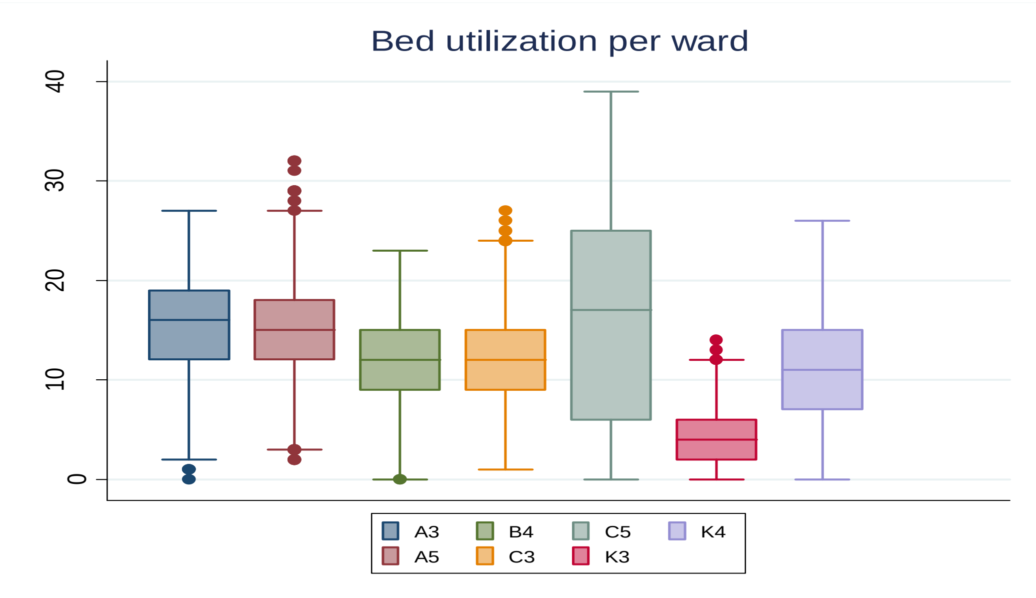

Figure 12: Boxplot of the bed utilization in wards during 01-05-2013 to 30-04-2014, n = 12861, source: Xcare & ORSuite.

We will analyze ward utilization in more detail. Therefore, we created Table 8 with a statistical overview of the wards per patient type. The total CV for C5 and K3 is relatively high compared to the other wards. However, other wards obtain fluctuations as well. This is consistent with the boxplot of Figure 12. The variation for emergency patients is high as well, but the mean is small. Therefore, the impact of this flow is relative small. Elective clinical patients increase the fluctuations at the C5 and K3, because of their high value for CV. Elective M10 patients increase variability at the C5 and K3.

Table 8: Mean, standard deviation, and CV for utilization per ward per patient type during 01-05-2013 to 30-04-2014, n=12861, source: Xcare & ORSuite.

Ward	Elective M10			Elective Clinical			Emergency			Total		
	Mean	St. dev	CV	Mean	St. dev	CV	Mean	St. dev	CV	Mean	St. dev	CV
A3	0,06	0,23	4,06	13,27	5,02	0,38	1,97	1,93	0,98	15,30	5,17	0,34
A5	0,11	0,41	3,83	13,15	4,40	0,33	1,68	2,13	1,27	14,93	5,30	0,36
B4	0,20	0,57	2,85	10,13	4,16	0,41	1,66	1,32	0,80	11,99	4,30	0,36
C3	0,04	0,25	6,03	8,88	3,41	0,38	3,45	2,77	0,80	12,37	4,70	0,38
C5	8,72	6,88	0,79	7,16	5,72	0,80	0,34	0,59	1,74	16,21	11,00	0,68
K3	1,84	2,09	1,14	1,43	1,45	1,01	1,13	1,15	1,02	4,40	2,94	0,67
K4	0,90	1,35	1,50	9,33	4,56	0,49	0,66	0,82	1,24	10,89	5,31	0,49

We mentioned earlier that the number of patients does not exceed the maximum capacity in most wards, but Appendix B shows that many wards treated patients of another specialty. This means that there are boarded patients and thereby probably overutilized wards or incorrectly marked treatment codes, though medical patients can cause boarding as well. Appendix C shows the utilization per ward during the first quarter of 2014. You can see that there are fluctuations in each ward during this period. These figures also show the number of admissions during this period. It seems like the curves of utilization and admissions match. The correlation coefficient between admission and utilization confirms this, especially for C5, K3, and K4 (see Table 9). We can tentatively conclude that, when we regulate admissions we can regulate the utilization of wards.

Table 9: Correlation between utilization and admissions in wards during 01-05-2013 to 30-04-2014, n = 10642, source: Xcare.

Ward	Correlation coefficient
A3	0,38
A5	0,49
B4	0,56
C3	0,41
C5	0,94
K3	0,89
K4	0,76

Figure 13 shows the LoS of elective M10 patients. M10 patients are day treatment patients and discharge will be on the same day as admission. However, the figure shows patients with a longer LoS than one day. These patients fluctuate the utilization, because it was not the intention to treat them longer than one day. The average LoS of day treatment patients is 0.44 days with a standard deviation of 0.43 days.

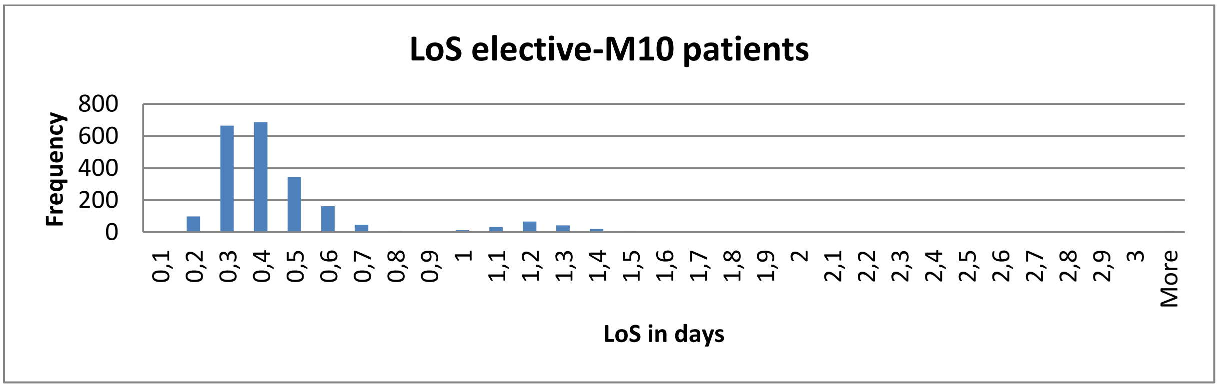

Figure 13: Length of stay for elective day treatment patients during 01-05-2013 to 30-04-2014, n = 4251, source: Xcare.

Elective clinical patients have an average LoS of 3.9 days with a standard deviation of 6.0 days. Figure 14 shows the LoS of these patients. Most patients leave the hospital within 1.5 days (one night) followed by on 2.5 days (two nights). Patients with a short LoS could be classified as short stay (SS, <= 1.5 days) and the other patients as long stay (LS, > 1.5 days). However, a small group of patients has a LoS of 0.8 days and they are actually M10 patients.

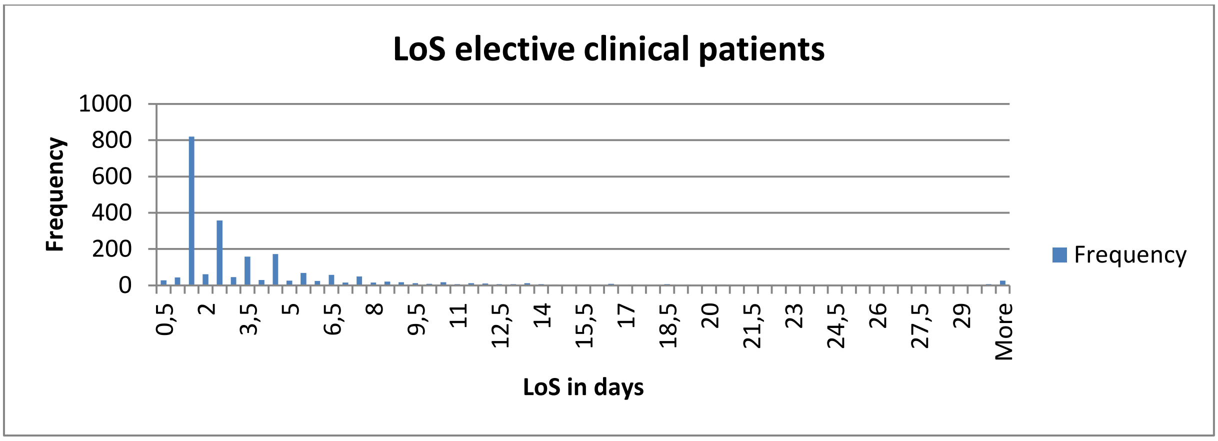

Figure 14: Length of stay for elective clinical patients during 01-05-2013 to 30-04-2014, n = 6393, source: Xcare.

Emergency patients are M10 and clinical. Figure 15 shows the distribution of emergency patients with an average LoS of 6.3 days and a standard deviation of 9.5 days. The LoS of emergency patients is relatively long compared to clinical patients.

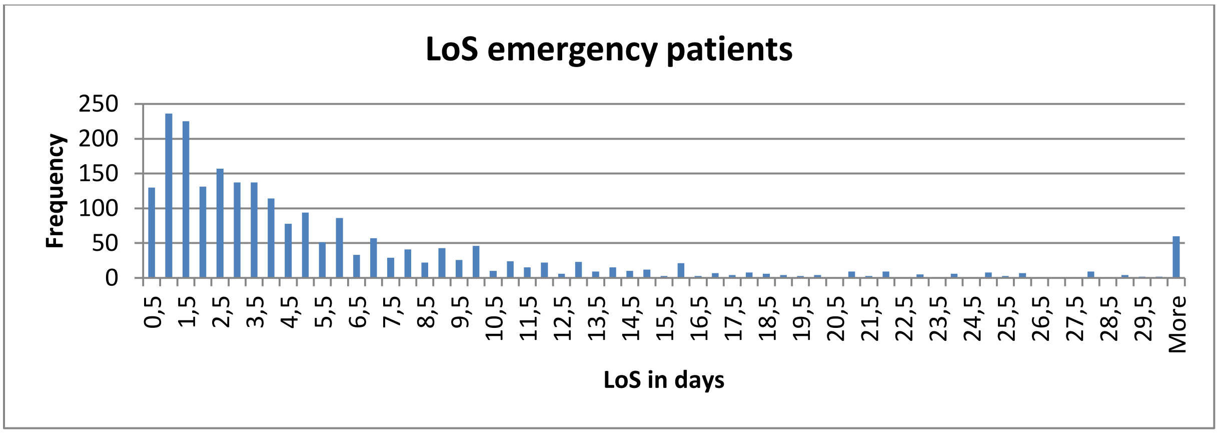

Figure 15: Length of stay for elective day treatment patients during 01-05-2013 to 30-04-2014, n = 2217, source: Xcare.

M10 patients are discharged at the day of surgery if we assume that M10 patients do not stay overnight. Therefore, the admissions of this patient group should be constant to level ward utilization. Figure 16 shows the admission of M10 patients during one quarter at weekdays. We conclude that it is far from constant and the alignment between specialties is insufficient.

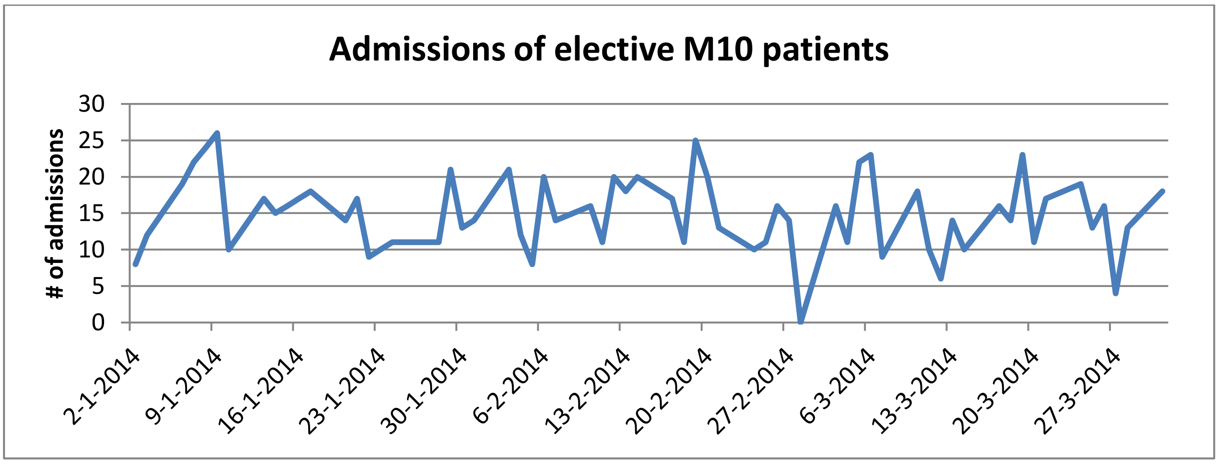

Figure 16: Number of M10 admissions each day during 01-01-2014 to 31-03-2014 at weekdays, n = 935, source: Xcare.

2.5 Problem analysis

The meeting with heads of wards and data analysis gives us insight in the current processes. The core problem can be stated as:

Variability in bed utilization is too high.

This problem is not a problem itself, but is caused by several other factors. These factors are sub-problems and can be identified as follow:

- Insufficient alignment between specialties in scheduling of patients
- Insufficient alignment between wards and scheduling of patients
- Insufficient alignment between specialties and wards
- Insufficient synchronization between admission and discharge
- Bad division of OR time over days and specialties
- Scheduling of patient types

Data analysis identifies fluctuations in the elective stream. Moreover, the alignment between specialties is insufficient in for example M10 patients. The patient flow can be more constant if the patient flow per specialty is more stabilized, if alignment between other specialties is improved or if there is more/better communication between wards and the patient scheduling process.

Other sub-problems are identified in the meetings with heads of wards and are not directly identified in the data analysis. It seems that specialties get a preference position in OR time scheduling, This is because specialties of one ward get too much OR time at the same day while dividing the OR time of these specialties over different days decreases demand on that particular ward. Additionally, some patient types need a specific care level and should be divided over the week, such as oncology patients.

2.6 Conclusions

The following questions and corresponding answers conclude this chapter:

2.1 Which key-players can be identified in the planning process and how is OR and ward planning currently organized?

The planning process of MST is divided in centrally and decentrally organized planning. Centrally organized planning consists of an admission desk that plans patients for general surgery, gynecology, ENT surgery, ophthalmology, orthopedics, plastic surgery, and urology. Decentrally organized planning plans patients for their specialty itself. Special dental care, stomatology, and neurosurgery belong to this process.

2.2 How do wards experience current performances?

Ward staff experiences the current performance as "all or nothing", especially in wards in which many specialties are located. Ward planning needs more attention in the patient scheduling process to reduce fluctuations in ward utilization. It is hard to align central and decentral processes and the admission planning does not know what the consequences of their planning are on the wards.

2.3 What performance indicators can be identified?

Performance indicators are subdivided in OR and ward related indicators. We use utilization, makespan, leveling, and throughput as main indicators and these indicators are subdivided into sub-indicators.

2.4 What is the current performance?

We conclude that fluctuations in bed utilization are too high. Many wards treat patients of different specialties. Therefore, they are strongly dependent on the alignment/communication between specialties. The example of M10 admissions shows a highly fluctuated graph, as shown in Figure 16, and thereby insufficient alignment between patient scheduling process and wards/ORs. The emergency flow does not have a large influence on fluctuations in ward utilization. Mainly the elective patient flow introduces fluctuations.

2.5 What is the core problem, what are the consequences, and what factor(s) influences the problem?

We identify alignment/communication between different stakeholders as root cause for our main problem. This results in fluctuations in ward utilization. These problems arise in the admission scheduling process of elective patients.

3 Literature research

Historically required rights play a major role in current hospital organizations (De Bruin, Nijman, Caljouw, Visser, & Koole, 2007). This result in misbalance between the actual needs and what is delivered. Hospitals see waits, delays and cancellations as inevitable and regrettable part of the care process (Haraden & Resar, 2004). They try to cope with delays by adding resources, but this increases the misbalance much more. These options are no longer available due to savings in healthcare. However, according to Haraden and Resar (2004) delays are not a resource problem, but a flow problem. Well-organized care will improve the patient flow. Therefore, this literature research reflects on bottlenecks in patient flow and which solution approaches can be identified related to the problems identified in Section 2.5.

The beginning of each section explains which keywords we used to obtain the information for that particular part. We used the literature review by Litvak and Long (2000), Agnetis, Coppi, Pranzo, and Sbrilli (2013) and Van Oostrum (2009) as starting point. This leads to a subdivision of our literature research in causes of fluctuations in patient flows & health care processes and organization of OR planning to level bed utilization. From there we selected other articles out of the reference list. If there was still an information gap, we tried to find information using search terms related to that gap. These terms are given at the beginning of each section. Google Scholar and Scopus are used to obtain the literature.

To regulate patient flows, we have to know the causes of fluctuations and knowledge about fluctuation management. According to Litvak and Long (2000) variability is the key determination factor for fluctuations. Therefore, Section 3.1 describes variability in patient and health care processes. Section 3.2 explains how OR planning can be organized and how to incorporate bed leveling to cope with these fluctuations. It is followed by choice of the intervention and a conclusion in respectively Section 3.3 and Section 3.4. Readers who already have knowledge about these subjects can continue with Chapter 4.

3.1 Variability

Patient flow – Fluctuations – Managing – Variability – Variation – Causes of fluctuations

Hospitals deliver care for patients with different types of diseases. All these types have different characteristics with respect to the patient flow. In addition, each disease delivers their amount of fluctuations in utilization. Harper and Shahani (2002) mentioned variability as a factor that influences patient flows. Variability arises due to for example differences in LoS or surgery duration. Litvak and Long (2000) divided variability in natural and artificial variability.

According to Litvak and Long (2000) natural variabilities are clinical, flow, and professional variability. Patients with the same disease have differences in degree of illness, choices for treatments, and responses to treatments. In addition, medical practitioners deliver care in different ways. Natural variability cannot be eliminated, but it has to be managed in the best possible way (Litvak & Long, 2000). The best way to manage this group of variability is by creating homogeneous groups. These groups are compiled by using the disease type or severity.

Artificial variability is described as non-random, non-predictable, and driven by individual priorities (Litvak & Long, 2000). Moreover, this type of variability outweighs variation caused by randomness of disease presentation. Artificial variability increases when managing of variability dysfunctions. According to Litvak and Long (2000) variability in OR utilization is caused for 80% by elective scheduled patients. The variation is not related to unexpected changes, but to the introduction of artificial variation into the system. This form of variation is easier to eliminate, for example by revision of schedules. However, improving patient flows cannot be done at an individual level. It should be done as an interdependent system. An individual improved department often worsens the problem for other departments. We refer to Litvak (2005) for a more detailed description of variability management.

3.2 Organization of OR planning to level bed utilization

OR planning – OR scheduling – Bed utilization – Tactical phase – Bed leveling – Bed occupancy

There are two OR management problems according to Agnetis et al. (2013): the master surgical schedule problem (MSSP) and the surgical case assignment problem (SCAP). The first problem is typically a tactical level problem and the second focuses on short time horizon and is therefore an operational level problem. Both problems focus on maximizing OR utilization. We do not consider the second problem, because it is not a problem on the tactical level. Poor OR scheduling leads to problems in wards as well, i.e. fluctuations in bed utilizations and workload. This is at the expense of quality of care. Ward planning is often not included in OR scheduling due to uncertainty in for example LoS (Vanberkel et al., 2011). However, to overcome variability in bed utilization ward planning should be included.

To give a chronological representation, we first explain master surgical scheduling in Section 3.2.1. Section 3.2.2 explains how an input for a master surgical schedule (MSS) is created by using models. The last section shows possibilities to include ward utilization.

3.2.1 Master surgical scheduling

OR scheduling – OR planning – MSS – Master Surgical Schedule – Modeling – Van Oostrum – Approach – Tactical phase

A critical resource of a hospital is the OR. The activities inside an OR have a large impact on other departments in a hospital. Master surgical scheduling is used to schedule ORs. According to Carter and Ketabi (2012), there are two types of MSS: block scheduling and open scheduling. We do not consider open scheduling, because MST does not use this scheduling type. Block scheduling is defined in different ways. Beliën and Demeulemeester (2007) define MSS on specialty level by assigning blocks to specialties. Another way to define MSS is on procedure level by assigning procedures to ORs (Van Oostrum, Bredenhoff, & Hans, 2010). Master surgical scheduling is used direct/indirect for optimization of OR schedules, leveling of ward utilization and construction of robust schedules for tactical level (Van Oostrum et al., 2010). However, the first two aspects are rising.

There are different patient flows in master surgical scheduling process. Patient flow can be observed as care path for patients through different departments in a hospital. Van Oostrum et al. (2008) divided patient flow in three categories, namely:

- Elective patient types that frequently occur
- Elective patient types that rarely occur

- Emergency patients

The first category of patients can be scheduled at a higher planning level, because of the volume and predictability of the involved patient types. The opposite of this patient group is the second group. These patients are difficult to predict, because of their seldom occurrence. This also applies to the third group. They cannot be planned in advance, but slack may be used to cope with the unpredictability of the second and third group (Van Oostrum et al., 2008). In this way, overtime and thereby surgery cancellations can be minimized.

MSS is executed in a centralized or decentralized form (Van Oostrum et al., 2010). In the centralized form, a planner decides about the division of OR time and assignment of patients. The disadvantage of this form is small autonomy for surgeons. The workload on a tactical level is substantial due to requirement of data. However, predictability and utilization are high by the use of historical data. In a decentralized situation, surgeons decide about the assignment of patients. Therefore, the surgeons have a full autonomy. This results in lack of communication between surgeons. Intensive online operational control is necessary due to a lack of communication. However, the managerial workload on tactical level, amount of required data and OR utilization are low.

3.2.2 Modeling of patient flow in ORs

Modeling – Patient Flow – OR scheduling – Simulation – OR capacity planning – Approach

Since several decades, researchers try to model the patient flow in ORs. Harper and Shahani (2002) mentioned four different approaches for modeling of patient flows in hospitals: queuing, integer programming, forecasting, and simulation. These methods support the creation of an MSS. For a more extensive description we refer to Harper and Shahani (2002) and related articles.

Queuing measures the time a patient is in a “system” and the time spent in a queue (Marshall, Vasilakis, & El-Darzi, 2005). This method can help the planners to test scenarios and to tackle problems in the patient flows. They use analytic approximations (heuristics) or simulations in which each location is modeled with a queue. Discrete event simulation (DES) is preferred to model the analytic approximation. DES changes states on a fixed moment in time. According to Marshall et al. (2005), the advantage of DES is that capacity constraints can be incorporated. A disadvantage is a long running time and large output data. In addition, this method is often ward or hospital specific.

Another method is integer programming. This method starts with a linear program followed by assignment of extra constraints to the original program (Bosch & Trick, 2005). The hardness of solving depends on the amount of constraints. The goal is to solve an optimization problem with a minimizing or maximizing objective function and integer values. This method can be used in the strategic and tactical stage.

Forecasting uses patient movements as input information for the planner (Harper & Shahani, 2002). The planner creates long term (number of ORs) and short-term (staffing) decisions based on historical data. It is necessary to make a proper choice of time series for admissions and discharges in hospitals (Lin, 1989). This has a direct influence on the reliability of forecasting results.

Dumas (1985) uses a simulation model to level bed utilization. It is necessary to incorporate the features of the real situation such as waiting time, surgery duration, and length of stay to build a model that reflects the real situation (Dumas, 1985). The outcomes are evaluated and if necessary, adjustments are made. The best scenario for the current situation is chosen out of different setups. A disadvantage of a simulation model is a possible long running time.

3.2.3 Modeling bed utilization leveling

Bed utilization – Bed occupancy – Fluctuations – Modeling – Leveling – Tactical level

Many researchers included ward planning in the OR scheduling process. We give an overview of these different studies and methodologies by using the article of Agnetis et al. (2013). They divided studies in tactical and operational level. We only consider the studies that use the tactical level scheduling approach, because the operational level is outside our research scope. We refer to Agnetis et al. (2013) and related articles for a more extensive description of each method.

Beliën and Demeulemeester (2007) introduce different mixed integer programming (MIP) models for minimization of the total expected bed shortage. These models consist of two different constraints. The demand constraint ensures that each surgeon gets a number of operating room blocks and the capacity constraint limits the amount of available blocks. Random generated situations are solved by various MIP based heuristics and simulated annealing (Beliën & Demeulemeester, 2007). They considered any objectives in a follow-up study. The first objective is a maximally leveled bed occupation followed by minimizing of OR sharing. Finally, the MSS should be easy to understand and is repetitive in many situations. This scenario has been tested in a Belgian hospital and results were described by Beliën, Demeulemeester, and Cardoen (2009).

Chow, Puterman, Salehirad, Huang, and Atkins (2011) created an intervention by combining two models. This consisted on the one hand of a Monte Carlo simulation model for the prediction of surgical bed occupancy (MSS cycle) and on the other hand of an MIP model to level surgical bed occupancy. The second model uses a mix of patients with a minimized bed requirement in each block.

Santibáñez, Begen, and Atkins (2007) used a MIP model to schedule OR blocks for specialties into ORs for elective patients. The aim is to minimize the peak bed usage or to stabilize waiting lists. In addition, it calculates the patient mix and the maximum throughput given the amount of available resources. This model is used at single day planning level and for hospitals with two types of beds (regular and special). Constraints can be switched on/off to calculate different scenarios.

Vanberkel et al. (2011) designed an MSS with a team of employees. This MSS was submitted to staff and they decided whether the MSS was acceptable or if changes should have been made. They calculated how ward occupancy was affected with the approved schedule. Thereafter, a new MSS was created without submission of staff members. This was done by swapping a specialty-operating block of one day with a specialty-operating block of another day by taking into account essential restrictions. The model evaluated each possible proposed MSS. This process continued until ward and OR staff was satisfied. The final MSS reduced fluctuations and peak demand in wards.

Van Essen, Bosch, Hans, Van Houdenhoven, and Hurink (2014) created a local search method based on a detailed formulation. A second method simplifies the objective function and thereby the complexity. The LoS of patients is considered as stochastic. The simplified method gives promising results compared to the original method with a reduction of 20% in bed requirement.

Van Oostrum et al. (2008) introduced their model as a model that covers the number of ORs, available time and the capacity. However, they do not consider the personal restrictions. Slack is introduced to compensate possible overtime. The aim of the created MSS cycle is to reduce bed requirement. This is solved by a column generation approach and by mixed integer linear programming (MILP).

Vissers, Adan, and Bekkers (2005) focused on the cardiothoracic surgery planning by using an MILP model. They created a patient mix for each day, because each patient group requires other resources. The model evaluates scenarios on a tactical and strategic level. This model tries to minimize the over- and underutilization of resources.

We will expand the literature research with the approach of Glerum (2014). Glerum (2014) tries to level bed utilization by minimizing artificial variation in bed demand and improving OR planning. This research is based on Van Oostrum et al. (2008). Glerum (2014) created an MILP model and a Quadratic Assignment Problem (QAP). These models provide admission planners with advice. This advice consists of a mix and volume of patients they should preferably schedule on each session to minimize fluctuations in bed utilization. In this way, they reduce fluctuations in bed utilization and bed requirements.

3.3 Intervention selection

The context analysis and literature research are used to select one or more interventions that match the requirements of MST. Data analysis gives insight into patient flows and makes clear that the elective patient flow introduces fluctuations in bed utilization. Additionally, the contribution of the emergency flow to fluctuations is minimal. This is confirmed by Agency (2004). Fluctuations in ward utilization could possibly decrease if we schedule patients based on OR outflow. This means that the inflow consists of the right mix of patients such that the ward utilization is more constant. In this way, the alignment between different specialties improves. Instead of regulating the elective patient flow, we can redesign the OR schedule. This improves the outflow to wards and thereby alignment between stakeholders, but it is much more difficult to realize this due to resistance of different stakeholders.

LoS improvement is difficult to realize, but nurses have more time when workload is reduced and when they can predict their workload better. In this way, patient contact and patient care can be intensified. This results in a possible improvement of LoS. Moreover, the workload in the morning is high due to admissions, because many patients are assigned to a bed before surgery while they actually do not need a bed. The discharge process introduces more variation than the admission process and therefore has priority (Agency, 2004). Improving LoS and discharge processes requires an intensive role of nurses and a possible increase of workload.

Another option is to give real-time insight in ward utilization. In this way, specialties can react on it to adapt their sequence of surgeries. Real-time insight at wards gives nurses the opportunity to react on it and it gives an overview of the situation.

All interventions are related to OR scheduling or admissions planning. Surgeons have their preferences in OR scheduling and are not very flexible. Redesigning of the OR schedule results in resistance and is difficult to realize in a short period. The OR department of MST sees their department as leading and most profitable and is therefore difficult to involve. Admission planning has less influence on ORs and uses the current OR schedule. Using the current OR schedule means maintaining of current circumstances and only change the content of it. Therefore, our main focus is on redesigning the process of the elective patient admissions, because it has a high improvement potential according to the NHS Modernisation Agency (2004), Litvak and Fineberg (2013) and Glerum (2014). Managing variation in admissions leads to reduction of cancellations, improvement of clinical quality, and reduction of waiting lists (Agency, 2004). Moreover, our data analysis confirms that there is more variability in the elective flow when compared to the emergency flow. When we regulate patient admissions, we can regulate ward utilization.

Glerum (2014) mentioned that his model can be used to optimize other hospitals that face the similar planning and scheduling problems. MST uses a surgery schedule on specialty level and schedule patients on the first available session without considering the resulting ward utilization. The mathematical model fits the requirements of MST. Glerum (2014) used a Mixed Integer Linear Programming model (MILP model) and a Quadratic Assignment Problem model (QAP model), but advices us to use only the QAP model because of more promising results. Therefore, we use the QAP model and expand the existing research with a simulation model to calculate the results for MST and to vary input settings for a sensitivity analysis. We refer to Chapter 4 for the description of the QAP model.

3.4 Conclusions

Sub-questions are created to support and to give an answer on the main question. The following sub-questions and corresponding conclusions are found:

3.1 What causes high fluctuations in bed utilization?

Variability is the main cause of fluctuations in patient flows. Variability is divided in natural and artificial variability. Natural variabilities are clinical, flow and professional variability. These types of variability cannot be eliminated, but it has to be managed in the best possible way. Artificial variability is described as non-random, non-predictable and driven by individual priorities. The variation is not related to unexpected changes, but to the introduction of artificial variation into the system and is easier to manage.

3.2 How can OR planning on a tactical level be organized to level bed utilization?

MSS is used to create OR schedules. The literature mentioned four different methods to support the creation process of such an MSS, namely queuing, integer programming, forecasting, and simulation. Additionally, many researchers included ward planning in the OR scheduling process. The most interesting approach for us is of Glerum (2014). This approach provides admission planners with advice. This advice consists of a mix and volume of patients they should preferably schedule on each session to minimize fluctuations in bed utilization.

3.3 What improvement concept is applicable for the situation at MST?

As mentioned before, the approach of Glerum (2014) is most interesting for MST. We use the QAP model, because it has the most promising results and MST faces similar planning and scheduling problems as described by Glerum (2014). We expand this approach with a simulation study.

4 QAP model

Chapter 3 introduced possible interventions. We decide to redesign the admission planning of the elective OR flow with the aim to reduce fluctuations in wards by the model of Glerum (2014). Therefore, Section 4.1 starts with the model description followed by the experiment settings in Section 4.2. Finally, Section 4.3 shows the results related to the QAP model output and Section 4.4 shows the relation between QAP model and fixed quota.

4.1 Model description

This QAP model is developed by Glerum (2014). We briefly describe the model in this section. For an extensive description, we refer to Glerum (2014) Chapter 5 and 6. Glerum (2014) used the following goals:

1. Minimizing artificial variation in bed demand by improving the OR planning.
2. Creating strategies to cope with natural variation in bed demand

Glerum (2014) describes their model as:

> *"The mathematical optimisation model is based on multiple forms of mathematical programming and is programmed in IBM ILOG CPLEX optimisation studio 12.5. We use mathematical programming because it provides us with solutions for our combinatorial optimisation problem where we optimally use our resources. Mathematical programming also provides flexibility in adding and modifying constraints. The phase one objective is to reduce fluctuations in the demand for beds by assigning volume and mix of case types to OR sessions for each day in the planning cycle. The mathematical model gives an answer to the following question:*
>
> > *Given a certain Master Surgery Schedule and expected demand, when should we schedule which case types and in what volumes?*
>
> *The mathematical model is based on the technique used by Van Oostrum et al. (2008) to relate the surgical schedule to resulting bed demand. However, there are differences between the approach and goal of our research compared to Van Oostrum et al. (2008). Van Oostrum et al. (2008) aim to minimise the number of opened ORs and the resulting bed requirement, by creating an optimal cyclic surgery schedule from a set of surgical procedures. We aim to minimise the bed requirement, by creating an optimal case mix per OR session within an existing cyclical block schedule. We therefore provide a refinement on the existing MSS on a specialty level, whereas Van Oostrum et al. (2008) create a new MSS on procedure type level. For a description of these different types of MSSs see Section 3.3.1. We choose this approach because the St. Antonius hospital currently uses an MSS on specialty level and a new MSS on procedure type level is considered to have a low probability of being implemented. Van Oostrum et al. (2008) create their cyclical schedule based on the most frequently occurring medically homogenous case types whereas we use case types based on LOS duration. We can therefore capture all elective demand in our model, where Van Oostrum et al. (2008) disregard infrequently occurring procedures. Contrary to Van Oostrum et al. (2008) we do not use a probabilistic representation of the surgery duration, because we only use*

surgery duration to ensure the case mixes resulting from the model are practically feasible within the existing OR time. Goal 1 covers our main goal and idea of the intervention to redesign admissions planning of elective patients" (Glerum, 2014).

Appendix D shows input parameters, indices, and decision variables used in the mathematical model. Additionally, Appendix D describes the objective function and constraints of the QAP model.

4.2 Experiment settings

This section describes the various settings that are required to execute the model. We do not give an extensive description about the analysis behind different parameters, because Glerum (2014) gives a detailed description about these findings in Section 6.1 and 6.2.

The following input parameters are given in Appendix E, they describe all surgical specialties and surgical wards:

- Surgical schedule (480 minutes OR capacity per full OR session)
- Case types per specialty
- Designated ward per case type
- Forecasted demand per case type
- Expected length of stay per case type
- Expected surgery duration per case type

Glerum (2014) created case types in the following way:

> *"The deterministic expected surgery duration is based upon the assumption that surgery durations follow a lognormal distribution. We make this assumption considering the data has a low predictive value. We fit the data to a lognormal distribution and use the expected value as an estimator for the surgery duration. This logistical information serves as the bases for the creation of case types. The highest aggregation level in the case types will be the specialty to which the patients belong, corresponding with the blocks in the master surgery schedule. The division of patients into subgroups within a specialty is based on the surgery duration and length of stay, with their corresponding stochastic distributions" (Glerum, 2014).*

We created case types in the same way as Glerum (2014) did. Designated wards were difficult to create, because some specialties are divided over different wards and the model cannot handle this. Therefore, we assigned SS and LS patients of each specialty to one specific ward. This means that all general surgery patients are located at the A3 instead of A3 and C3. In the new hospital, general surgery is located at one floor, so the model is a representation of the future. We refer to Glerum (2014) Paragraph 6.1.2 for an extensive description about parameter settings.

Table 10 gives insight in the patient population that is suitable for planning. The data is derived from quarter one 2014. We exclude emergency patients, because they cannot be planned in advance. Children are excluded, because they are treated in special wards and these wards are outside the scope of this research. Patients with missing data are excluded as well. To analyze the demand for specialties, it is necessary to exclude patients that have multiple OR visits during their LoS.

Table 10: Patients suitable for planning by the model out of the period 01-01-2014 to 30-03-2014, n = 3677, source: Xcare & ORSuite.

	Scheduled by the model		Not scheduled by the model				Total population
	Percentage	# of patients	Children	Emergency	Missing data	Multiple visits	
KCH	76%	73	14	9	0	3	96
CHI	64%	931	81	321	8	92	1447
GYN	66%	266	2	119	11	6	404
KNO	76%	143	40	2	0	2	187
OOG	71%	29	10	2	0	0	41
ORT	90%	588	38	28	0	2	656
PCH	80%	184	14	16	2	15	231
URO	74%	175	43	12	0	7	237
NCH	83%	269	8	47	1	13	325
BZH	28%	15	35	0	0	3	53
Total	**73%**	**2673**	**285**	**556**	**22**	**143**	**3677**

The percentage of patients that can be scheduled differs per specialty. The more patients we can include in the model, the closer wards come to an improvement potential. A lot of uncertainty remains in wards if the model cannot schedule patients.

4.3 Experiment results

The QAP model reaches a 1.63% optimality gap after 73 seconds. This optimality gap is considered as small enough to be acceptable. Figure 17 shows the case mix output for the integrated approach in MST. The graph shows that DT patients are divided over the week and most SS patients are planned in the first half of the week. Additionally, LS patients are planned especially in the second half of the week.

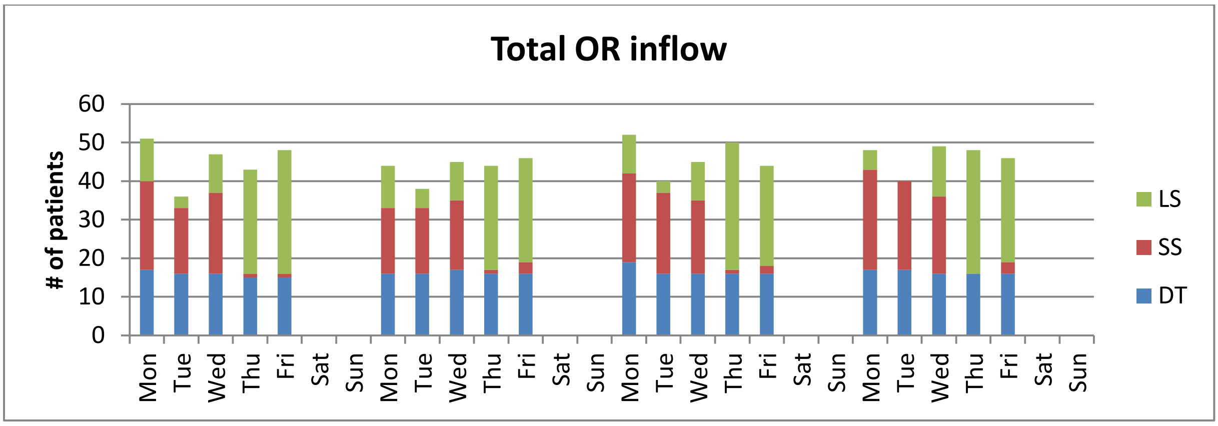

Figure 17: Case mix for all ten specialties, n = 904, source: optimization model.

Figure 18 shows the results of the case mix in relation to bed utilization (weekends excluded). It is clear that the QAP model reduces variation in bed utilization. C5 treats many different specialties, but due to more predictability of DT patients the variance is lower. However, if a patient occupied a bed for half a day, we set it as a full day. Therefore, results could probably overestimate the bed utilization.

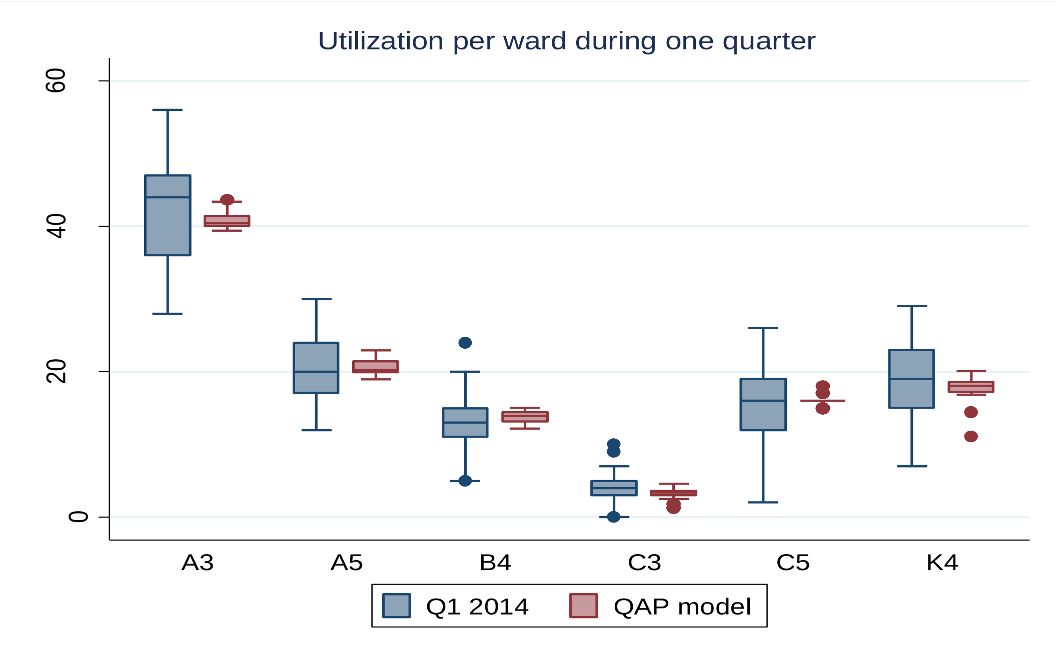

Figure 18: Variation in six different wards during 06-01-2014 to 30-03-2014, n = 2712, source: ORSuite and Xcare & optimization model.

The QAP model has consequences for the variation of OR utilization as well. Figure 19 shows the variation in utilization for all twelve ORs in MST during sixteen weeks. The dispersion of data for many ORs is larger than in the realized situation of Q1 2014, but the utilization for the QAP model does not exceed 100%. According to the QAP model a lot of OR time is unused. However, 27% of the surgery related patient population is not included.

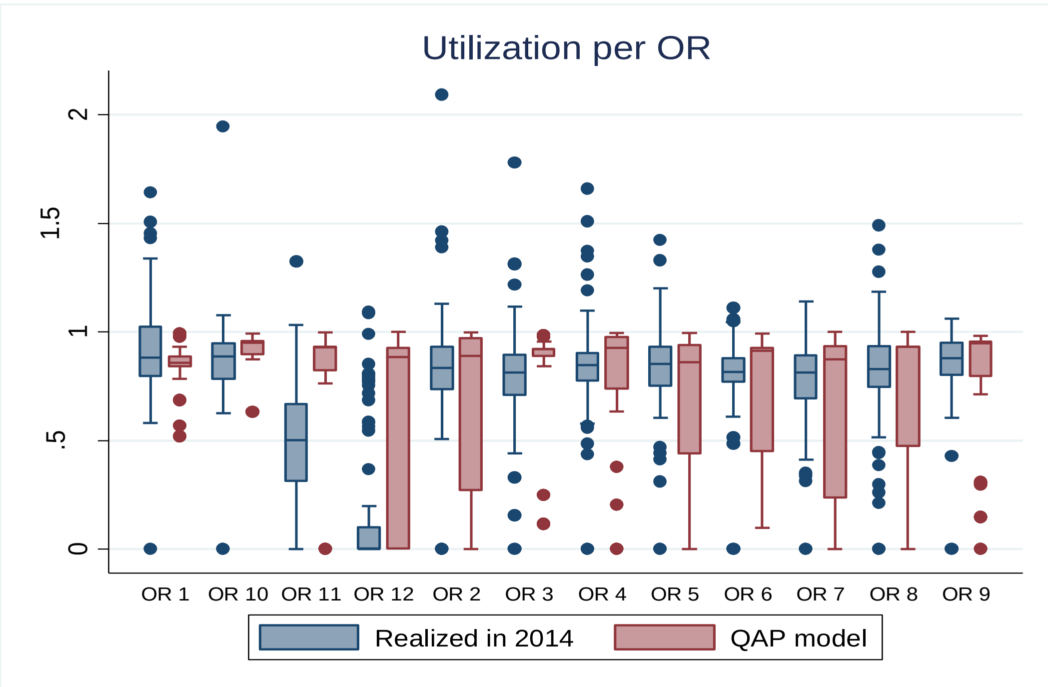

Figure 19: Variation in OR utilization during 06-01-2014 to 27-04-2014, n = 3616, source: ORSuite and Xcare & optimization model.

Figure 20 shows the number of OR days per specialty in each OR. The variation in OR utilization is higher if more specialties use a particular OR. For example, OR 1 is mainly used by neurosurgery and has a small variation in the boxplot. OR 5 is used by four specialties and has a high variation in the boxplot of Figure 19.

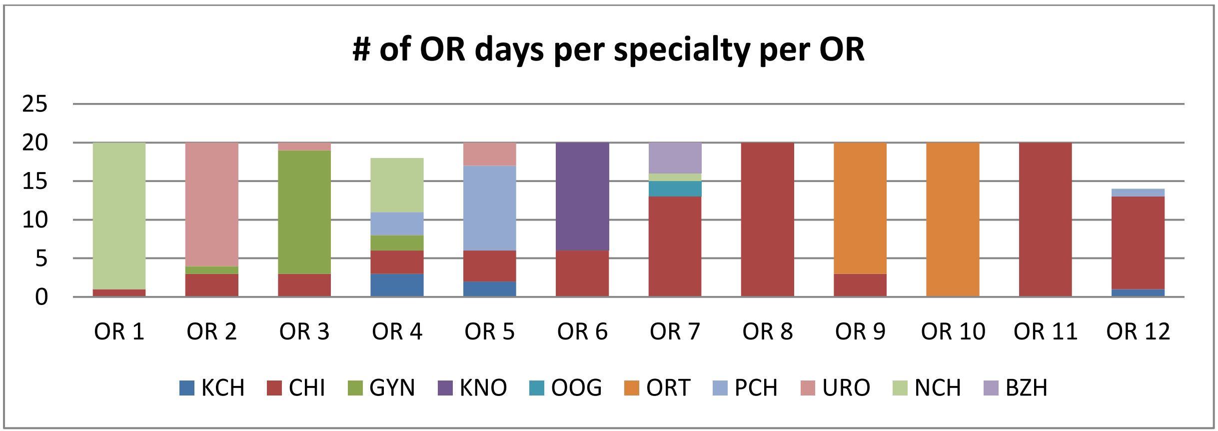

Figure 20: Number of OR days per specialty per OR during four weeks according to the surgery schedule in Appendix E, source: BLOKplan.

4.4 Fixed quota vs. QAP model output

As mentioned before, MST uses fixed quota in the planning process of elective patients. This principle supports admission planners to schedule patients according to guidelines. These guidelines consist of a minimum and maximum value. The number of patients that should be planned each day lies between these values. It is interesting to see what the difference is between the fixed quota and the output of the QAP model. We visualized the fixed quota and QAP model output per specialty in Appendix G and gave one example in Figure 21. All figures are based on the month March.

It is remarkable that almost all specialties fit the fixed quota. For some specialists the minimum of fixed quota is higher than the QAP model output (see Figure 21 for an example of neurosurgery). However, children are included in the fixed quota and excluded in the QAP model. When we “fill” the gaps with children, every QAP model output reaches the minimum of fixed quota. Additionally, some specialties exceed the maximum of the fixed quota. We cannot conclude that it does not fit in the OR schedule, because it depends on the surgery duration of a patient type.

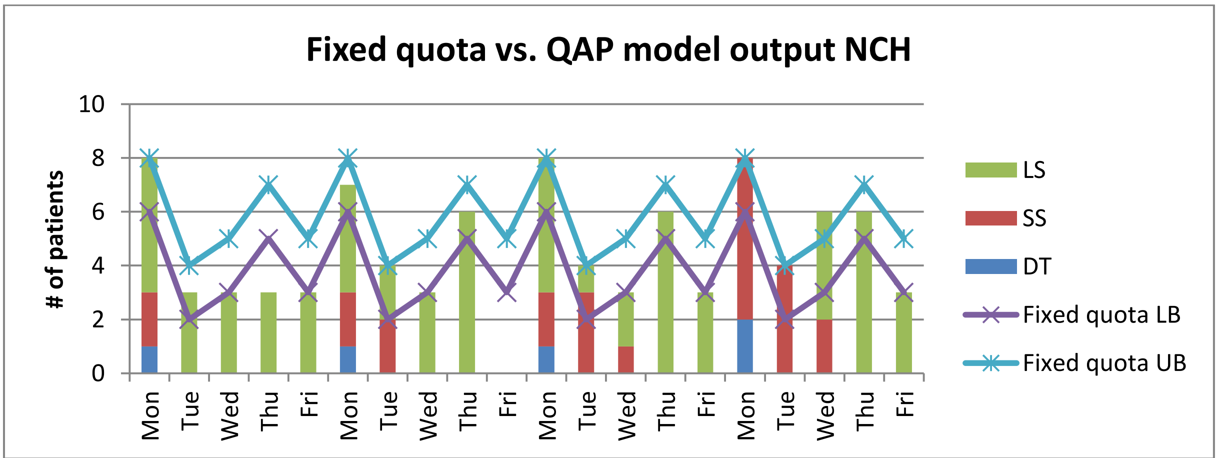

Figure 21: Fixed quota vs QAP model output for NCH in March 2015, n = 91, source: ORdashboard & optimization model.

4.5 Conclusion QAP model

This chapter describes the QAP model of Glerum (2014). We draw conclusions based on the following sub-questions:

4.4 How can we model the intervention?

Glerum (2014) proposed a QAP model for determining the optimal mix of patients as input for ORs. This mathematical optimization model is built in IBM ILOG CPLEX optimization studio.

4.5 What experimental settings do we use?

The optimal case mix of patients is based on Length-of-Stay (LoS), within an existing MSS. The model uses deterministic surgery duration and stochastic LoS. We use 73% of the total surgery related patient population, because we exclude children, emergencies, incomplete data, and multiple visits.

4.6 How does the model operate?

The QAP model reduces variation in bed utilization. Moreover, the model reduces maximum bed requirements with a total of 29.4%. Table 11 shows the bed requirements per ward. Reduction in bed requirements is most successful in C3, but C3 has a relatively small amount of patients. Additionally, reducing variation in bed utilization has a negative impact on OR utilization, because variation in OR utilization increases in most ORs. MST can use the QAP model output as additional information to specify the fixed quota, because it seems like a good fit between the model output and fixed quota. However, extra research is needed to get more insight into the patient population, because more improvement can be reached if all patients are scheduled in the QAP model.

Table 11: Maximum bed requirements during 06-01-2014 to 30-03-2014, n = 2712, source: ORSuite and Xcare & optimization model.

	Q1 2014	QAP model	Difference
A3	56	44	-21.4%
A5	30	23	-23.3%
B4	24	15	-37.5%
C3	10	5	-50.0%
C5	28	18	-35.7%
K4	29	20	-31.0%
Total	177	125	-29.4%

4.6 Limitations

Some specialties are located in different wards, such as general surgery (A3 and C3). The QAP model cannot handle this, so we assumed that this specialty is located at the A3 only. This limits the outcomes of the QAP model for MST. By using the case mixes in the current situation, admission planners should be alert in scheduling the right mix of patients for general surgery. For example, the right mix of oncology and vascular patients per day. For more limitations we refer to Section 5.5 of Glerum (2014).

5 Simulation model

This chapter describes the simulation model. It is used to evaluate the effects of introducing the case mix, out of Chapter 4, in MST. This chapter is based on the methodology of Law (2007). The steps of this methodology are visualized in Figure 22. Each section of this chapter corresponds with a step out of the methodology.

5.1 Objective and scope

The simulation model is used to analyze the outcome of the QAP model of Chapter 4 and to test the influence of changes in the case mix. Therefore, the following main-question is used:

How does the output of the model in Chapter 4 perform according to a simulation?

The following questions are used to find the answer on the main-question:

- How can we simulate the process of MST by using the output of the intervention?
- What experiment settings do we use?
- How does the simulation operate?

The scope of the simulation study consists of the elective patient flow. This flow starts with the admission of the patients followed by a surgery and finally treatment in ward. We do not consider emergency and children, because these flows are outside the scope of this research. We use Siemens Plant Simulation 11 for the simulation study and do not consider other software tools, because it is a time consuming process to select the best tool and we do not have that time. Siemens Plant Simulation is a DES tool. DES has proven itself as an effective tool to aid the decision making in healthcare settings (Günal & Pidd, 2010; Mes & Bruens, 2012).

5.2 Conceptual model

Designing and programming a proper simulation model takes a lot of effort. It will often be faced with trial and error in each step. To reduce the number of errors, we want to know how and what our model needs to do. Therefore, we formulated the surgery related processes of MST in the form of flowcharts (see Appendix I). We divided the elective patient flow in admission of patients, surgery and ward related processes. Each part is described in a flowchart. Additionally, we have made some assumptions to simplify the model. The following assumptions are most important and have the largest impact on the patient flow:

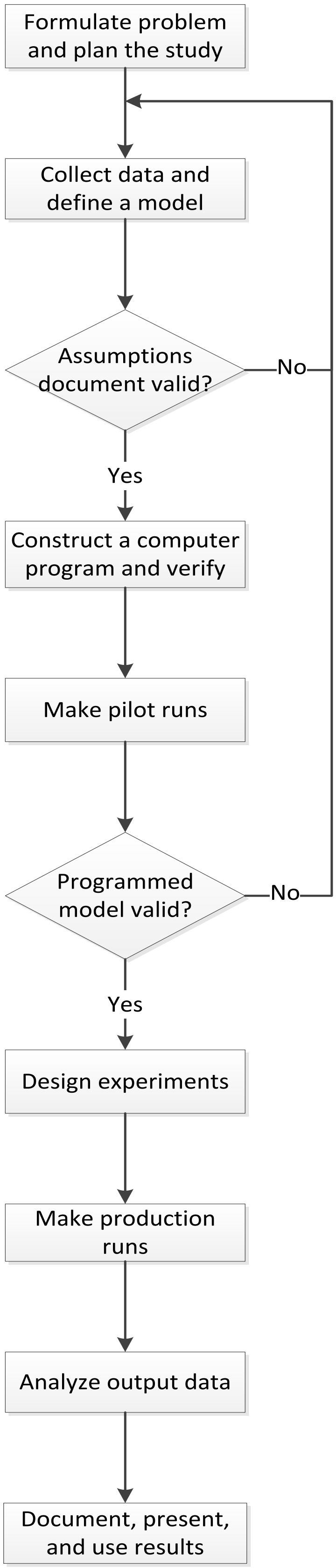

Figure 22: Steps in a simulation study (Law, 2007).

- All patients for surgery arrive at 8.00 a.m.
- LoS is based on a lognormal distribution using random numbers.
- Surgery duration is based on a lognormal distribution using random numbers.
- There is no closing time for ORs.
- Staff characteristics are not included

5.3 Data gathering

We used the same distribution for LoS as in the QAP model. These distributions are created by using historical data out of Xcare and ORsuite. According to the data analysis of Chapter 2, the distribution of surgery duration has the same shape as LoS distribution. Glerum (2014) states this as well. Therefore, we made the assumptions to use a lognormal distribution for surgery duration. These distributions are based on the historical data out of Xcare and ORsuite. Appendix H shows all distributions per patient type. We used the case mixes of Chapter 4 and the surgery schedule of Appendix E as input parameters. All historical data and settings are out of the same period as used for the QAP model, namely the first quarter of 2014. Except the surgery schedule, this is a version of the first quarter in 2015. This surgery schedule is imported out of BLOKplan.

5.4 Model description

This simulation model is used to verify the output of the QAP model and to compare it with the reality. Figure 23 shows the home screen of the simulation model. The blue selection consists of methods and generators to initialize the model, to reset the model, to set parameters at the beginning of the day, and to save values at the end of the day. The red selection consists of the different departments related to patients and surgeries. The orange selection contains the OR schedule, info about specialties and patients for surgery. The green selection consists of results related to wards and ORs. In the purple selection one can observe the variables of the current simulation. Each part of the red selected frame is explained in the remainder of this section. The other frames are self-explanatory and can be found in the simulation model itself.

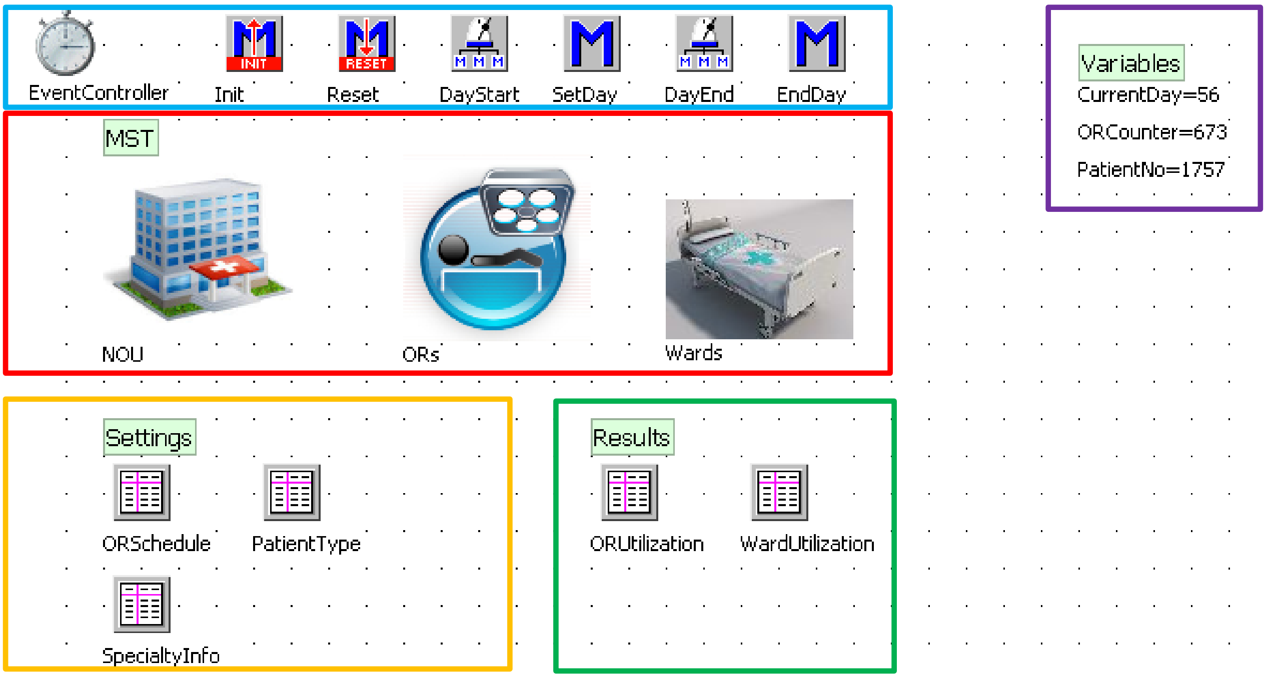

Figure 23: Home screen simulation model.

Frames description

NOU: The NOU is the department before surgery and is displayed in Figure 24. The table *NumberOfPatients* gives the amount of patients that should enter the NOU and patients will enter the hospital in *ElectiveEntrance*. The *Admission* method gives LoS and ORtime for each patient. These values are based on a lognormal distribution that is determined by historical data. Next the patient will be sent to the *WaitingRoom*. According to the patient type and availability of an OR, the patient will be sent to the OR with the method *EnterOR*.

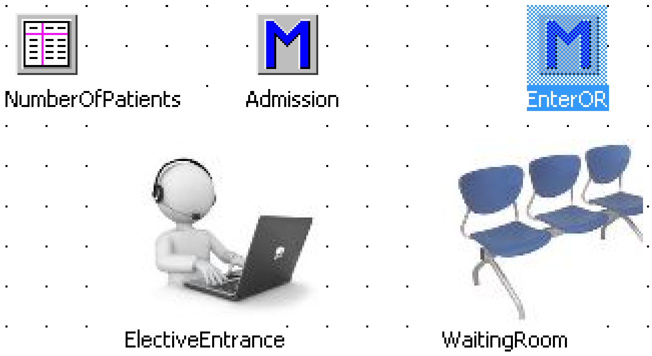

Figure 24: Overview of the NOU.

ORs: Each OR is displayed in Figure 25. The method *Outflow* regulates the patient flow after surgery depending on the patient type. Surgery time depends on the characteristic/attribute of a patient. The table *ORDashboard* gives insight in the performance of each OR and saves some important OR related data values. Each OR is specified for a particular specialty at the beginning of each day according to the *ORSchedule* of the home screen.

Figure 25: Overview of ORs.

Wards: Figure 26 shows the available wards. Each ward treats specific patient type(s) and the LoS is based on the characteristic/attribute of a patient. Upon discharge, the patient will be sent to the *Exit* of the hospital with the method *Discharge*.

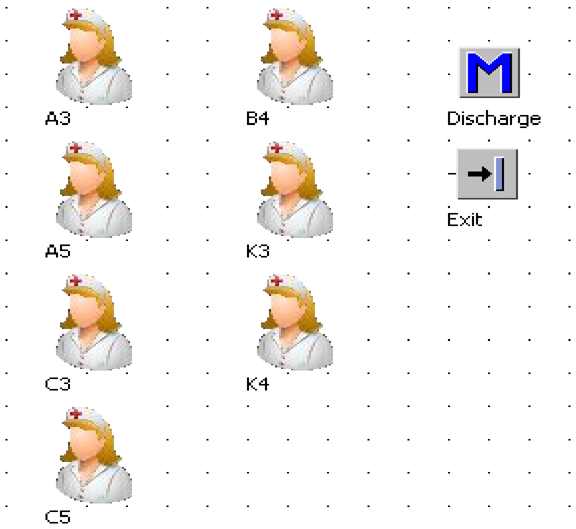

Figure 26: Overview of wards.

Patients

The hospital cares for 30 different patients types: 10 specialties and each specialty has DT, SS and LS patients. These types are translated to 1,2,…,30 and each patient has several other characteristics/attributes. Table 12 shows the different characteristics/attributes.

Table 12: Patient's attributes.

Characteristics/Attributes	Description
PatientNo	The number of a patient
PatientType	Patient type 1,2,….,30
DestinationOR	In which OR the patient undergoes surgery
LoS	The LoS of the patient in ward
ORtime	Surgery time of a patient

5.5 Verification

"Verification is concerned with determining whether the assumptions document has been correctly translated into a computer program" (Law, 2007). Varies methods are available to check whether the simulation model is valid, i.e. debugging, reviewing the model, and run the model under variety of input parameters and check if the output is reasonable. First, we use debugging such that the model runs without any bugs by using bullet points and auxiliary variables. This is done for each part of the model. We conclude that the model is valid to this point. Second, the model is reviewed by hospital staff and by comparing process documents with our simulation model. Therefore, we consider that the model is verified to this point as well. Finally, we run the model with small and large datasets to see if the model corresponds with the expected outcomes. The output seems reasonable and we conclude that the model is verified based on these three points.

5.6 Validation

"Validation is the process of determining whether a simulation model is an accurate representation of the system, for the particular objective of the study" (Law, 2007). To validate our model we compared our performance outcomes with the performance of the real situation in 2014. These outcomes will never give the same solutions, because of different seed values. However, the smaller the differences the higher the validity. Table 13 shows the difference in outcomes between quarter one 2014 and

simulation model. We give an example of one specialty and it shows that the differences in surgery duration and LoS are small. Other specialties show similar results. Therefore, we conclude that the input parameters for surgery duration and LoS are valid.

Differences in ward and OR utilization are relative large. We calculated the amount of surgeries per specialty for the QAP model and these values are rounded up. Therefore, the amount of surgeries for many patient types is higher compared to the realized situation in 2014. This probably results in higher ward utilization. OR utilization probably differs due to another surgery schedule. Quarter one 2014 uses the schedule of that particular period and the simulation model uses the surgery schedule of quarter one 2015. Therefore, we assume that these values are valid as well.

Table 13: Information for validity analysis between quarter one in 2014 and simulation model, source: Xcare and Simulation model.

	Q1 2014	Simulation model	Difference in %
Average Surgery duration KCH DT	3322	3314	-0.2
St. dev. Surgery duration KCH DT	1325	1307	-1.4
Average LoS KCH DT	41449	40955	-1.2
St. dev. LoS KCH DT	30299	29476	-2.5
Average Surgery duration KCH SS	4893	4841	-1.0
St. dev. Surgery duration KCH SS	1631	1616	-0.9
Average LoS KCH SS	91750	91754	0.0
St. dev. LoS KCH SS	25370	24876	2.0
Average Surgery duration KCH LS	8744	8697	-0.5
St. dev. Surgery duration KCH LS	4568	4521	-1.0
Average LoS KCH LS	816806	820564	+0.4
St. dev. LoS KCH LS	954070	946270	-0.8
Ward utilization A3	40.4 beds	45.4 beds	11.0
Ward utilization A5	19.4 beds	21.3 beds	9.8
Ward utilization B4	12.3 beds	13.3 beds	7.5
Ward utilization C3	3.6 beds	3.8 beds	5.3
Ward utilization C5	12.1 beds	15.0 beds	19.3
Ward utilization K4	15.9 beds	17.0 beds	6.5
OR utilization	74.93%	70.78%	-5.9

Values of the simulation model are not the same as the realized situation of quarter one 2014, because the simulation model uses the improved results of the QAP model and the realized situation of 2014 not. Moreover, the simulation model uses assumptions. However, we conclude that the simulation model is valid to simulate the results of the QAP model.

5.7 Experiment design

This section describes the characteristics and settings of the experiments. Section 5.7.1 describes varies experiments. It is followed by a short description about common random number in Section 5.7.2. Section 5.7.3 describes the length of the warm-up period. Finally, Section 5.7.4 gives the number of replications for each experiment.

5.7.1 Experiment settings

We do only one experiment for this chapter, but uses the simulation model for the sensitivity analysis of Chapter 6 as well. We use the simulation model for the following sections of the sensitivity analysis:

- Influence of changes in the optimal case mix
- Influence of closing ORs

These changes in settings are explained in detail in the associated sections of Chapter 6. The results in this chapter are based on the case mix op Chapter 4. The simulation model calculates the utilization of wards and ORs.

5.7.2 Common random numbers

A proper variance reduction technique is the use of common random numbers for all of the experiments. We use these common random numbers, because in this way each experiment has the same conditions. It reduces the variance and therefore narrows the confidence interval. This leads to results that are more accurate.

5.7.3 Warm-up period

Data analysis gives us insight in the length of the warm-up period. We determine the warm-up period by using Welch. A3 and C3 are used to calculate this period, because these wards have the highest contrast in terms of bed utilization. Law (2007) mentions that it is better to choose the length of the warm-up period too high rather than too small. C3 gives a warm-up period of 56 days and A3 of 84 days (see Appendix J). Therefore, we choose a length of the warm up period of 84 days. We use w=14, because of a good configuration with the data.

5.7.4 Number of replications

In our situation, the run length of one replication is the period until the surgery schedule repeats (four weeks) times the number of repetitions of this schedule. We set the length of each replication to fifteen schedule repetitions, because some patients have a long LoS. Therefore, we need a long run length for a replication to include the influence of these patients. It is necessary to use the right number of replications. If the number of replications is chosen too small, this results in low accuracy of the outcome. The accuracy increases with the number of replications is chosen too large, but here a tradeoff occurs since it will also increase the time an experiment will take and thus decrease efficiency. The number of replications is chosen corresponding to a relative error allowed of $\gamma = 0.10$ and the confidence interval of $\alpha = 0.05$ of the average ward utilization.

To show how many replications we need for each experiment, we run the model fifteen times with fifteen OR schedule repetitions in each run. This system is a non-terminating system, because there is no start/stop and the beginning or end of the week. We deleted the first 84 days (three schedule repetitions) of each replication, because there is a warm-up period of 84 days due to the non-terminating system. Thereafter, we calculate the mean of ward utilization in A5 by taking the average of each replication. This ward is used, because it leads to the highest number of replications. Our aim is to find a sufficiently large number of replications for each experiment. We calculate the number of replications with the following formula:

$$n^* = \min\{i \geq n: \frac{t_{i-1,1-\frac{\alpha}{2}}}{|\bar{X}_n|} \leq \frac{\gamma}{1+\gamma}$$

Here $\frac{\gamma}{1+\gamma}$ is the corrected target value, $\gamma = 0.10$ and $\alpha = 0.05$.

Table 14 shows a small part of the calculation of replications. The n* is smaller than y' first for i is four. Therefore, the amount of replications is four.

Table 14: Calculation of number of replications.

Mean	Cum. mean	St. Dev.	Cum. St. Dev.	Cum. St. Dev. of means	i	t-inv	n*	y'
45.4	45.4	5.2	5.2		1			0.09
49.4	47.5	4.9	5.4	2.8	2	12.7	0.53	0.09
49.2	48.0	4.5	5.2	2.2	3	4.3	0.12	0.09
47.7	47.9	4.3	5.0	1.8	4	3.2	0.06	0.09
47.6	47.9	5.3	5.1	1.6	5	2.8	0.04	0.09

Summarizing, we execute four replications and each replication has a run length of fifteen times four weeks. The first three schedule repetitions (three times four weeks) are deleted, because of the warm-up period. Therefore, each replication has a run length of 48 weeks (twelve times four weeks).

5.8 Experiment results

Results in this section are based on a period of twelve weeks, because input data for the QAP model is based on the same period. We select the first twelve weeks of the simulation model and uses quarter one of 2014 as realized situation. Appendix K shows the utilization of all six wards. Using case mix matrices delivers a more stable and predictive pattern than the realized planning of Q1 2014. The simulation model shows higher utilization than the QAP model, but the simulation model has fewer up and down peaks in ward utilization compared to Q1 2014. The trends in the figures above are visualized in boxplot of Figure 27. These values confirm the findings that the simulation model reduces the variation as well, but compared to the QAP model the variation is higher. As mentioned before, the average utilization does not differ that much.

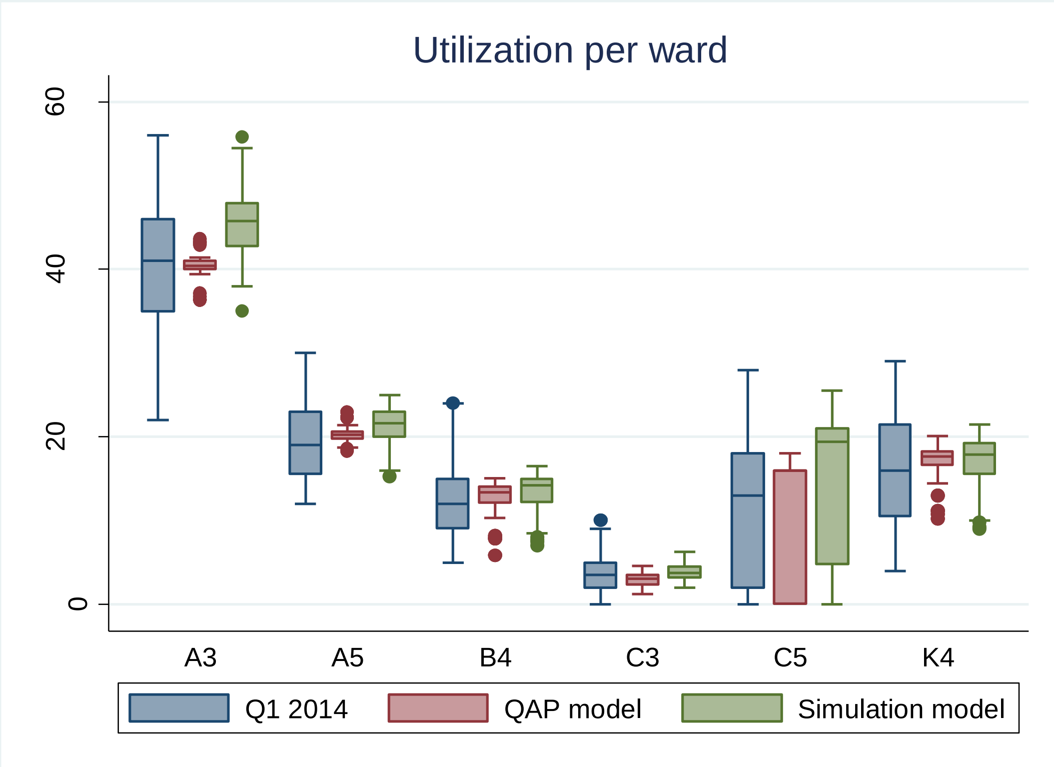

Figure 27: Variation in six different wards during 06-01-2014 to 30-03-2014, n = 2712, source: ORSuite and Xcare & optimization model & simulation model.

The simulation model increases the variation in OR utilization compared to the QAP model. There are more outliers as well, because of using stochastic surgery durations. Figure 28 shows the variation in OR utilization. Glerum (2014) already recommended to investigate the possibility to create sub-groups within the case types, by subdividing a case type into different clusters with homogeneous surgery durations. This will possibly improve the OR utilization and prevent outliers. Additionally, Glerum (2014) mentioned to extend their research by using stochastic surgery durations in the QAP model. On average OR utilization does not differ that much, namely 74.93%, 73.98%, and 70.78% for respectively Q1 2014, QAP model and simulation model.

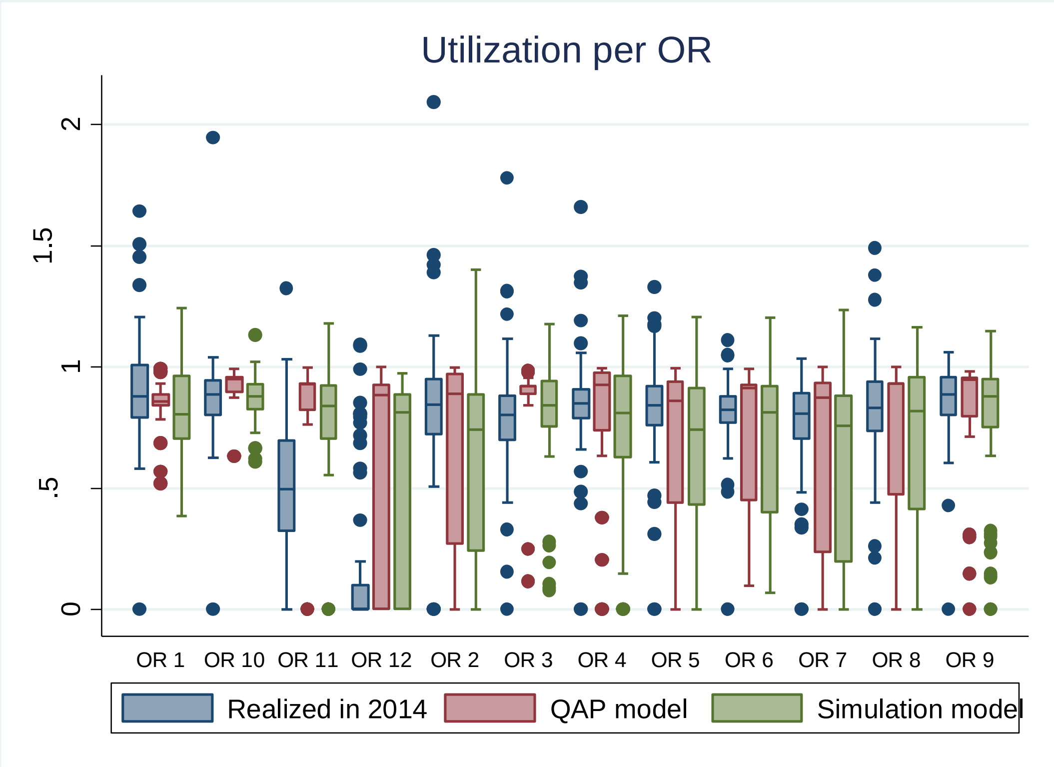

Figure 28: Variation in OR utilization during 06-01-2014 to 30-03-2014, n = 2712, source: ORSuite and BLOKplan & optimization model & simulation model.

5.9 Conclusion simulation model

The following conclusions follow from this chapter:

5.1 How can we simulate the process of MST by using the output of the intervention?

The model is created in Siemens Plant Simulation 11. All patients arrive at 8 a.m. and arrive in a general waiting room before surgery. Patients are operated according to the case mix of the QAP model. If the right OR is available, the patient will be sent out of the general waiting room to that particular OR. After surgery, the patient will move to the corresponding ward. The patient will be discharged when the assigned LoS time is over.

5.2 What experimental settings do we use?

We use common random numbers to create even conditions for each experiment. Additionally, we need a warm-up period of three surgery schedule repetitions and four replications to get valid results. Surgery time and LoS are based on a lognormal distribution. The OR schedule of MST in the first quarter of 2015 functions as OR schedule for the simulation model. Children and emergency patients are excluded.

5.3 How does the simulation operate?

The simulation model confirms the positive results related to ward utilization. Variation is reduced in all wards and the total bed requirement is reduced with 14.1% (see Table 15). K4 and B4 deliver most bed savings. OR utilization varies a bit more than in the QAP model, but the average OR utilization is does not differ that much (74.93%, 73.98%, and 70.78% for respectively Q1 2014, QAP model and simulation model). The realized situation of Q1 2014 delivers better results related to utilization of ORs.

Table 15: Maximum bed requirements during 06-01-2014 to 30-03-2014, n = 2712, source: ORSuite and Xcare & optimization model & simulation model.

	Q1 2014	QAP model	Simulation model	Difference Q1 2014 & QAP	Difference Q1 2014 & Simulation
A3	56	44	56	-21.4%	-0.0%
A5	30	23	25	-23.3%	-16.7%
B4	24	15	17	-37.5%	-29.2%
C3	10	5	6	-50.0%	-40.0%
C5	28	18	26	-35.7%	-7.1%
K4	29	20	22	-31.0%	-24.1%
Total	177	125	152	-29.4%	-14.1%

5.10 Limitations simulation study

Our assumptions will limit our findings. Normally, patients arrive throughout the day which reduces waiting time. In our simulation, patients arrive all together at 8.00 a.m. and the LoS starts at the same time. This has no influence in OR utilization, but for ward utilization it probably has. For example, patients with a LoS of 0.6 days and admission time of 8.00 a.m. are discharged at 22.30 p.m., but in reality if this patient has an admission time of 12.00 p.m. discharge is at 02.30 a.m. This is impossible so the patient is discharged on the next morning. Therefore, the utilization and LoS in reality will be higher/longer than in the simulation study. Our simulation study has probably underestimated values.

OR utilization in the simulation model sometimes is around 200%, because of missing closing times. OR utilization of 200% is not realistic. Therefore, the scheduling process should include possible long surgery times or cancel patients if closing times are exceeded. Cancellation of patients possibly leads to more fluctuations in ward utilization, because the patient is rescheduled on next day or is discharged. OR utilization of more than 100% means overtime for surgeons and overtime should be minimized.

The results are different compared to the QAP model. Our simulation model can handle LoS longer than 28 days while the QAP model has a maximum LoS of 28 days. The ward utilization in the QAP model is probably underestimated compared to reality and the simulation model. Additionally, the simulation model generates LoS and surgery duration according to random numbers. This possibly results in too many patients with a long surgery duration or LoS on the same day. Underutilized or overutilized wards and/or ORs are the consequence.

6 Sensitivity analysis

This chapter describes the influence of changes in the case mixes or composition of patient population. Section 6.1 shows seasonality effects and Section 6.2 describes what happens according to expected changes in the patient population. Section 6.3 explains what happens if we make changes in the case mix for orthopedics followed by the influence of closing ORs in Section 6.4. Finally, Section 6.5 describes the influence of reducing OR capacity in the QAP model.

6.1 Seasonality effect

This section describes the difference between winter (Q1) and summer (Q3). Therefore, this section is used to analyze seasonality effects of patient flows. Table 16 shows the patient population per month of both quarters. The difference between Q1 and Q3 is small, but the total population of Q1 for all patient types is larger.

Table 16: Patient population in Q1 and Q3 during one month.

Specialty	# of patient types Q1			# of patient types Q3		
	DT	SS	LS	DT	SS	LS
KCH	19	2	5	19	2	2
CHI	127	74	111	108	70	117
GYN	28	25	37	22	15	37
KNO	10	36	7	14	30	7
OOG	9	1	0	11	1	0
ORT	81	40	77	87	33	64
PCH	35	17	11	30	11	10
URO	6	38	16	8	36	22
NCH	5	24	62	10	13	59
BZH	5	0	0	8	0	0
Total	325	257	326	317	211	318

Differences in surgery duration between both quarters are small and negligible. Therefore, we used the same surgery duration for both quarters and made the assumptions to keep the LoS equal as well, because the LoS depends on of the surgery duration. Case mix matrices are based on the same OR schedule as in Q1. The QAP model reaches an optimality gap of 1.62% after 6 seconds by using the population of Q3. Total case mixes of Q1 and Q3 are given in Figure 29 and Figure 30. For DT patients is the inflow is leveled in both quarters. Additionally, the division of SS and LS patients looks similar in both situations, but in Q1 there are more scheduled SS patients on Thursday or Friday compared to Q3.

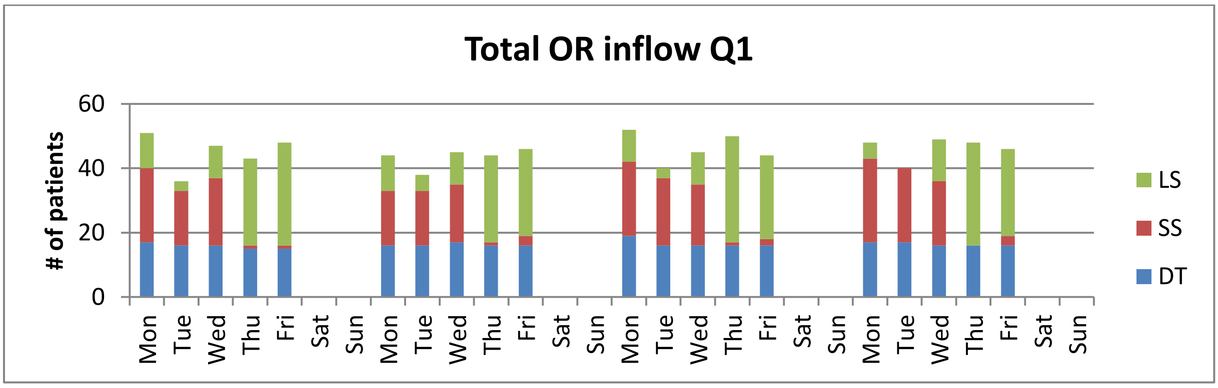

Figure 29: Case mix for all ten specialties together out of the QAP model for Q1.

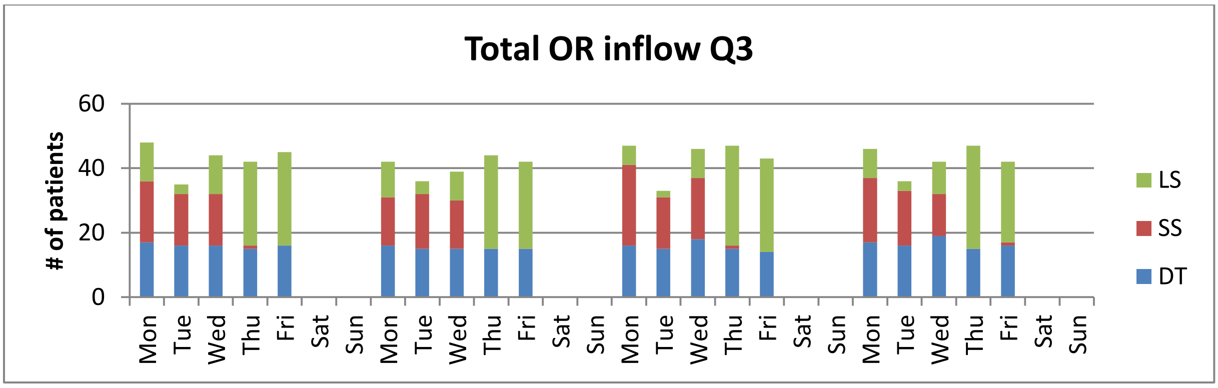

Figure 30: Case mix for all ten specialties together out of the QAP model for Q3.

However, there are differences between OR inflows if we compare all individual specialties with each other. For example, in Q3 KCH and GYN use two ORs less according to the case mixes. This is mainly caused by the decrease of SS patients in Q3. The ORs that are used in Q1 for only SS patients are often unused in Q3. Each day, the ratio of SS and LS patients decreases due to a smaller population, although the differences are small. On the contrary, the division of DT patients within a specialty changes much more. However, due to the alignment between specialties and more predictability of these patients DT patients are evenly distributed in the total overview of Figure 29 and Figure 30. Figure 31 shows the utilization of wards and ORs for Q1 and Q3. Due to a decrease in the number of patients utilization in wards and ORs is lower for Q3 than for Q1. Additionally, the variation in OR utilization in most of the ORs is higher for Q3, because of using a smaller patient population in the same OR schedule.

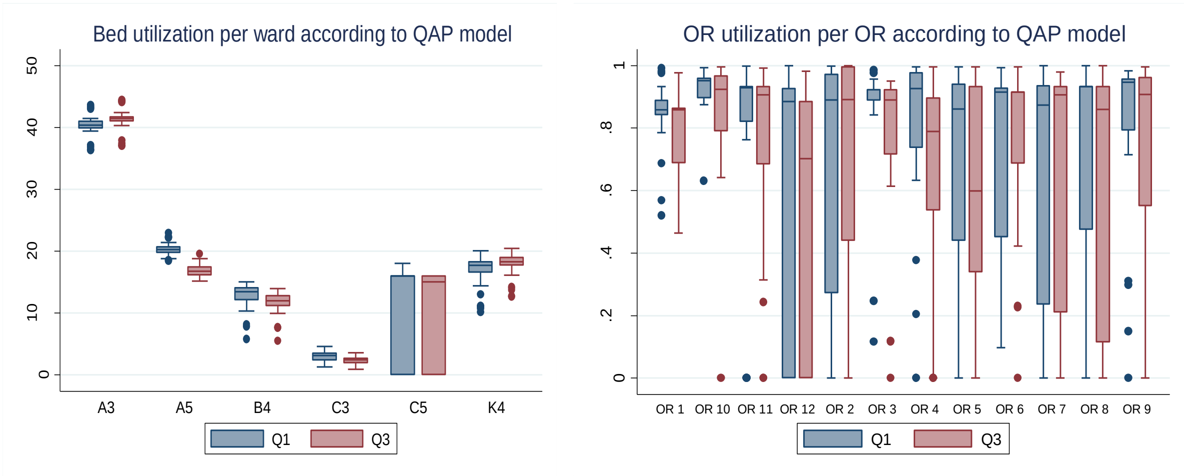

Figure 31: Bed utilization per ward and OR utilization per OR according to the case mix matrices during Q1 and Q3.

A decrease in the patient population implies a necessity for revision of the OR schedule and less surgery time for specialties. In summer season specialists are not available, caused by holidays. These are not included in our calculation. Moreover, not all patients are included in the QAP model and this will lead to underutilization of wards and ORs. However, we can conclude that the QAP model delivers promising results according to ward utilization and these results are similar for Q1 and Q3.

6.2 Influence of changes in patient population

MST mentioned the trend that the number of DT patients will increase in the upcoming years. This will not influence the case mixes a lot. If the alignment between specialties is sufficient and the number of DT patients is evenly distributed over the days then MST can level bed utilization. DT patients are the easiest patient type to schedule, because of their high predictability of LoS. This patient group is growing due to the increasing quality of care. In this way, SS/LS patients will be transformed to DT patients. Improvement in the quality of care will decrease LoS and the trend is to discharge patients as soon as possible.

An increasing DT patient population has consequences for ORs as well. DT patients have relative shorter surgery durations than other patient types. OR utilization will be lower if SS/LS patient will be transformed to DT patients. This implies a necessity to revise the OR schedule and probably less surgery time for some specialties.

6.3 Influence of changes in case mix

Some patients should be classified as strict patients, because one particular surgeon is able to operate them. Another option is that a surgeon cannot operate a specific patient type on a particular day. Therefore, we will make some changes in the case mix to test the influence of these changes on ORs and wards. For example, according to the case mix some DT patients should be operated on Monday. Suppose the right surgeon is not available and there is not enough capacity left on another day so DT patients should be switched with another patient type of another day. We will use orthopedics to analyze such situation(s), because this specialty consists of many surgery related patients and has no sub-division like general surgery. We exclude the analyses of C5 and DT patients, because of a good predictability. The following situations are used:

1) All SS patients from Monday to Thursday

- 4 SS and 2 DT of 1st Monday switched with 4 LS of 1st Thursday
- 4 SS and 2 DT of 2nd Monday switched with 4 LS of 2nd Thursday
- 4 SS of 3rd Monday switched with 2 LS of 3rd Thursday
- 4 SS of 4th Monday switched with 3 LS and 1 DT of 4th Thursday

2) All LS patients from Friday to Tuesday
   - 4 LS of 1st Friday switched with 2 SS of 1st Tuesday
   - 4 LS of 2nd Friday switched with 5 DT of 2nd Tuesday
   - 2 LS of 3rd Friday switched with 3 SS of 3rd Tuesday
   - 3 LS and 1 DT of 4th Friday switched with 5 SS of 4th Tuesday

Situation 1

OR 9 and OR 10 are available for orthopedics. Therefore, we do not analyze the other ORs. Figure 32 shows the results by changing the composition of the case mixes according to the first situation. Changes in the case mix introduce more variation in OR utilization, especially in OR 9. Additionally, there are more and higher overutilized ORs. OR utilization should be lower than one since not all patients are included. Children and emergency patients need OR time as well.

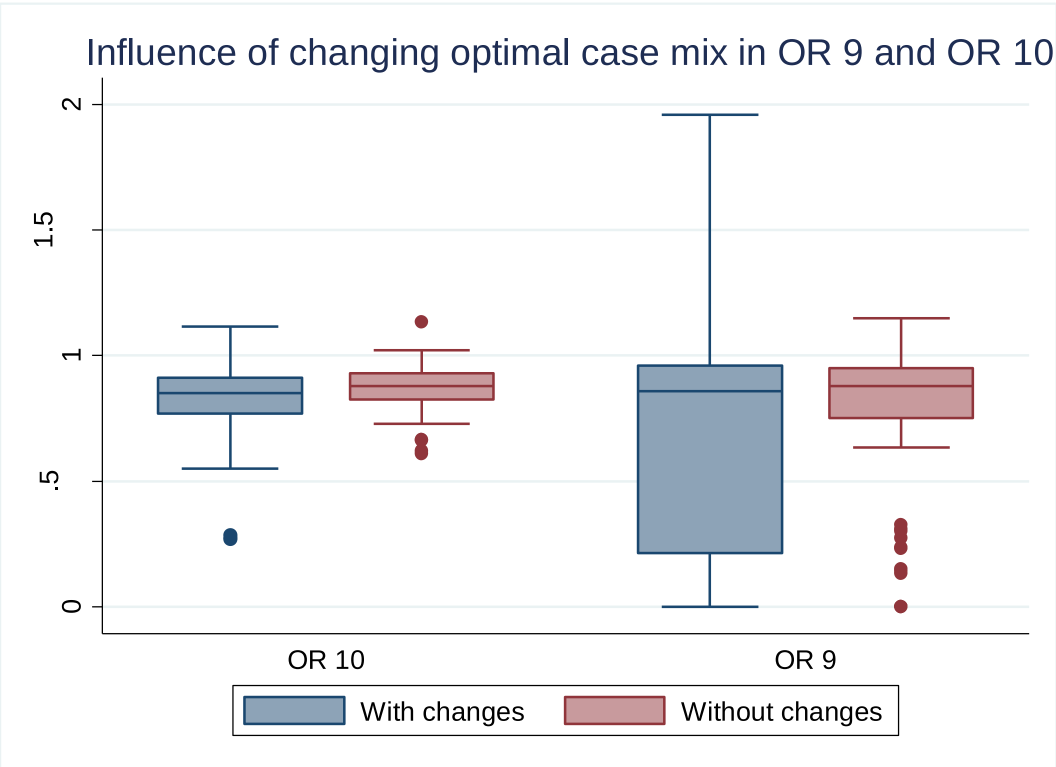

Figure 32: Utilization of OR 9 and OR 10 according to the simulation model by using the case mix and by changing the composition of the case mix for orthopedics (situation 1).

Changes in composition of orthopedic case mix increase fluctuations in ward utilization. Figure 33 shows the difference between the case mix of the QAP model and changes that are made according to situation 1. According to this figure, changes in the composition of the case mix leads to more peaks and troughs in bed utilization of A5. It shows the importance of planning SS patients in the beginning of the week and LS patients at the end of the week.

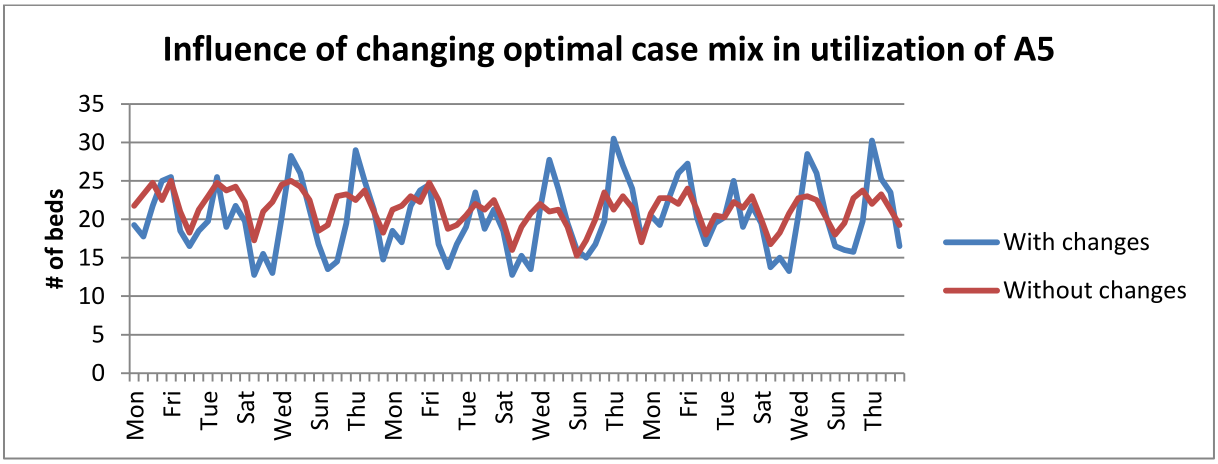

Figure 33: Utilization of A5 according to the simulation model by using the case mix and by changing the composition of the case mix for orthopedics (situation 1).

Situation 2

Variation in OR utilization increases by changing the case mix according to situation 2, especially in OR 10 (see Figure 34). Additionally, there are more and higher overutilized ORs. OR utilization should be lower than one, because not all patients are included. Children and emergency patients need OR time as well.

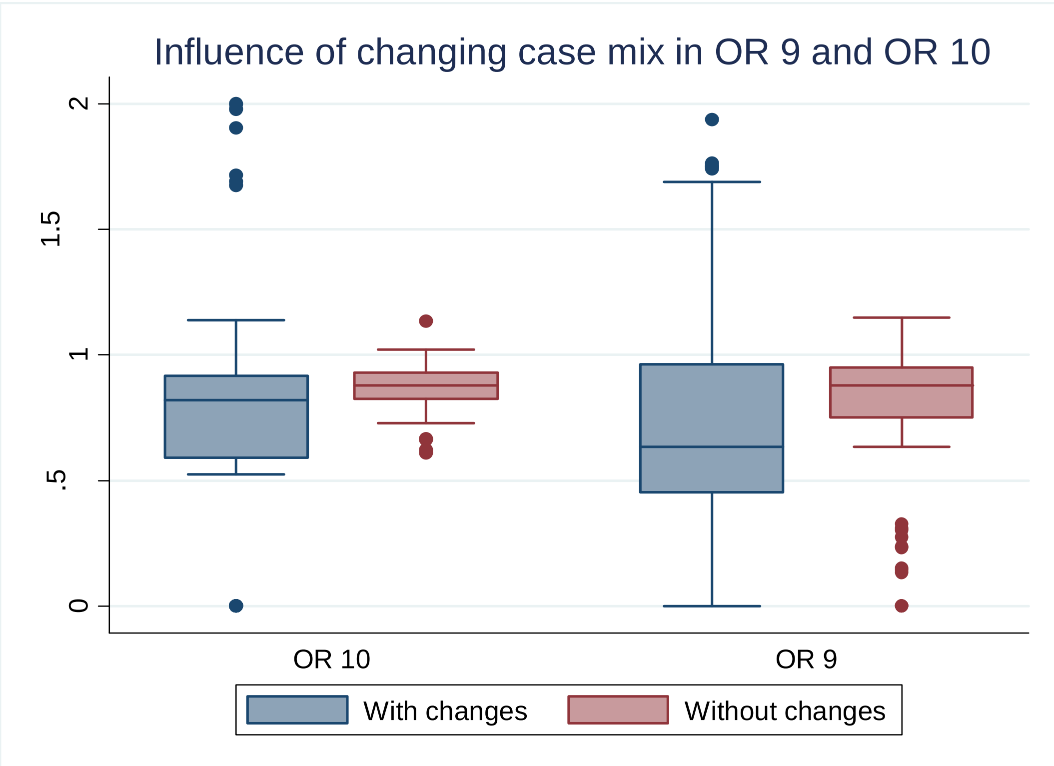

Figure 34: Utilization of OR 9 and OR 10 according to the simulation model by using the case mix and by changing the composition of the case mix for orthopedics (situation 2).

Changes in case mixes according to situation 2 have a negative impact on the utilization of A5 (see Figure 35). Utilization is many times higher than in the situation without changes. At some point the requirement of beds even increases to a maximum of 27 beds while the case mix reaches a maximum of 25.

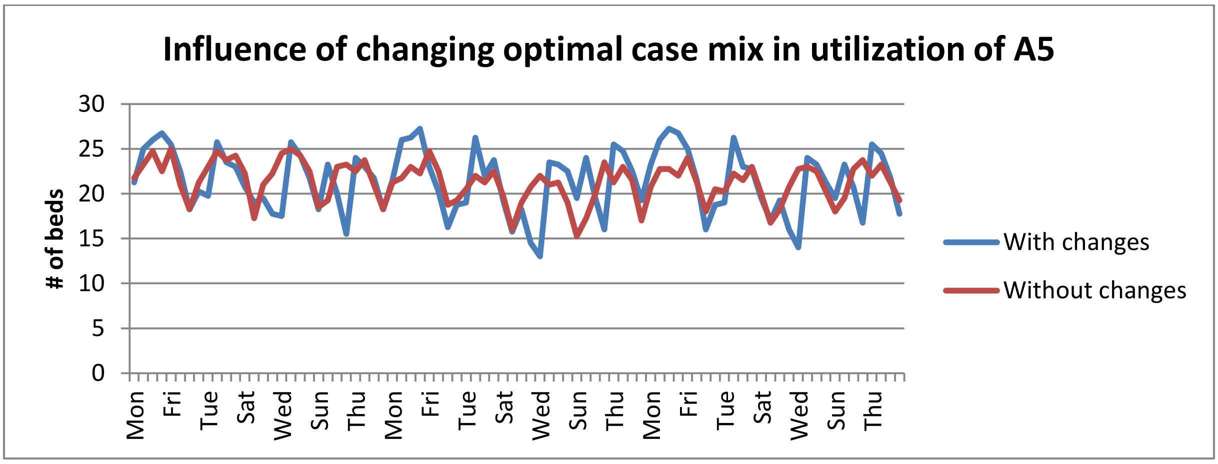

Figure 35: Utilization of A5 according to the simulation model by using the case mix and by changing the composition of the case mix for orthopedics (situation 2).

6.4 Influence of closing ORs

We are interested in the consequences of closing ORs that treats one or two patients per day. These patients are reallocated to underutilized OR days. Underutilization in this case means that the lowerbound of the fixed quota is not reached yet. Table 16 shows ORs that can be closed and slots for reallocation of patients. We think that OR utilization will be a bit higher when a few ORs will be closed, because some ORs will get more patients for surgery. Ward utilization will not change that much, but due to deviations from case mix fluctuations in ward utilization will increase.

Table 17: Possibilities for OR closing and reallocation of patients.

Specialty	Closing OR	Patient reallocation to
KNO	1st Tuesday 1st Thursday 2nd Wednesday 4th Tuesday	1st Monday 1st Friday 3rd Tuesday 4th Monday and 4th Wednesday
PCH	1st Wednesday	2nd Monday
URO	2nd Thursday 3rd Tuesday	1st Thursday and 2nd Tuesday 2nd Tuesday

Figure 36 and Figure 37 show the results when closing the ORs that are mentioned before. The variation in utilization in C3 and K4 are higher when some ORs are closed. We did not include C5, because moving a DT patient from one day to another day means a decrease of one patient on a day and increase of one patient on the other day.

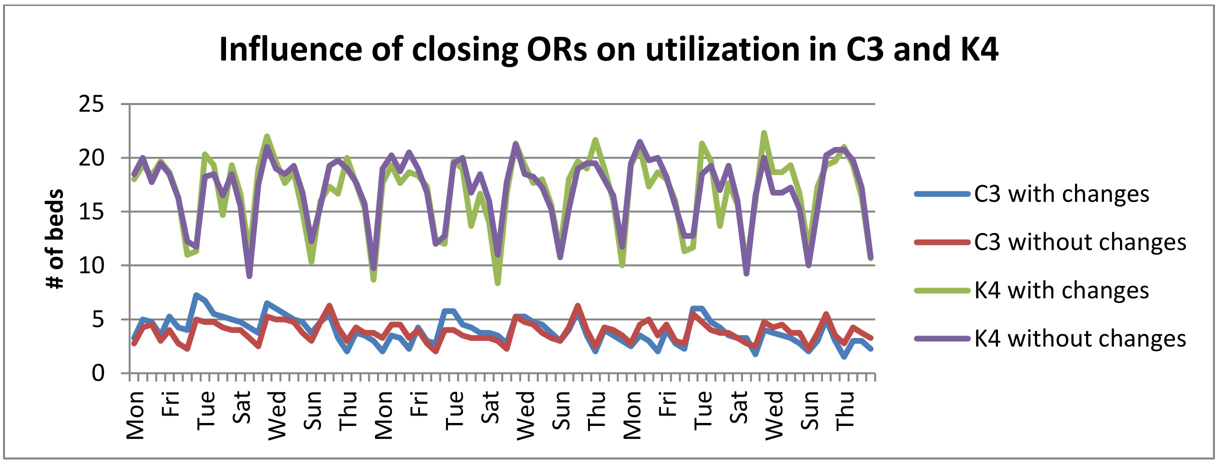

Figure 36: Influence of closing ORs on utilization in C3 and K4, n = 2712, source: simulation model.

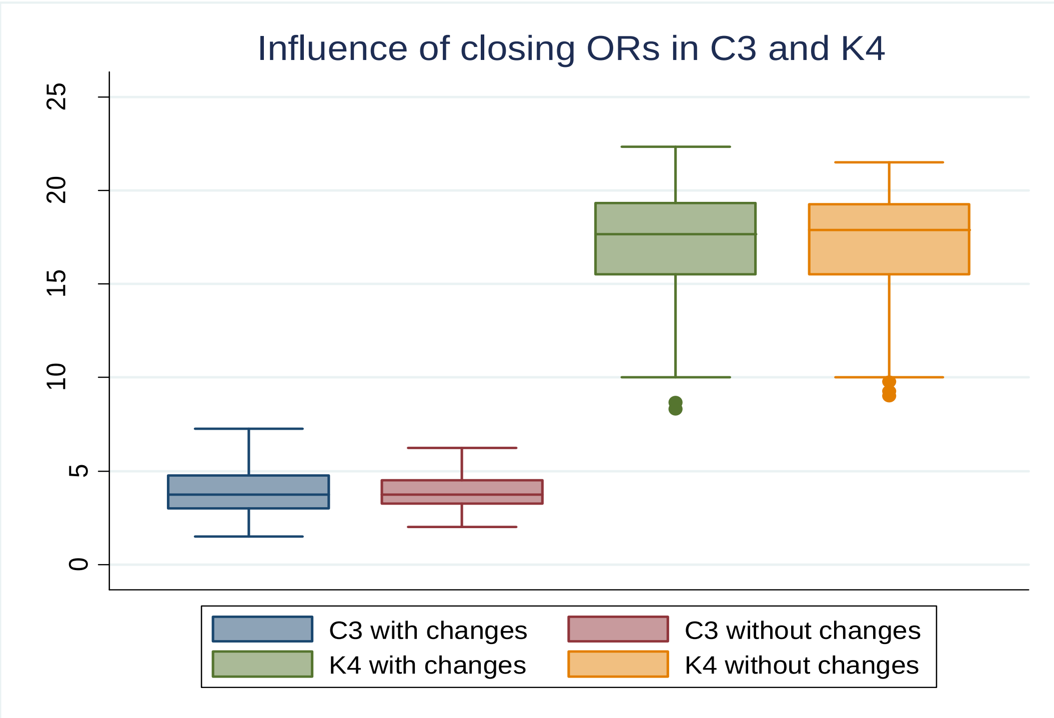

Figure 37: Influence of closing ORs on utilization in C3 and K4, n = 2712, source: simulation model.

Figure 38 shows the utilization in ORs. Variation in OR utilization does not change that much if we close some ORs although some ORs are higher utilized. However, not all patients are included in the output of the QAP model so it could be that closing ORs is not feasible.

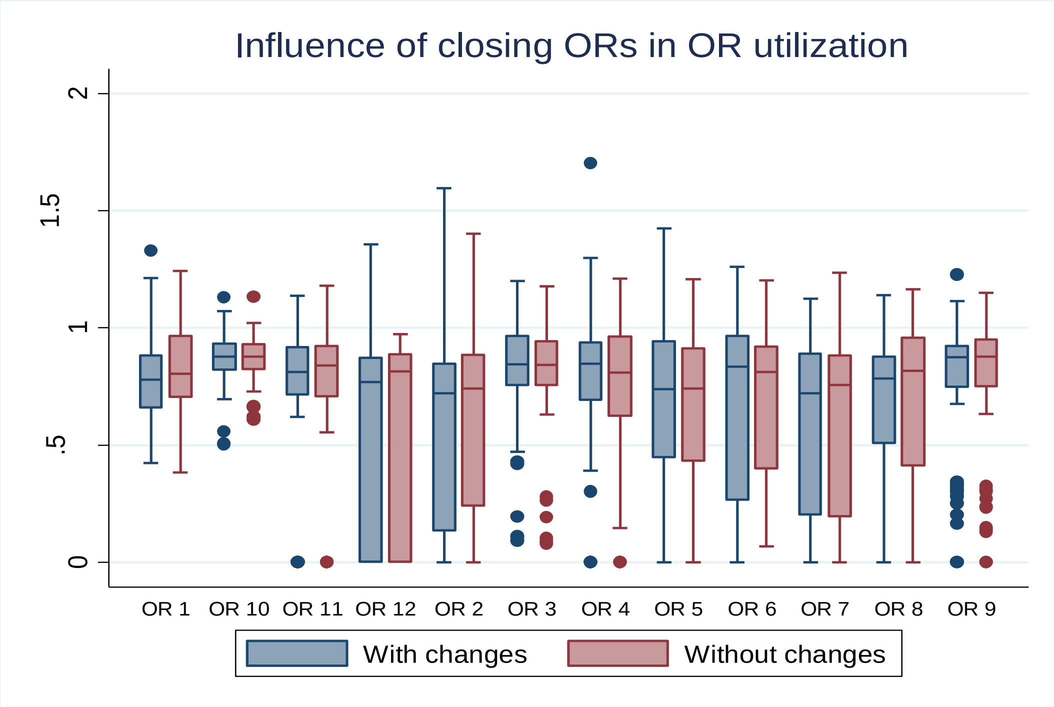

Figure 38: Influence of closing ORs on OR utilization for all twelve ORs, n = 2712, source: simulation model.

6.5 Reduction of OR capacity for elective admission planning

We are curious about what happens if we decrease the available OR time per OR in the QAP model. In Chapter 4 and 5 the available OR time is set as 480 minutes per OR session if there is a full OR available. Therefore, the model can plan patients up to a maximum of 480 minutes. In this way, there is no time left for delays or possible emergencies. First, we decreased the available OR time with one hour, but the model could not handle this. By trial and error we came up to a minimum of 455 minutes per OR. We expect that the utilization will be higher per OR and that some surgeries are moved to another session, because some surgeries do not fit in 455 minutes.

Figure 39 shows the OR utilization per OR. The total utilization is higher for ORs except for OR 8 and OR 11. These ORs are reserved for general surgery. OR 7 has a high variation in OR utilization as well. This OR is mainly used for general surgery. Therefore, probably too much OR time is assigned to general surgery. However, this specialty needs about 20% of their OR time for emergency patient (according to Figure 6). This should be analyzed in more detail to be sure that ORs can be closed.

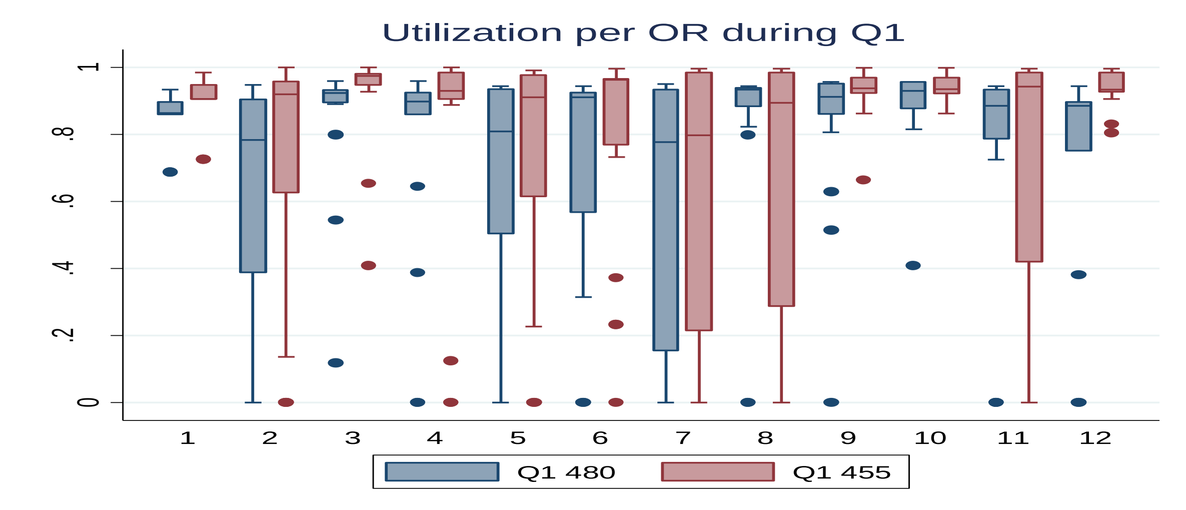

Figure 39: Utilization per OR during Q1 for a maximum available OR time of 480 and 455 minutes, n = 904, source: QAP model.

The utilization of wards does not change when we decrease the available OR time (see Figure 40). Only in the B4 the variation in utilization increases a bit. However, C5 has a high variation in utilization due to a utilization of 16 beds at weekdays, but in the weekends this ward is empty.

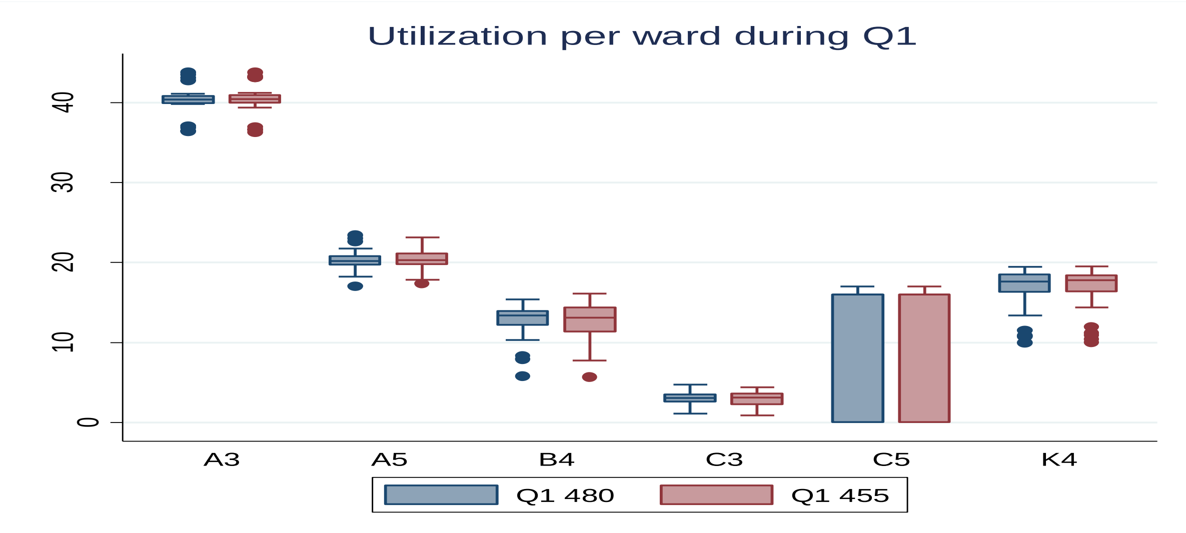

Figure 40: Utilization per ward for Q1 with an OR capacity of 480 and 455 minutes, n = 904, source: QAP model.

6.6 Conclusion sensitivity analysis

We used the following question to find the influence of changes in parameter settings:

What is the influence of changing parameters on the performance of ORs and wards?

To determine the influence of seasonality effects, we analyze the differences between quarter one and three. Differences between quarter one and quarter three are small. The patient population of quarter three is smaller. This results in lower OR and ward utilization. Therefore, revision of the OR schedule is necessary to align OR capacity on the patient population. Detailed analysis is necessary to say something about seasonality effects.

MST expects more DT patients in the upcoming years. This patient group is relatively easy to schedule, because of their predictability. The utilization at C5 will be leveled only if the alignment between specialties is sufficient.

Changes in the case mix of orthopedics have negative influence on ward utilization and OR utilization. Reallocation of LS patient to the beginning of the week results in more bed requirements during the week. Scheduling of SS patients in the second half of the week decreases utilization in the weekend. Therefore, changes in the case mix have influence in ORs and wards. It is necessary to analyze the consequences before changes are made.

Closing ORs has a small impact on OR and ward utilization. However, we closed only ORs with one or two patients in the case mix. Specialties like CHI and ORT have often have two or more OR sessions a day. The consequences of closing other ORs are not tested and probably have positive effects in ORs and wards. However, many patients are not included yet. Therefore, closing ORs is probably not allowed.

Reduction of OR capacity in the QAP model leads to higher utilization and less variation in utilization of ORs. Especially ORs for general surgery show high variation in utilization. Possibly too much surgery time is assigned to this specialty, so decreasing the number of ORs for general surgery is interesting. However, many patients are not included.

7 Implementation

This chapter describes the implementation process for the intervention to obtain leveled bed utilization in wards of MST. The process consists of decision rules related to patient scheduling based on the output of the QAP model. Moreover, we will give an advice to maintain and improve interventions that support ward utilization leveling. The ideal situation integrates an optimization approach in the MST planning tool, but it is unrealistic to realize this in a short period.

Glerum (2014) divided his implementation process in seven steps and starts with only one specialty in the first step to keep focused on fine-tuning the process for that particular specialty. We will expand this to set decision rules for patient scheduling of all specialties in MST.

7.1 Patient scheduling decision rules

We conclude that the QAP model output delivers promising results. These results should be rewritten as decision rules, such that admissions planners can easily follow these rules without use of difficult optimization tools. This is the first step to optimize patient admission planning and ward utilization leveling. Therefore, scheduling rules per patient type for each specialty are described in the remainder of this section. For every specialty, it applies that scheduling of DT patient should be aligned between specialties. Moreover, every day about 16 DT patients should be planned and divided over all specialties together, otherwise C5 has to deal with fluctuations. Appendix F can be used for detailed scheduling decision rules.

KCH: This specialty has only OR time on Monday and Friday. According to the output of the QAP model, the following rules apply:

- Spread DT patients over OR time
- Plan SS patients on Monday
- Plan LS patients on Friday

CHI: Each day of the week this specialty has OR time, but the amount of ORs differs per day (four or five). The following rules are set for CHI:

- Plan DT patients on Monday, Tuesday, Wednesday or Thursday
- Plan SS patients on Monday, Tuesday or Wednesday
- Plan LS patients on Thursday or Friday, exceptions on Monday

GYN: This specialty has OR time on almost every day. However, every two weeks a double OR session on Tuesday occurs. DT patients are mainly scheduled in the extra session. The following planning rules are suitable for GYN:

- Plan DT patient on Tuesday or Wednesday
- Plan SS patients on Monday, Tuesday or Wednesday
- Plan LS patients on Thursday or Friday

KNO: Most of the patients of this specialty are SS patients and should be planned at the beginning of the week. The following guidelines for planning are created for KNO:

- Plan DT patients on Thursday or Friday

- Plan SS patients on Monday, Tuesday or Wednesday, exceptions on Friday
- Plan LS patients on Friday

OOG: This specialty is relatively easy to schedule. Almost all patients are DT patients and OOG has an OR for only one day every two weeks. Therefore, we did not create planning rules for this specialty.

ORT: This specialty treats many patients, but there is a clear trend in the output of the QAP model. We set the following planning rules for ORT:

- Plan DT patients on Monday, Thursday and Friday, exceptions on Tuesday
- Plan SS patients on Monday or Tuesday
- Plan LS patients on Wednesday, Thursday or Friday, exceptions on Monday

PCH: There is no trend in the QAP model output for this specialty. Therefore, we did not create planning guidelines, but we advise to use the case mix matrix out of Appendix F.

URO: Most patients of this specialty are SS patients. According to the QAP model output the following guidelines are suitable for URO:

- Plan DT patients on Thursday
- Plan SS patients on Monday, Tuesday or Wednesday
- Plan LS patients on Thursday or Friday

NCH: This specialty mainly treats LS patients. If there are SS patients, they should be planned at the beginning of the week. Otherwise, LS patients can be planned during the whole week.

- Plan DT patients on Monday
- Plan SS patients on Monday or Tuesday, exceptions on Wednesday
- Plan LS every day of the week

BZH: This specialty only has DT patients. Therefore, we did not create guidelines for BZH.

7.2 Implementation of intervention

We start with a short introduction about implementation strategy according to the literature. Finally, we describe the implementation process by using a seven-step approach.

7.2.1 Implementation strategy

The implementation process has to deal with four different mindsets: care, cure, control and community (Glouberman & Mintzberg, 2001a, 2001b). Due to a distrusting relationship between these mindsets health care is a disconnected system (Van Oostrum, 2009). UHBristol (2009a) explains by means of the clinical audit cycle, how to implement an intervention successfully. UHBristol defines clinical audit as:

"A quality improvement process that measures current patient care and outcomes against agreed standards of best practice." (UHBristol, 2009b)

They proved that this cycle is an effective manner for change in clinics and leads to improvements in patient care, management and outcomes. A maximized likelihood is important to make the change successful. This likelihood arises when staff is motivated, key players are involved, enough resources are available (i.e. finances) and people have confidence in validity and reliability of the project (UHBristol, 2009a). The implementation phase starts when likelihood is created. This phase starts with defining a plan of approach and a timeline for the pilot. After the pilot, an evaluation takes place and possible adjustments are made. This process continues until the intervention is standardized. However, it does not mean that the implementation succeeds. UHBristol (2009a) mentioned the following reasons for failing:

- Lack of resources
- Lack of motivation
- Inadequate management of the processes
- Lack of communication

To prevent failing one has to create a multidisciplinary team with representatives of staff groups, involve people with authority and ensure that the management agrees with the project (UHBristol, 2009a).

7.2.2 Implementation roadmap

We propose a seven-step approach for the implementation of this intervention in MST. This approach is based on the literature of Section 7.2.1. Figure 41 shows this approach.

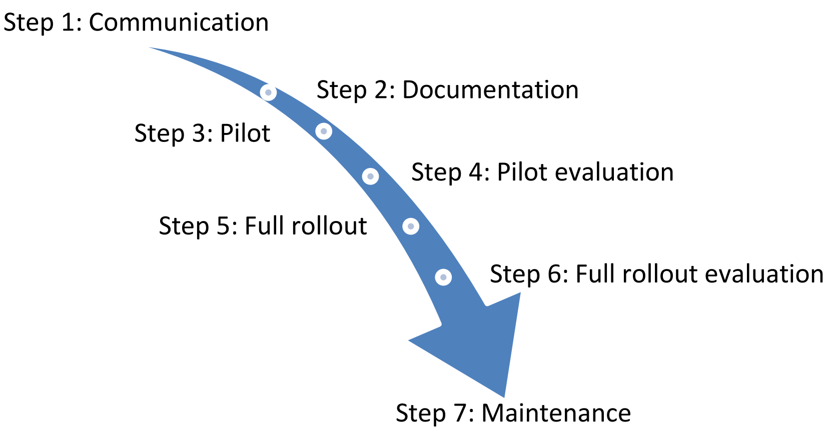

Figure 41: Seven-step approach for the implementation of the intervention

The remainder of this section shows the outline of the seven-step approach. Each part of the approach is described by bullet-points. Using these points in our opinion leads to a successful implementation of the intervention.

Step 1: Communicate with admission planner(s), OR coordinator(s), surgeon(s), and nurse(s)

- Organize a meeting.
- Explain the approach.
- Ask staff feedback.
- Explain benefits for hospital and staff.
- Explain possible insecurities, but convince that benefits outperform the negatives.
- Explain the implementation process.

- Ask staff what indicators they would like to include in the evaluation phase.

Step 2: Document the change process and baseline measurement

- Write down the content and guidelines of the implementation process and let staff comment on it.
- Perform a baseline measurement with the same criteria that are going to be used for the evaluation. See for performance criteria Section 2.3.

Step 3: Pilot for one specialty

- Start a pilot for orthopedics, because this specialty is a good reflection of all specialties.
- Select a multidisciplinary team with representatives of each staff group.
- We suggest a pilot of two/three months (one quarter), because OR schedules are revised every quarter.
- First two weeks have to be excluded, because of start-up problems.

Step 4: Pilot evaluation

- Organize a feedback session every week and a general session at the end of the pilot.
- Compare baseline measurement with pilot measurement.
- Collect experiences from staff members.
- Incorporate the feedback and adjustments in the documentation.
- Include adjustments and feedback during the remaining time of the pilot.

Step 5: Full implementation for all specialties

- Use the documented guidelines and evaluation criteria for all specialties.

Step 6: Full implementation evaluation

- Organize a feedback session per specialty every week.
- Evaluate the full implementation in general after three months (one quarter).
- Make adjustments where needed.
- If necessary, go to Step 5 again (for all or some specialties).

Step 7: Maintenance of implementation

- Organize feedback session after three months during one year (each quarter).
- Continue this until the implementation is standardized.

7.3 Conclusion

Admissions planners should follow the planning decision rules to reduce fluctuations in bed utilization. We propose the seven-step approach of this chapter as guideline for the implementation of our intervention. Additionally, it is necessary to keep staff motivated and involve key-players during the whole implementation process.

8 Conclusions and recommendations

This chapter states the conclusions, limitations, and recommendations for further research. Section 8.1 gives an answer to the research questions and Section 8.2 states the limitations of our study. Section 8.3 provides recommendations for follow-up studies and for MST.

8.1 Conclusions

Our research considers tactical resource capacity planning for MST. The objective of the research is to propose interventions that reduce variability in bed utilization and determine the necessary steps for implementing this concept in the organization. Each sub-question is repeated and corresponding conclusions are given in the remainder of this section.

How can the current OR and ward planning be described and what is the current performance?

Context analysis shows fluctuations in the bed utilization of wards. The patient flow in MST consists of elective and emergency patients. Emergency flows cannot be planned in advance due to its unpredictability. However, data analysis shows that more fluctuations arise in the elective patient flow. Fluctuations are mainly introduced in wards in which more than one specialty is located. Therefore, the core problem is identified to be an insufficient alignment between specialties in elective patient scheduling.

What concepts are mentioned in the literature to organize the core problem(s)?

The literature mentions different methods to level bed utilization, but Glerum (2014) used an interesting approach. They used the approach of Van Oostrum et al. (2008) as starting point and developed it into new approach (MILP model and QAP model). We decide to use the QAP model for MST as well, because of a good balance between improvement potential and feasibility. Moreover, it fits the requirements of MST. The model provides admission planners with advice. This consists of a mix and volume of patients they should preferably schedule on each session to minimize fluctuations in bed utilization.

How can the current organization be improved to anticipate on and reduce variability in bed utilization?

Results of the QAP model show promising improvement potentials in bed utilization, as well as in bed requirements. Total bed requirements are reduced with 29.4%. Additionally, the QAP model introduces higher fluctuations in utilization than there were in quarter one of 2014. The OR utilization generally varies relatively little. For example, 74.93% versus 73.98% for respectively Q1 of 2014 and QAP model.

How does the output of the model in Chapter 4 perform according to a simulation?

Compared to the QAP model the variation in bed utilization for simulations is higher, though lower than the realized situation of quarter one in 2014. The total bed requirement is reduced with 14.1%. Fluctuations in OR utilization increases compared to QAP model. The average OR utilization is 70.78%.

What is the influence of changes in parameters on the performance of ORs and wards?

We conclude that the patient population in summer is a bit smaller compared to the one in winter. However, seasonal effects are unclear if one only considers the size of the patient population. More aspects should be included to draw useful conclusions about seasonal effects, for example holiday periods.

MST expects an increase in DT patient population. This is relatively easy to schedule, because of a good predictability of these patient types. Moreover, all DT patients should be spread out over weekdays such that ward utilization is leveled (about 16 each day).

Changes in the case mix have a negative influence on ward utilization, because fluctuations in bed utilization and bed requirements increase. This implies that it is necessary to plan SS patients in the first half of the week and LS patients in the second half whenever this is possible.

Some ORs were closed, because of low utilization. This does not influence utilization in ORs and wards significantly, by which we can conclude that some specialties possibly need less surgery time. However, some patient types are excluded and there should be surgery time for these patients.

Reduction of OR capacity in the QAP model leads to a higher utilization and the corresponding variation decreases. Especially ORs for general surgery currently show high variation in utilization. The assigned surgery time to this specialty might be too large, which makes it interesting to investigate a decrease in the number of ORs for general surgery. It should however be noted that many patients are not included yet.

How can the implementation phase be organized to implement the proposed interventions?

First, we created some planning decision rules per specialty for planning of elective patient. These rules are guidelines for admissions planners. General rules are:

- Spread DT patients over the week (about 16 a day)
- Plan SS patients in the first half of the week
- Plan LS patients in the second half of the week

We created a seven-step approach for the implementation of the intervention. This approach consists of communication, documentation, pilot, pilot evaluation, total rollout, rollout evaluation, and maintenance. It is necessary to motivate and involve staff during the whole implementation process to make the implementation of the intervention successful.

8.2 Limitations of this study

During this study, limitations were encountered in the data collection, in the QAP model and in the simulation model.

Data used for QAP model

It was hard to collect historical data. ORs and wards have separate data storage systems. Therefore, it is hard to connect these data files. We connected these files according to admission numbers, but had to deal with missing numbers. Additionally, admission times were incomplete by which these patients are also missing in our data analysis. 73% of the total surgery related patient population is included. The missing population consists of 22% children or emergencies and 5% data issues. The missing patients have influence on OR and ward utilization. However, data issues has a small influence, because it is only 5%. Emergencies and children are outside the scope of this research and should be analyzed in further research.

QAP model

Some specialties are located in different wards, such as general surgery (A3 and C3). The QAP model cannot handle this, so we assumed that this specialty is located at A3 only. This limits the results of the QAP model for MST. By using the case mixes in the current situation, admission planners should be alerted in scheduling the right mix of patients for general surgery. For example in creating the best mix of oncology and vascular patients per day. For more limitations we refer to Section 5.5 of Glerum (2014).

Simulation model

The simulation model can be improved by using stochastic arrival times, strict patients, and OR closing times. Stochastic arrival times improve LoS, because in our situation all patients arrive at 8.00 a.m. and the LoS starts at the same moment. Therefore, discharge is probably earlier than in reality. Moreover, we did not consider strictness of a patient. Some patients need a specific specialist and are therefore limited in their possibilities for surgery. This probably deviates from the case mix and has influence on ORs and wards. Additionally, closing times for ORs are necessary to get a better representation of OR utilization, because the utilization of 200% is not a credible representation.

According to the case mix, it is possible to schedule four LS patients with surgery duration of two hours in one OR session of eight hours, but there are LS patients with surgery duration of eight hours. These differences lead to changes in the case mix and ward utilization, because fewer patients can be scheduled if surgery duration is high and higher surgery duration leads to longer LoS. The influence of differences in surgery duration has a negative effect in the simulation model, because some days are far overutilized due multiple long surgeries in one OR session.

8.3 Recommendations

This section describes recommendations for MST and for further research.

OR schedule

OR analysis reveals a frequent underutilization of ORs. We recommend to revise the OR schedule, because some specialties need less surgery time than actually scheduled. However, not all patients are included and there should be time left for these patients. Additionally, the division of OR time over specialties should be analyzed. OR time, of specialties that are located at the same ward, should be divided over the week to evenly regulate the patient flow over the ward.

MST uses an OR schedule for about three months ahead. A more generic and repeatable schedule leads to more transparency for stakeholders. Additionally, admissions planners can probably use the guidelines for planning throughout the year. We advise to analyze the influence of using an MSS for more than three months.

QAP model

We will cite one recommendation of Glerum (2014), because we think that this will be a necessary step to improve the QAP model. “*We recommend investigating the possibility to create sub-groups within the case types, by subdividing a case type into different clusters with homogenous surgery durations.” (Glerum, 2014)*. More recommendations can be found in Section 9.2 of Glerum (2014).

Admission scheduling

Admission planners can follow the planning decision rules whenever there are enough patients available on the waiting list. We advise MST to analyze waiting lists in combination with the case mix. Additionally, admission planners should have the possibility to see the consequences of patient scheduling in ward utilization. Planning tools need an expansion package with this option.

Data

Data storage and outpatient clinics should include an extra data type, because we cannot make a division in patient types out of the current data. Each patient needs a classification as DT, SS, or LS. In this way, admission planners can easily schedule patients according to our guidelines.

Finally, general surgery consists of different sub-specialties. This limits the scheduling process in the QAP model, because differences in surgery time and LoS within this specialty are large. We advise to analyze this specialty in more detail to identify these differences and to create three new specialties instead of one specialty.

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Appendix A: Map of each ward floor in the new hospital

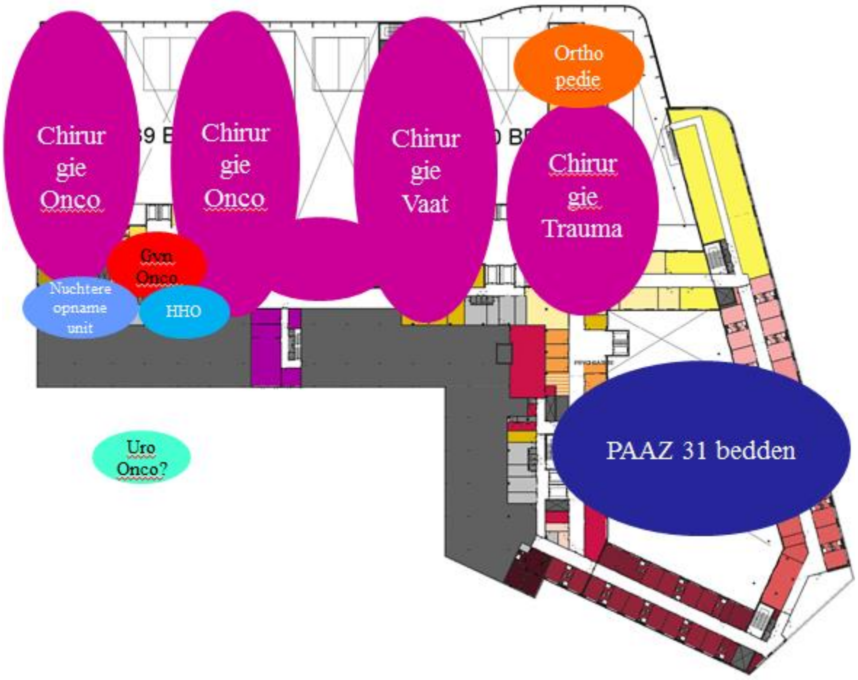

Figure 42: Capacity allocation on fourth floor in the new MST building.

Figure 43: Capacity allocation on fifth floor in the new MST building.

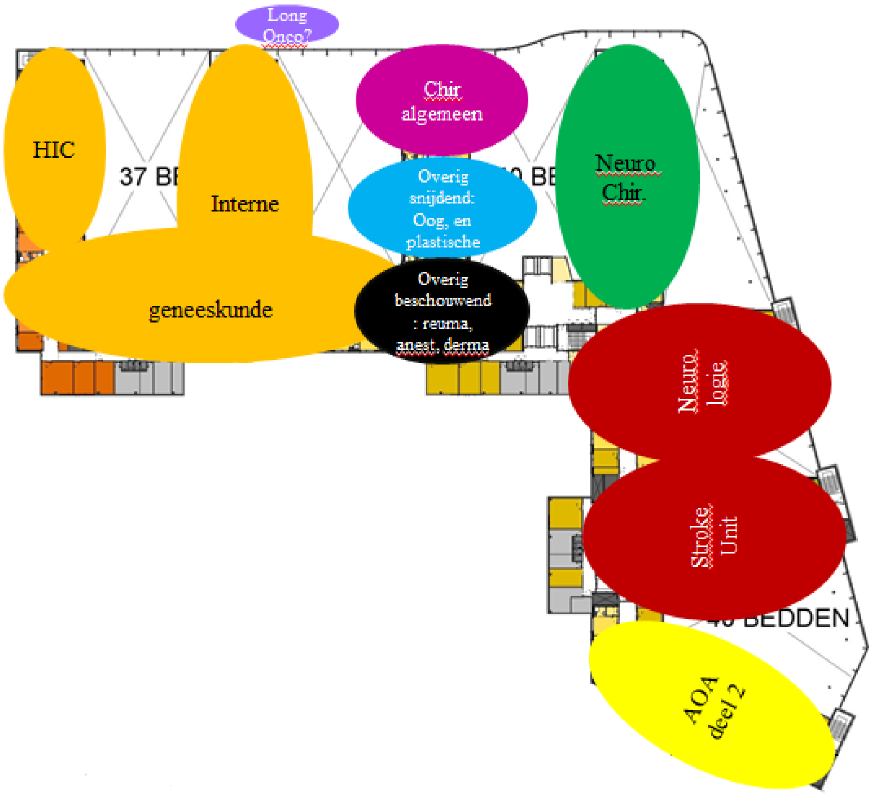

Figure 44: Capacity allocation on sixth floor in the new MST building.

Appendix B: Patient types per ward

Overview of patient types per ward. Wards should treat patient according to Table 3. Deviations from that table means that there are probably boarded patients. The data is of the first quarter in 2014 (01-01-2014 to 31-03-2014).

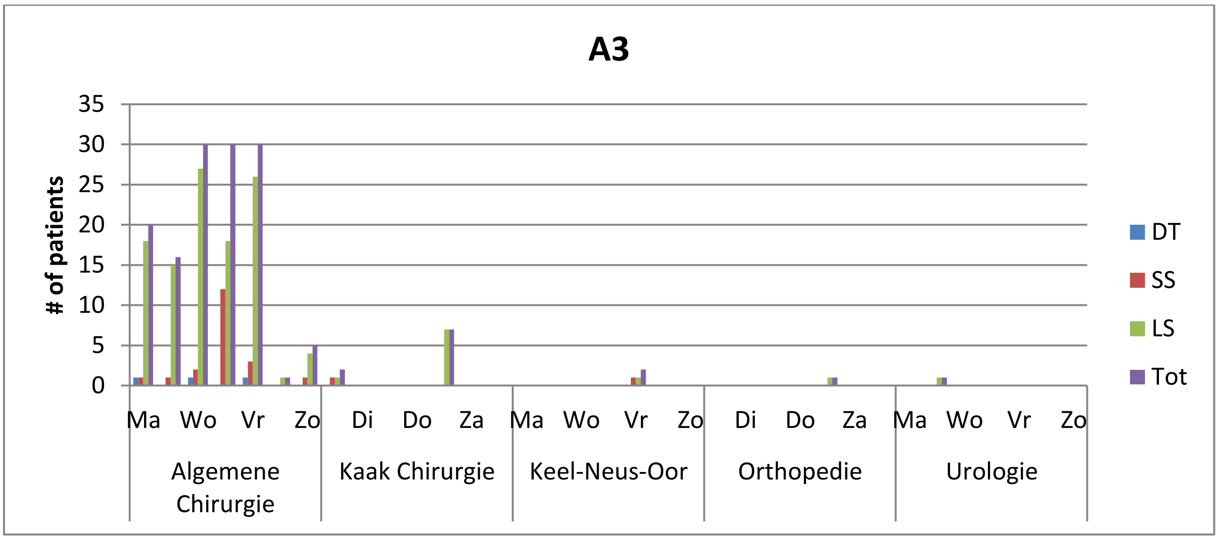

Figure 45:Number of patient types per specialty in A3 during 01-01-2914 to 31-03-2014, source: Xcare.

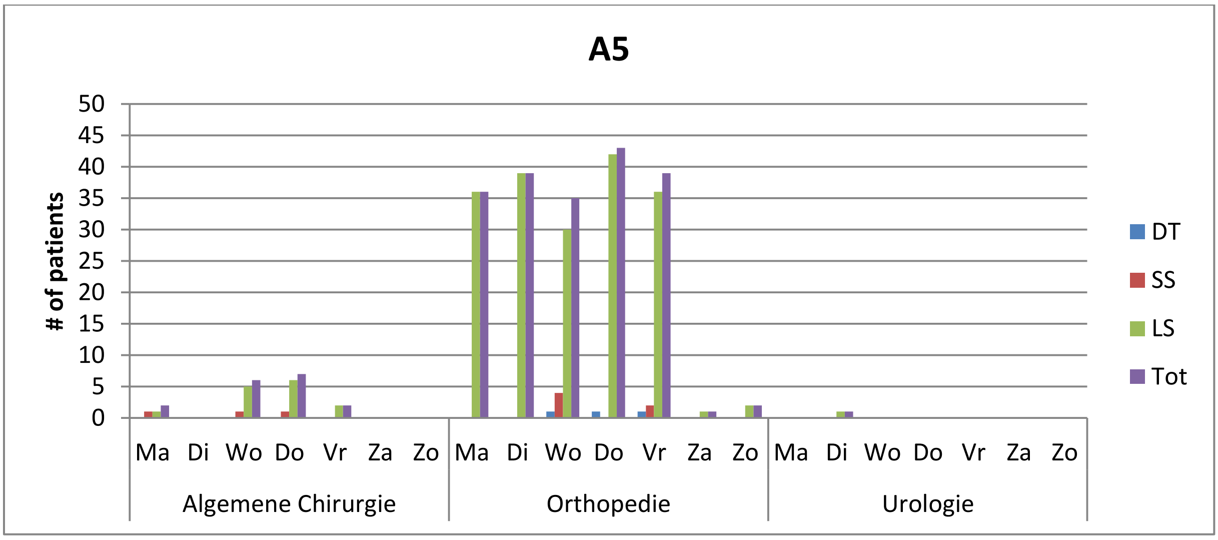

Figure 46:Number of patient types per specialty in A5 during 01-01-2914 to 31-03-2014, source: Xcare.

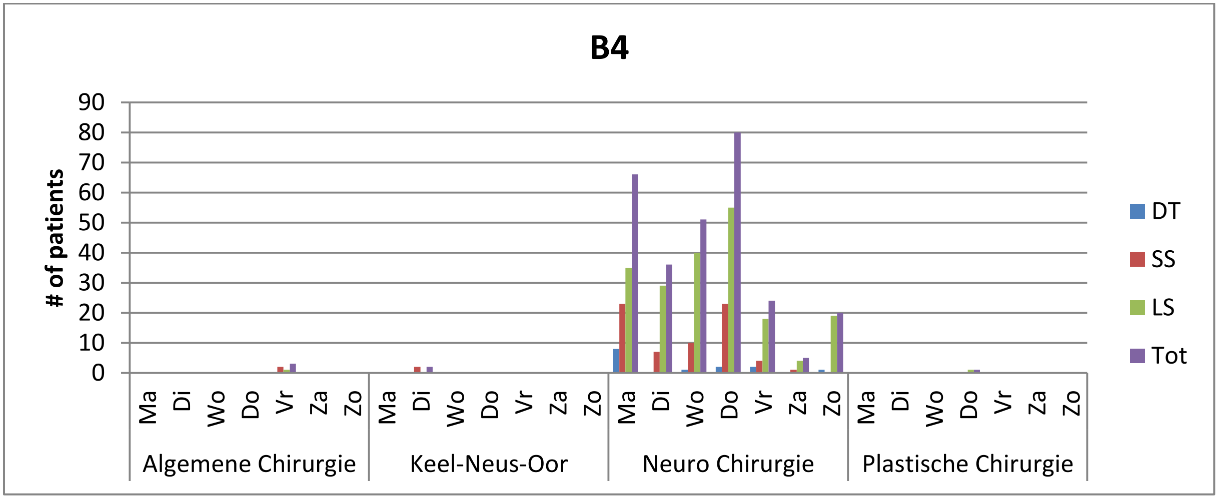

Figure 47:Number of patient types per specialty in B4 during 01-01-2914 to 31-03-2014, source: Xcare.

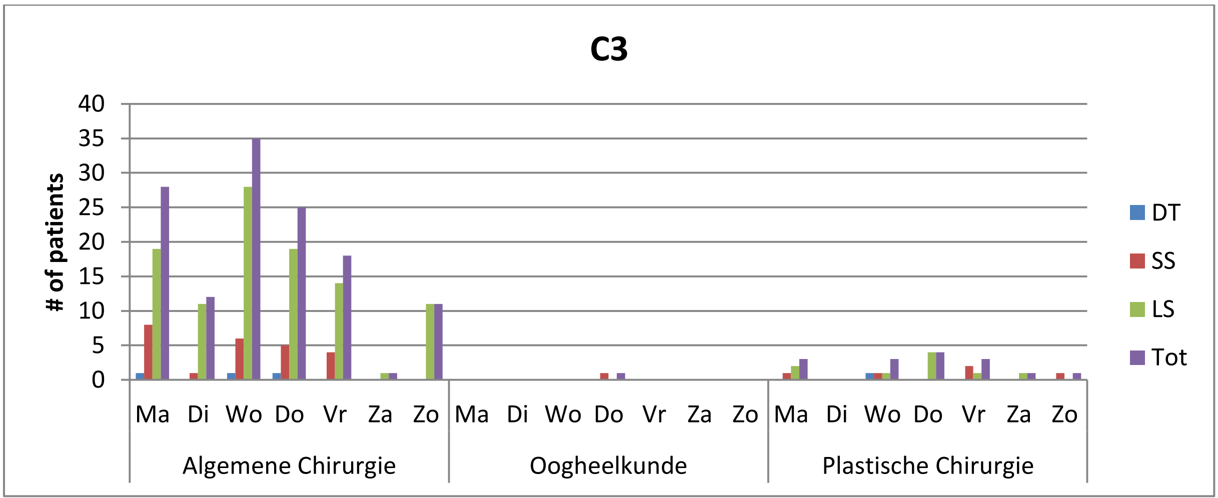

Figure 48:Number of patient types per specialty in C3 during 01-01-2914 to 31-03-2014, source: Xcare.

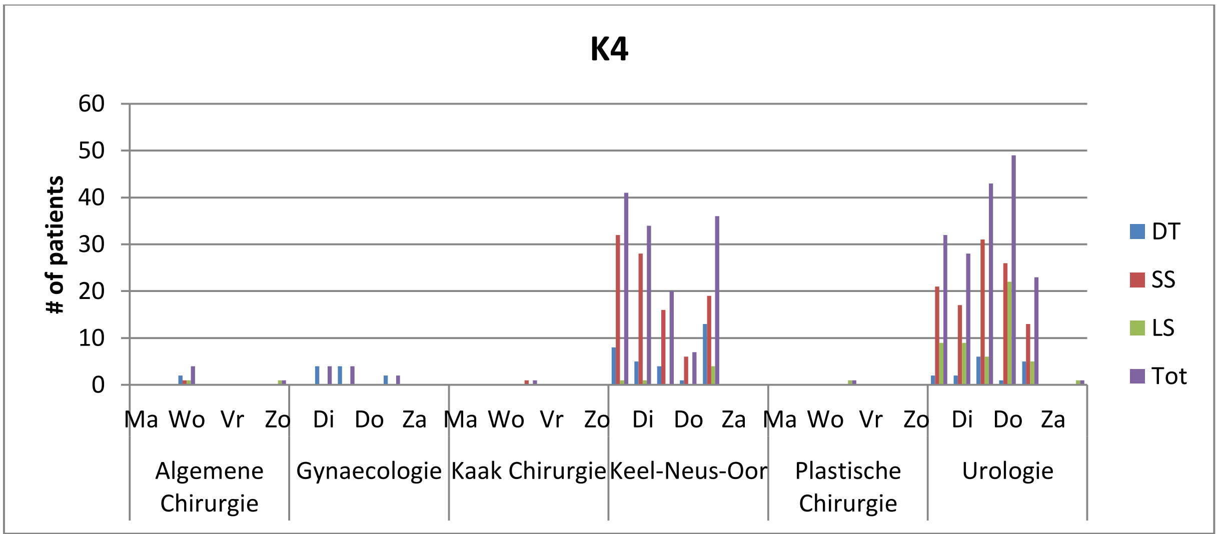

Figure 49:Number of patient types per specialty in K4 during 01-01-2914 to 31-03-2014, source: Xcare.

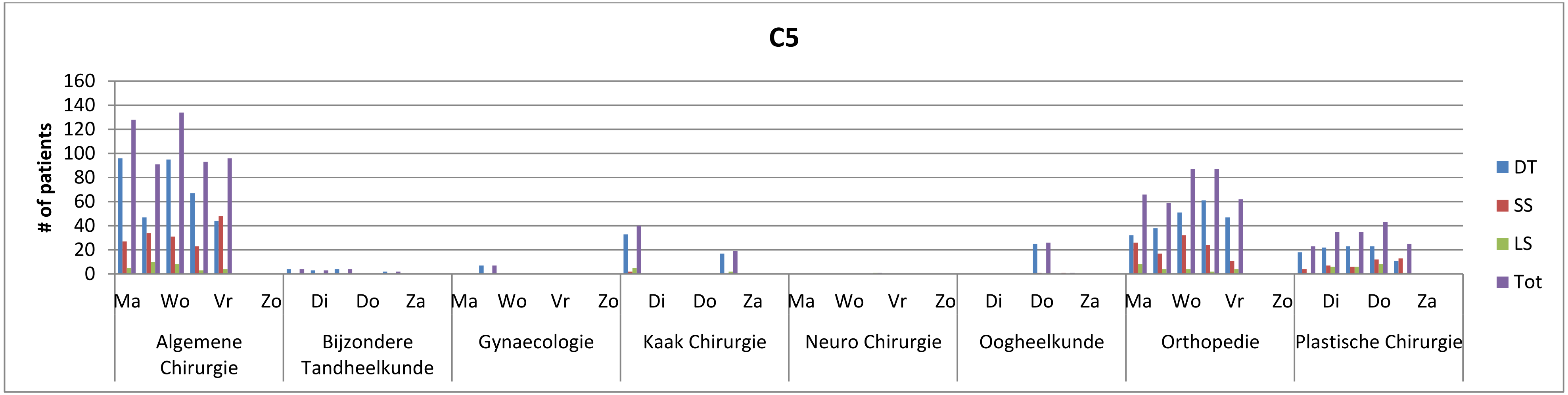

Figure 50: :Number of patient types per specialty in C5 during 01-01-2914 to 31-03-2014, source: Xcare.

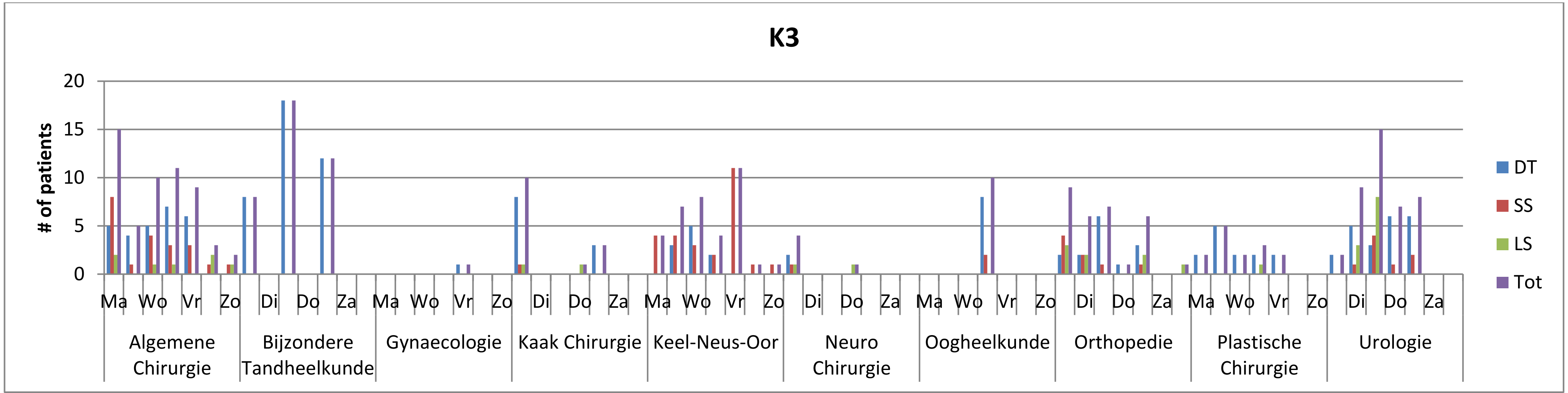

Figure 51:Number of patient types per specialty in K3 during 01-01-2914 to 31-03-2014, source: Xcare

Appendix C: Bed utilization per ward

These images show the utilization and admissions per ward during quarter one in 2014.

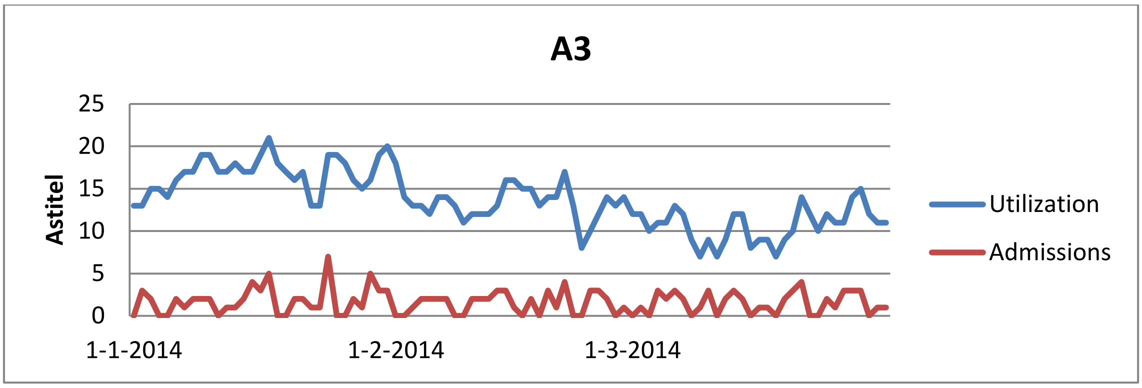

Figure 52: Utilization and admissions of A3 during 01-01-2014 to 31-03-2014, source: Xcare & ORsuite.

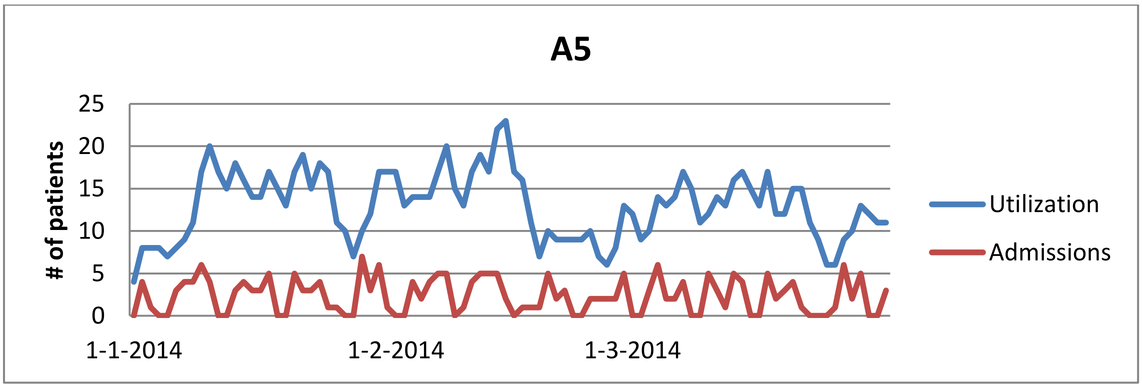

Figure 53: Utilization and admissions of A5 during 01-01-2014 to 31-03-2014, source: Xcare & ORsuite.

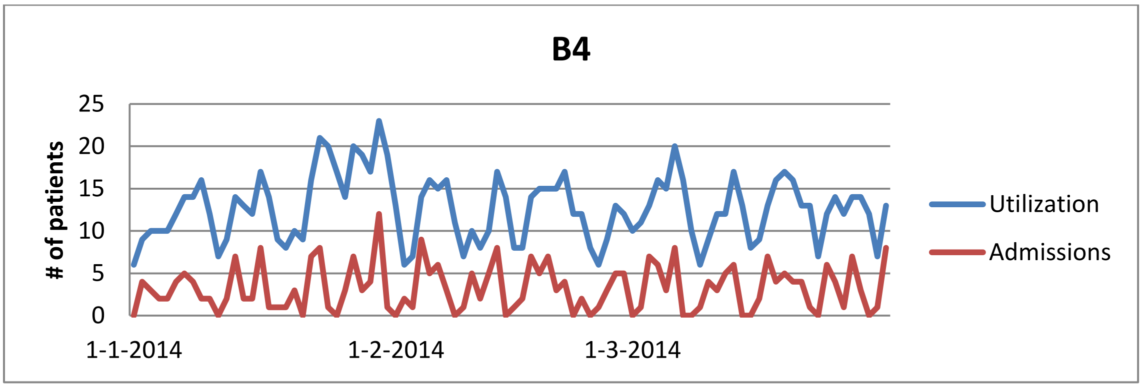

Figure 54: Utilization and admissions of B4 during 01-01-2014 to 31-03-2014, source: Xcare & ORsuite.

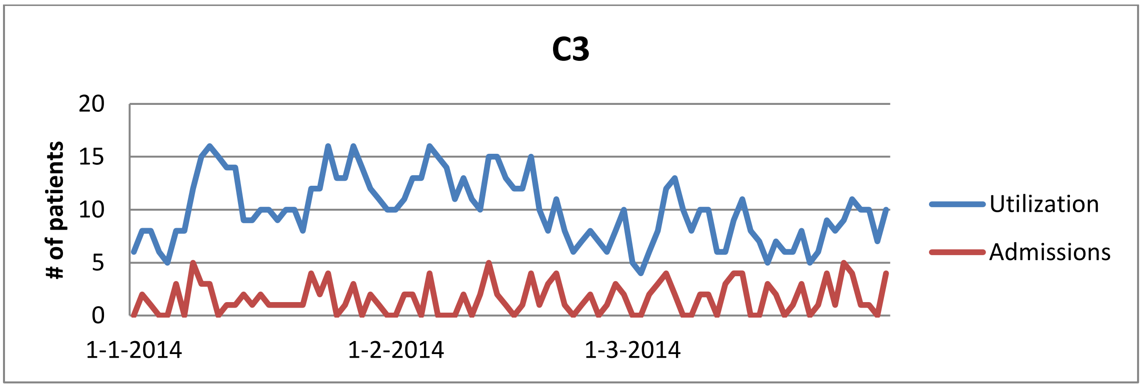

Figure 55: Utilization and admissions of C3 during 01-01-2014 to 31-03-2014, source: Xcare & ORsuite.

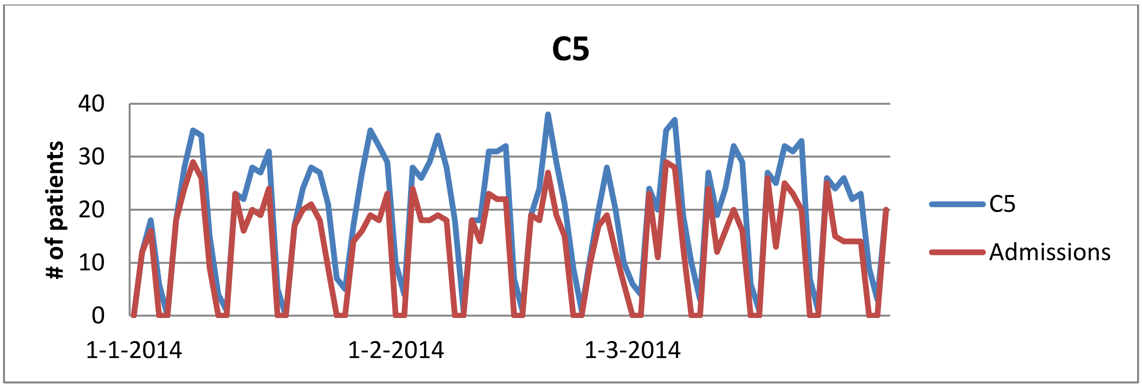

Figure 56: Utilization and admissions of C5 during 01-01-2014 to 31-03-2014, source: Xcare & ORsuite.

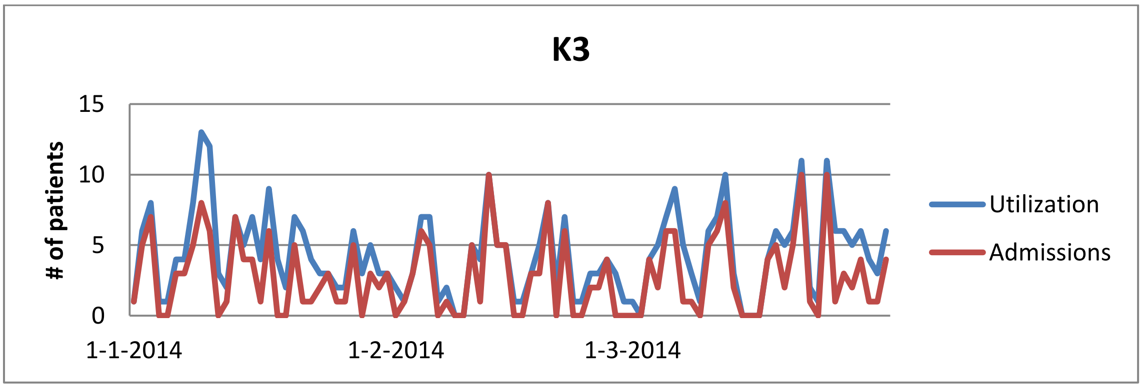

Figure 57: Utilization and admissions of K3 during 01-01-2014 to 31-03-2014, source: Xcare & ORsuite.

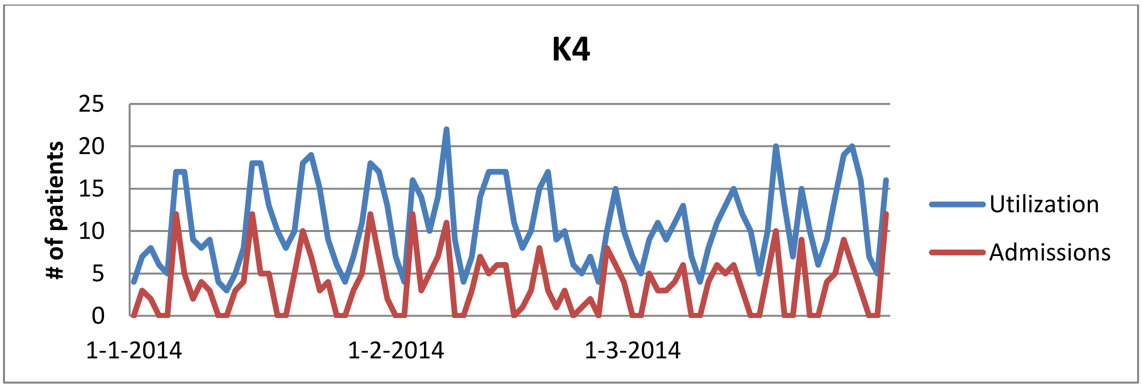

Figure 58: Utilization and admissions of K4 during 01-01-2014 to 31-03-2014, source: Xcare & ORsuite.

Appendix D: QAP model description

Entities, input parameters, and decision variables:

Table 18: Input entities

Entities	Set	Index
Cycle horizon	T	t
Operating rooms	J	j
Bed types	B	b
Case types	I	i
Set of ORs j and days t in which specialty i can perform surgery	S^i	j, t

Table 19: Input parameters

Parameters	Notation
Expected surgery duration in minutes needed by case type i	$e_i \in \mathbb{Z}^+$
Capacity of OR j on day t in minutes	$o_{j,t} \in \mathbb{Z}^+$
Demand for case type i	$d_i \in \mathbb{Z}^+$
Probability of case type i being in bed type b after t days	$p_{b,i,t} \in \mathbb{R}, 0 \leq p_{b,i,t} \leq 1$
Maximum number of nights required in bed type b by case type i	$I_{b,i} \in \mathbb{Z}^+$
Priority factor for bed type b, $\sum \boldsymbol{c_b} = \mathbf{1}$	$c_b \in \mathbb{R}, 0 \leq c_b \leq 1$
Setup time in minutes between operations	$St \in \mathbb{Z}^+$
Weight for objective 1	θ_1
Weight for objective 2	θ_2

Table 20: Decision variables

Decision variables	Notation
Number of case types i scheduled in OR j on day t	$V_{i,j,t}$
Maximum demand for bed type b (performance indicator goal 2)	Z_b
Maximum utilization of all ORs (performance indicator of goal 1)	U
Utilization of bed type b on day t	$ZZ_{b,t}$
Utilization of OR j on day t	$UU_{j,t}$
Number of setups needed in OR j on day t	$ST_{j,t}$

Quadratic Assignment Problem model:

Glerum (2014) describes the MILP model as follow:

> *"The objective function minimises two weighted goals: minimizing the peaks in OR utilisation and minimising the peaks in bed demand. Both measures are normalised by expressing them as percentages utilisation. The peaks in bed demand per bed type are determined by dividing the observed peak in bed demand by the theoretical optimal, completely levelled, bed demand. This is comparable to the technique used by Van Oostrum et al. (2008). Minimising peaks in OR utilisation might seem counterintuitive since maximising OR utilisation might free up an entire OR that can be closed. In this case however, considering the inherent variation in surgical durations per case type, we want to maximise the unscheduled time per session to maximise the chances an admission planner is able to fill a session according to the desired mix without overtime. Constraint (1) ensures that all demand is scheduled whilst only allowing case types to be scheduled on a day S_i their specialty has OR time. Constraint (2) sets decision variable $ZZ_{b,t}$ to reflect the daily peak in bed demand for each bed type and day. The term t-f in decision variable $V_{i,j,t-f}$ should be read as modulo T to incorporate patients still in a bed at the end of the cycle horizon. Constraint (3) sets decision variable and performance indicator Z_b at the peak of bed demand for bed b over the entire planning horizon, this is comparable to the technique used by Van Oostrum et al. (2008) to model a minmax objective. Constraint (4) determines the OR capacity needed by all case types scheduled on that day and OR. Constraint (5) ensures that this workload does not exceed the available capacity of the OR on that day. Constraint (6) sets decision variable and performance indicator U such that it reflects the peak in OR utilisation for all ORs in the planning horizon as a percentage compared to full utilisation. Constraints (7) and (8) determine how many setups are needed in an OR per day, which is equal to the number of surgeries minus one if there is more than one surgery scheduled, zero otherwise" (Glerum, 2014).*

Glerum (2014) changes MILP model to the QAP model as follow:

> *"As mentioned in Section 2.4 the goal is to minimise variation in the demand for resources. Even though reducing peaks in demand almost certainly also reduces variation in demand, it is not necessarily the case that minimizing the peak in demand also minimises demand variation. To this end we also model the case type scheduling problem as a Quadratic Assignment Problem (QAP), with the objective of minimising the squared deviation from the mean. To do this we make a few changes to the MILP formulation from Section 5.2.2:*
>
> *Additional decision variable AV_b: the average bed utilisation for bed type b over the cycle horizon (constraint 9)" (Glerum, 2014).*

Objective function:

$$minimize\ \frac{1}{T*B}\sum_{b\epsilon B}\sum_{t\epsilon T}(ZZ_{b,t}-AV_b)^2$$

Constraints:

$\sum_{(j,t)\in S^i} V_{i,j,t} = d_i$	$\forall i \in I$	(1)
$\sum_{i\in I}\sum_{j\in J}\sum_{f=1} p_{b,i,f} * V_{i,j,(t-f)^*} = ZZ_{b,t}$	$\forall b \in B, t \in T$	(2)
$ZZ_{b,t} \leq Z_b$	$\forall b \in B, t \in T$	(3)
$\sum_{i\in I} e_i * V_{i,j,t} + ST_{jt} * st = UU_{j,t}$	$\forall j \in J, t \in T$	(4)
$UU_{j,t} \leq o_{j,t}$	$\forall j \in J, t \in T$	(5)
$\frac{UU_{j,t}}{o_{j,t}} \leq U$	$\forall j \in J, t \in T$	(6)
$(\sum_{i\in I} V_{i,j,t}) - 1 \leq ST_{j,t}$	$\forall j \in J, t \in T$	(7)
$\sum_{i\in I} V_{i,j,t} \geq ST_{j,t}$	$\forall j \in J, t \in T$	(8)
$\frac{1}{T}\sum_{t\in T} ZZ_{b,t} = AV_b$	$\forall b \in B$	(9)

Appendix E: Input for the QAP model

BLOKplan

		H OK 1	H OK 2	H OK 3	H OK 4	H OK 5	H OK 6	H OK 7	H OK 8	H OK 9	H OK 10	H OK 11	P-OK	TCT OK 4	O OK 19	TCT OK 1	TCT OK
01-03-2015	Zondag																
02-03-2015	Maandag	NE	UR	CH	NE	KA	KN	CH	CH	OR	OR	CH	KN & PPA		OO & OO	CTC	CTC
03-03-2015	Dinsdag	NE	GY	GY	PPA	PL	KN	CH	CH	OR	OR	CH	BT	CH	OO & OO	CTC	CTC
04-03-2015	Woensdag	NE	UR	GY	PL	IG & UR	CH	CH	CH	OR	OR	CH	KN & PPA	CH	OO & OO	CTC	CTC
05-03-2015	Donderdag	NE	UR	GY	CH	PL	KN	OO & OO	CH	OR	OR	CH	PPA	CH	OO & OO	CTC	CTC
06-03-2015	Vrijdag	NE	UR	GY	CH	PL	KN	CH	CH	OR	OR	CH	KN & PPA	KA	OO & OO	CTC	CTC
07-03-2015	Zaterdag																
08-03-2015	Zondag																
09-03-2015	Maandag	NE	CH	CH	NE	PL	KN	BT	CH	OR	OR	CH	KN & PPA	CH	OO & OO	CTC	CTC
10-03-2015	Dinsdag	IG & NE	UR	UR	GY	CH	KN	CH	CH	OR	OR	CH	PPA	CH		CTC	CTC
11-03-2015	Woensdag	NE	UR	CH	PL	UR	KN	BT	CH	OR	OR	CH	KN & PPA	CH	OO & OO	CTC	CTC
12-03-2015	Donderdag	NE	UR	GY	NE	PL	CH	CH	CH	OR	OR	CH	PPA		OO & OO	CTC	CTC
13-03-2015	Vrijdag	CH	UR	GY	KA	PL	KN	CH	CH	OR	OR	CH	KN & PPA		OO & OO	CTC	CTC
14-03-2015	Zaterdag																
15-03-2015	Zondag																
16-03-2015	Maandag	NE	UR	GY	NE	KA	CH	CH	CH	OR	OR	CH	KN & PPA		OO & OO	CTC	CTC
17-03-2015	Dinsdag	NE	UR	GY	GY	PL	KN	CH	CH	CH	OR	CH	PPA	CH	OO & OO	CTC	CTC
18-03-2015	Woensdag	NE	UR	GY	PL	IG & UR	CH	BT	CH	OR	OR	CH	KN & PPA	CH	OO & OO	CTC	CTC
19-03-2015	Donderdag	NE	UR	GY	NE	PL	CH	OO & OO	CH	OR	OR	CH	PPA	CH	OO & OO	CTC	CTC
20-03-2015	Vrijdag	NE	UR	GY	CH	CH	KN	BT	CH	CH	OR	CH	KN & PPA		OO & OO	CTC	CTC
21-03-2015	Zaterdag																
22-03-2015	Zondag																
23-03-2015	Maandag	NE	CH	GY	KA	PL	KN	NE	CH	CH	OR	CH	KN & PPA	CH	OO & OO	CTC	CTC
24-03-2015	Dinsdag	IG & NE	UR	GY	PPA	PL	KN	CH	CH	OR	OR	CH	BT	CH		CTC	CTC
25-03-2015	Woensdag	NE	UR	GY	NE	CH	KN	CH	CH	OR	OR	CH	KN & PPA	CH	OO & OO	CTC	CTC
26-03-2015	Donderdag	NE	UR	GY	NE	CH	CH	CH	CH	OR	OR	CH	PPA	PL	OO & OO	CTC	CTC
27-03-2015	Vrijdag	NE	CH	GY	KA	PL	KN	CH	CH	OR	OR	CH	KN & PPA		OO & OO	CTC	CTC

Figure 59: OR schedule during 01-03-2015 to 27-03-2015, source: BLOKplan.

Table 21: Surgery related properties per patient type

Specialty	Type	Patients	Ward	Expected demand (28d)	Expected surgery duration (min)
KCH	DT	All DT	C5	19	57
KCH	SS	Clinical <= 1.5	A3	2	87
KCH	LS	Clinical > 1.5	A3	5	156
CHI	DT	All DT	C5	127	56
CHI	SS	Clinical <= 1.5	A3	74	82
CHI	LS	Clinical > 1.5	A3	111	146
GYN	DT	All DT	C5	28	56
GYN	SS	Clinical <= 1.5	K4	25	103
GYN	LS	Clinical > 1.5	K4	37	107
KNO	DT	All DT	C5	10	47
KNO	SS	Clinical <= 1.5	K4	36	106
KNO	LS	Clinical > 1.5	K4	3	104
OOG	DT	All DT	C5	9	52
OOG	SS	Clinical <= 1.5	K4	1	58
OOG	LS	n.a.	K3	0	-
ORT	DT	All DT	C5	81	44
ORT	SS	Clinical <= 1.5	A5	40	72
ORT	LS	Clinical > 1.5	A5	77	111
PCH	DT	All DT	C5	35	64
PCH	SS	Clinical <= 1.5	C3	17	98
PCH	LS	Clinical > 1.5	C3	11	153
URO	DT	All DT	C5	6	49
URO	SS	Clinical <= 1.5	K4	38	57
URO	LS	Clinical > 1.5	K4	16	156
NCH	DT	All DT	B4	5	52
NCH	SS	Clinical <= 1.5	B4	24	94
NCH	LS	Clinical > 1.5	B4	62	134
BZH	DT	All DT	C5	5	109
BZH	SS	n.a.	K3	0	-
BZH	LS	n.a.	K3	0	-

Table 22: LoS properties per patient type

Spec.	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
KCH	DT	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KCH	SS	1	0,75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KCH	LS	1	1	1	0,571	0,5	0,429	0,286	0,286	0,214	0,214	0,214	0,071	0,071	0,071	0,071	0,071	0,071	0,071	0	0	0	0	0	0	0	0	0	0
CHI	DT	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CHI	SS	1	0,8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CHI	LS	1	1	0,976	0,825	0,732	0,614	0,512	0,386	0,313	0,283	0,247	0,217	0,184	0,160	0,139	0,130	0,117	0,105	0,093	0,090	0,087	0,084	0,081	0,066	0,057	0,054	0,051	0,048
GYN	DT	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GYN	SS	1	0,743	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GYN	LS	1	1	0,982	0,321	0,193	0,138	0,101	0,055	0,037	0,028	0,009	0,009	0,009	0,009	0	0	0	0	0	0	0	0	0	0		0	0	0
KNO	DT	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KNO	SS	1	0,84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KNO	LS	1	1	1	0,429	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OOG	DT	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OOG	SS	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OOG	LS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ORT	DT	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ORT	SS	1	0,814	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ORT	LS	1	1	1	0,934	0,825	0,397	0,249	0,183	0,14	0,1	0,087	0,083	0,079	0,066	0,052	0,044	0,039	0,035	0,031	0,017	0,013	0,013	0,013	0,013	0,009	0,009	0,004	0,004
PCH	DT	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PCH	SS	1	0,86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PCH	LS	1	1	0,871	0,387	0,29	0,226	0,194	0,194	0,097	0,065	0,065	0,065	0,065	0,065	0,032	0	0	0	0	0	0	0	0	0	0	0	0	0
URO	DT	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
URO	SS	1	0,902	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
URO	LS	1	1	1	0,543	0,5	0,457	0,391	0,304	0,283	0,239	0,239	0,217	0,152	0,152	0,152	0,152	0,109	0,109	0,109	0,109	0,087	0,087	0,087	0,087	0,087	0,087	0,087	0,087
NCH	DT	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NCH	SS	1	0,943	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NCH	LS	1	1	0,973	0,397	0,304	0,245	0,163	0,152	0,12	0,092	0,071	0,071	0,054	0,038	0,027	0,016	0,016	0,016	0,011	0,011	0,011	0,011	0,011	0,011	0,005	0,005	0,005	0,005
BZH	DT	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BZH	SS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BZH	LS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix F: Output QAP model

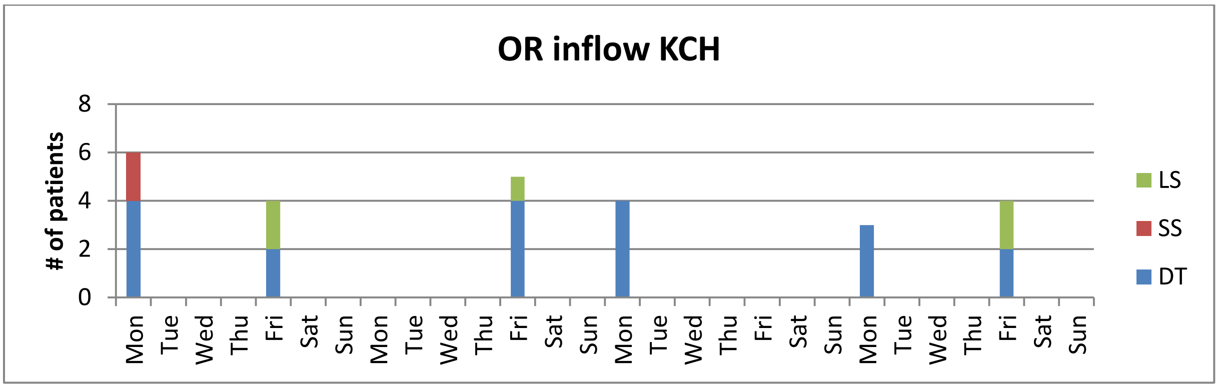

Figure 60: Case mix for KCH during four weeks, source: QAP model.

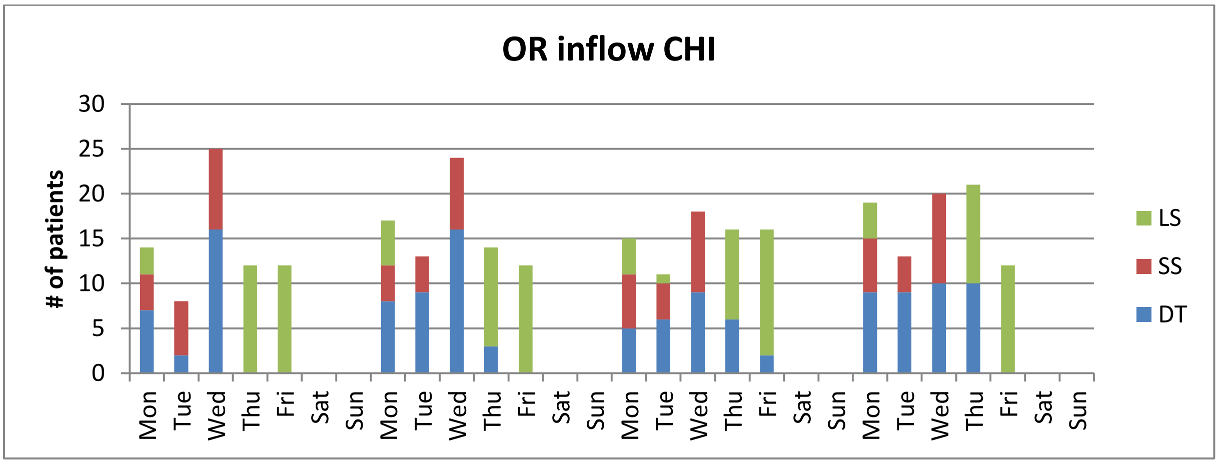

Figure 61: Case mix for CHI during four weeks, source: QAP model.

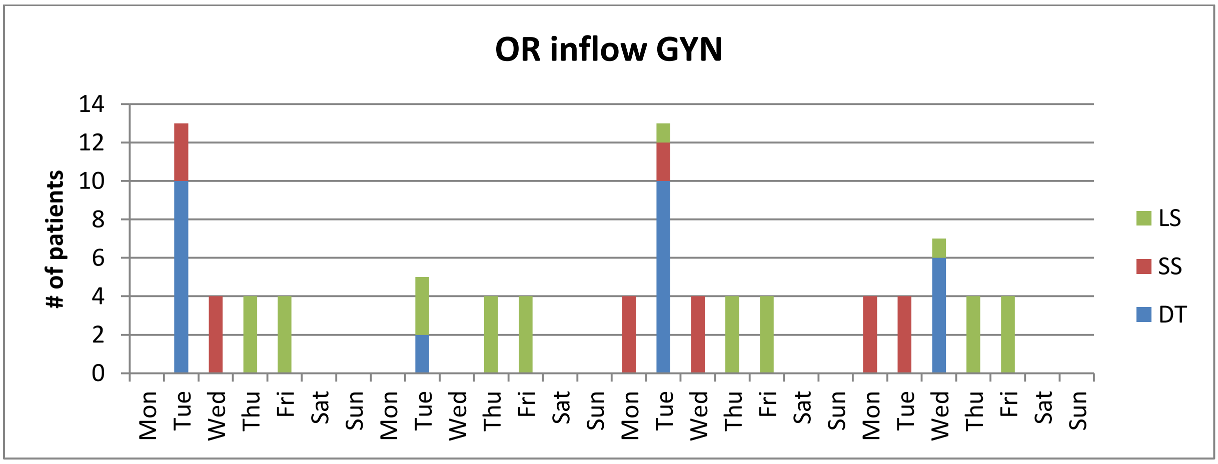

Figure 62: Case mix for GYN during four weeks, source: QAP model.

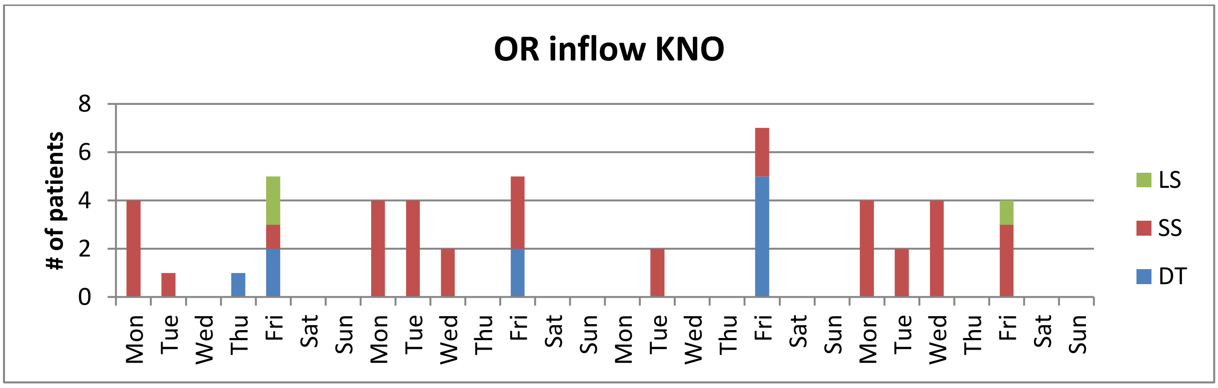

Figure 63: : Case mix for KNO during four weeks, source: QAP model.

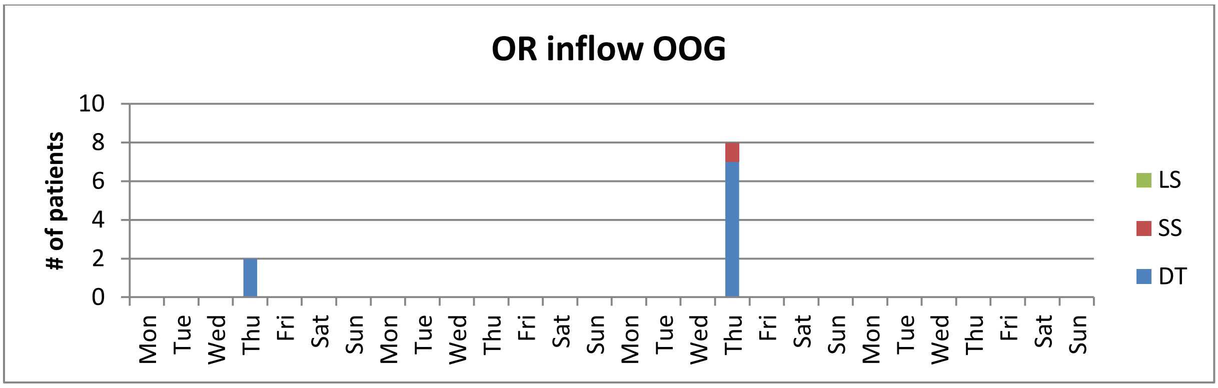

Figure 64: Case mix for OOG during four weeks, source: QAP model.

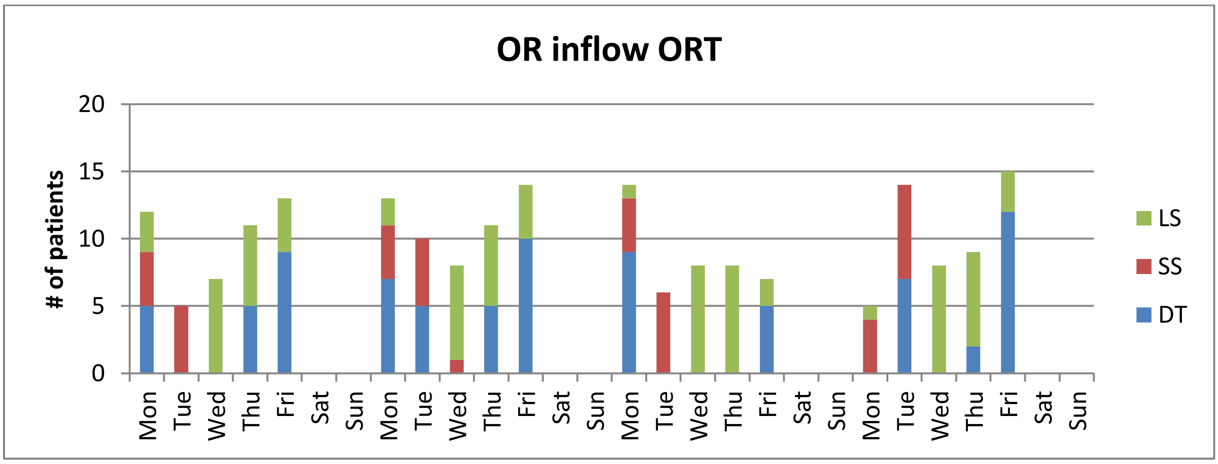

Figure 65: Case mix for ORT during four weeks, source: QAP model.

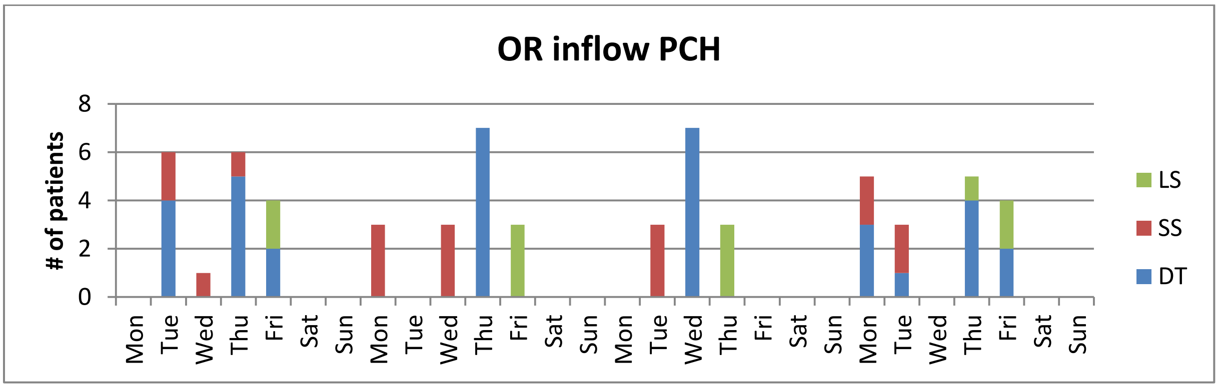

Figure 66: Case mix for PCH during four weeks, source: QAP model.

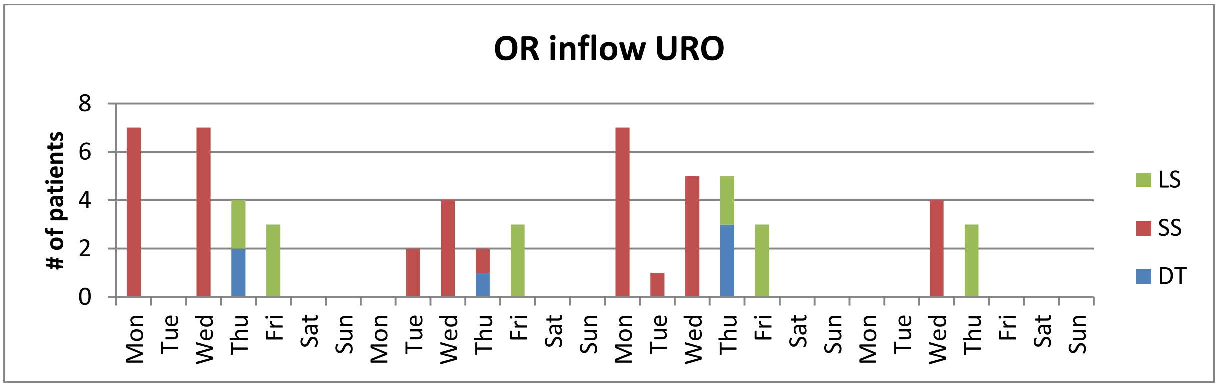

Figure 67: Case mix for URO during four weeks, source: QAP model.

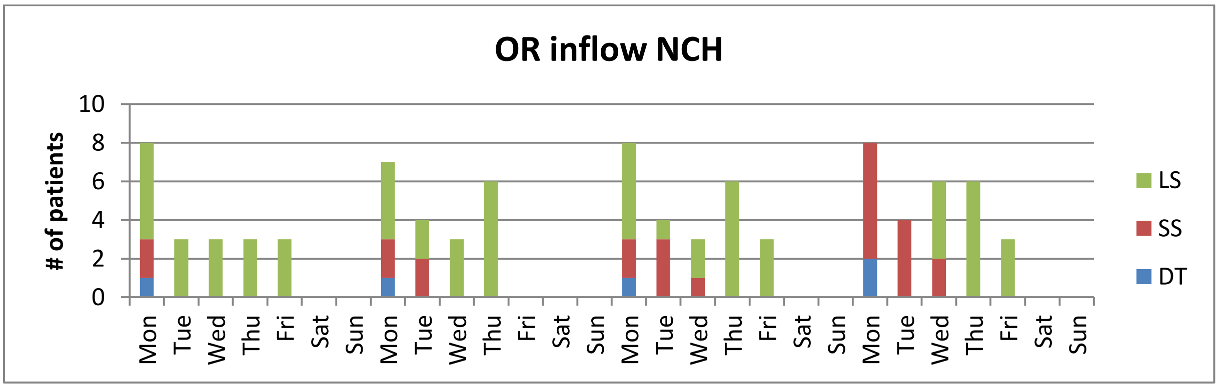

Figure 68: Case mix for NCH during four weeks, source: QAP model.

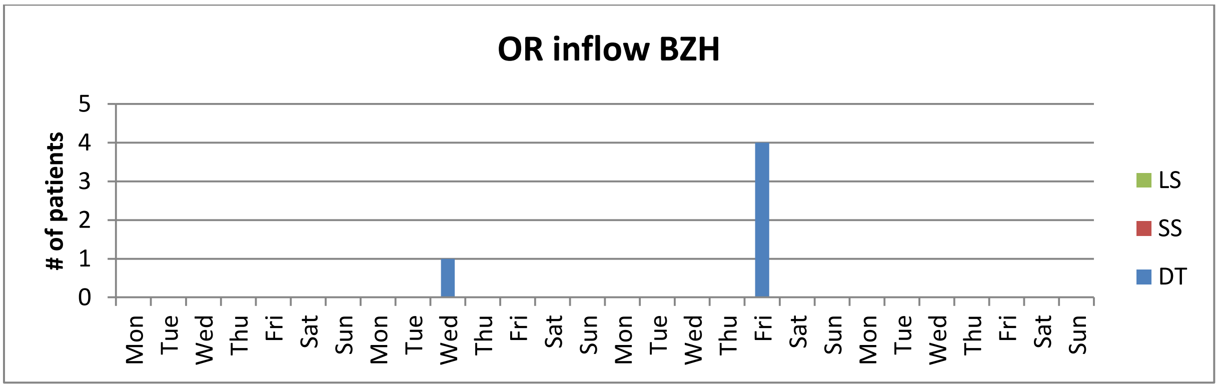

Figure 69: Case mix for BZH during four weeks, source: QAP model.

Appendix G: Fixed quota vs. QAP model output

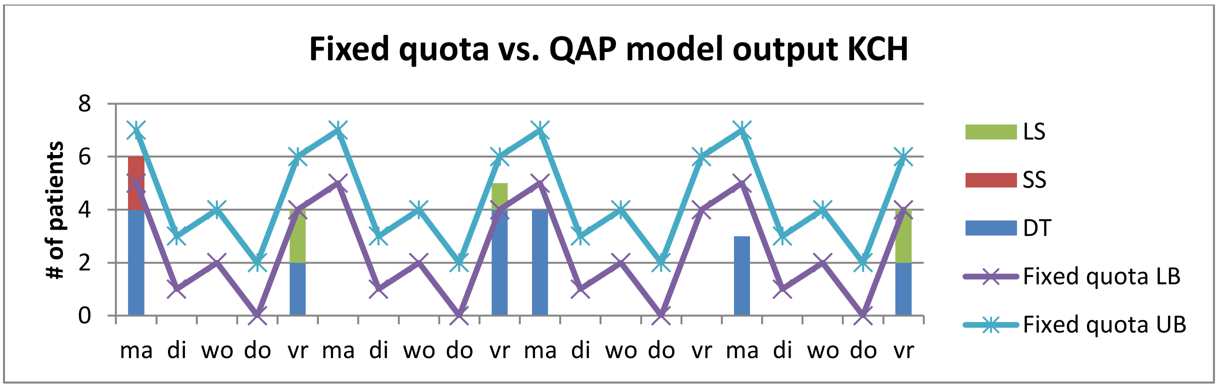

Figure 70: Case mix vs. fixed quota for KCH during four weeks, source: QAP model & ORdashboard.

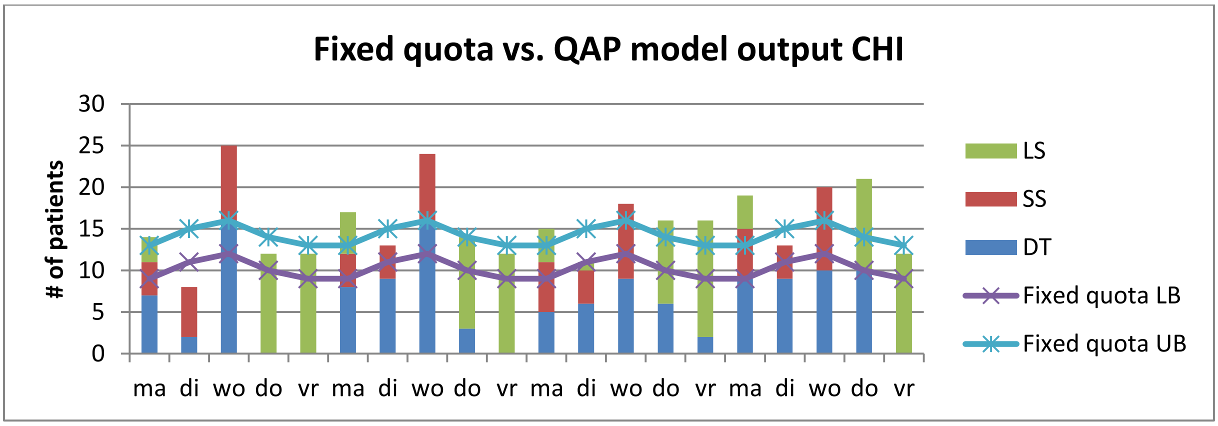

Figure 71: Case mix vs. fixed quota for CHI during four weeks, source: QAP model & ORdashboard.

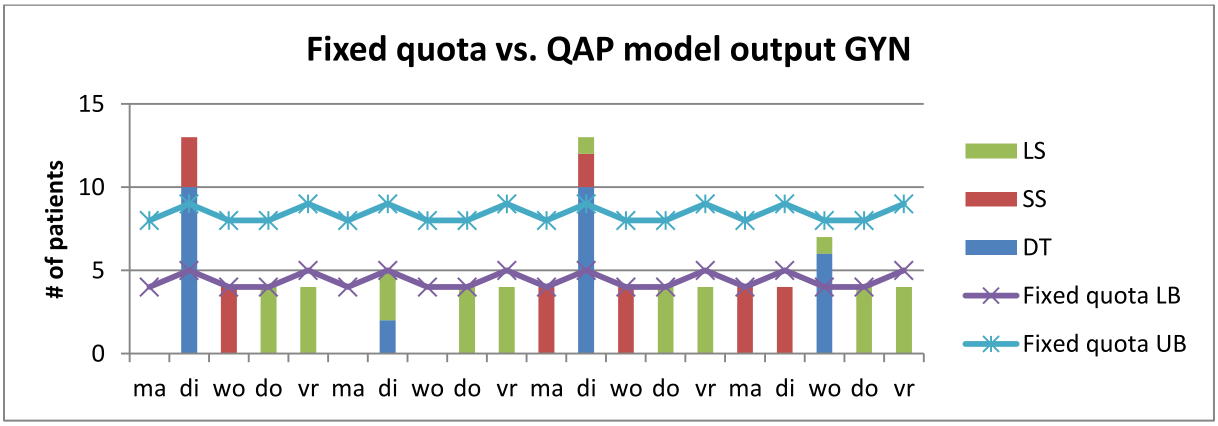

Figure 72: Case mix vs. fixed quota for GYN during four weeks, source: QAP model & ORdashboard.

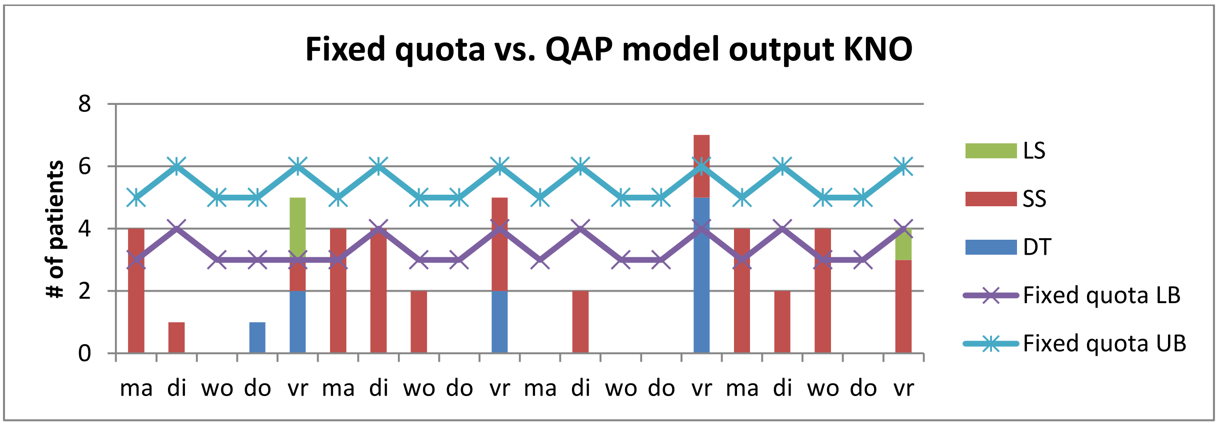

Figure 73: Case mix vs. fixed quota for KNO during four weeks, source: QAP model & ORdashboard.

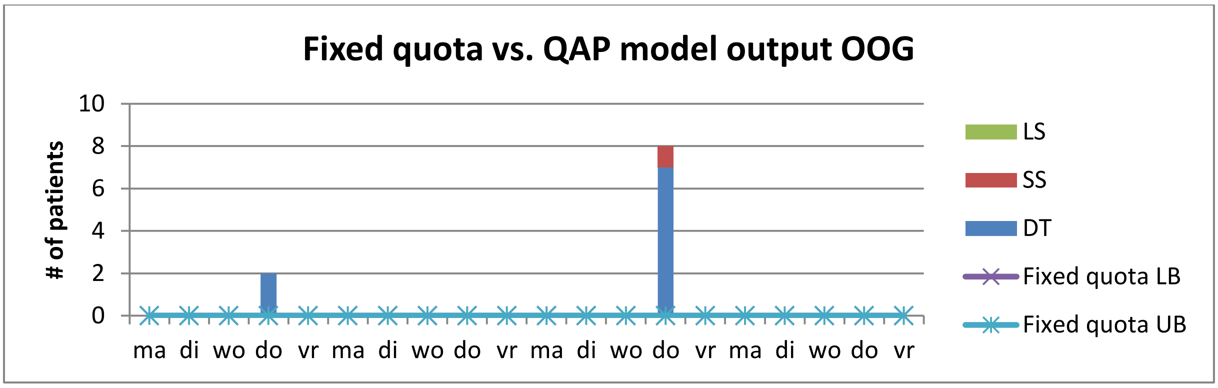

Figure 74: Case mix vs. fixed quota for OOG during four weeks, source: QAP model & ORdashboard.

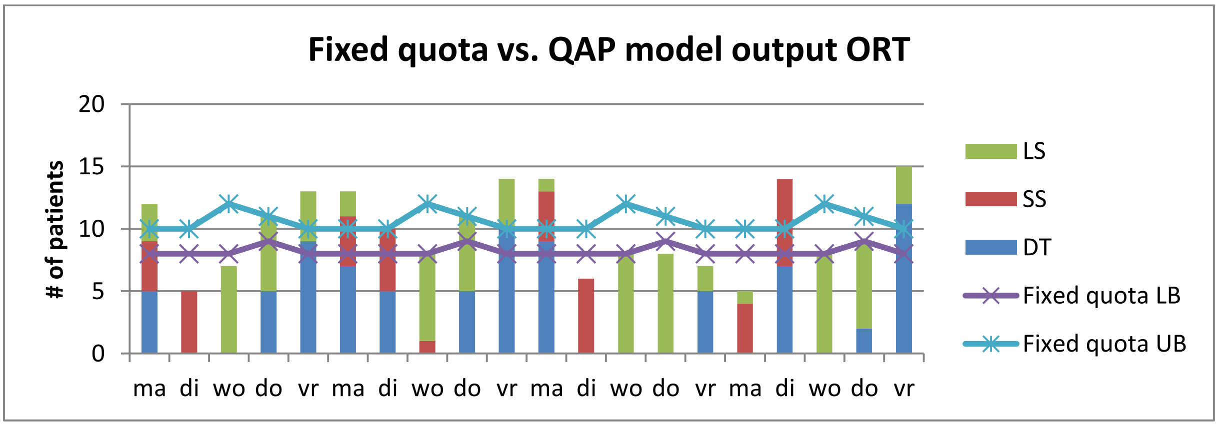

Figure 75: Case mix vs. fixed quota for ORT during four weeks, source: QAP model & ORdashboard.

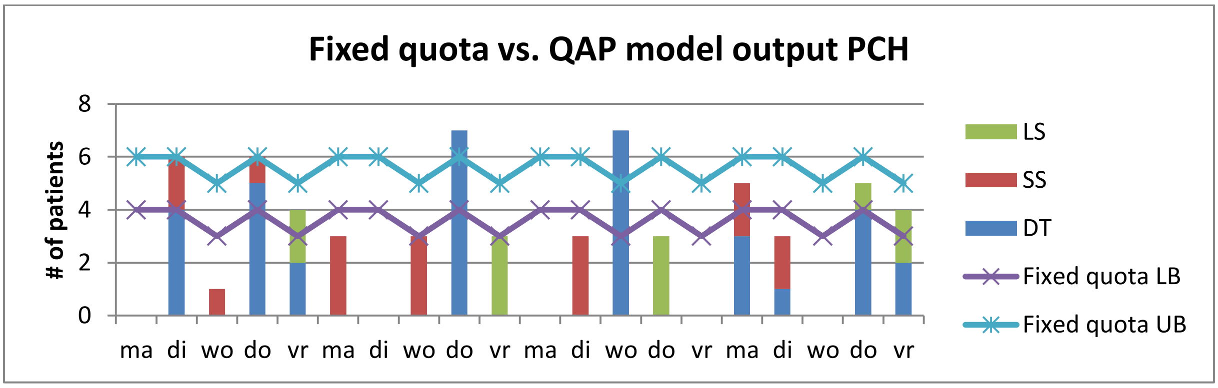

Figure 76: Case mix vs. fixed quota for PCH during four weeks, source: QAP model & ORdashboard.

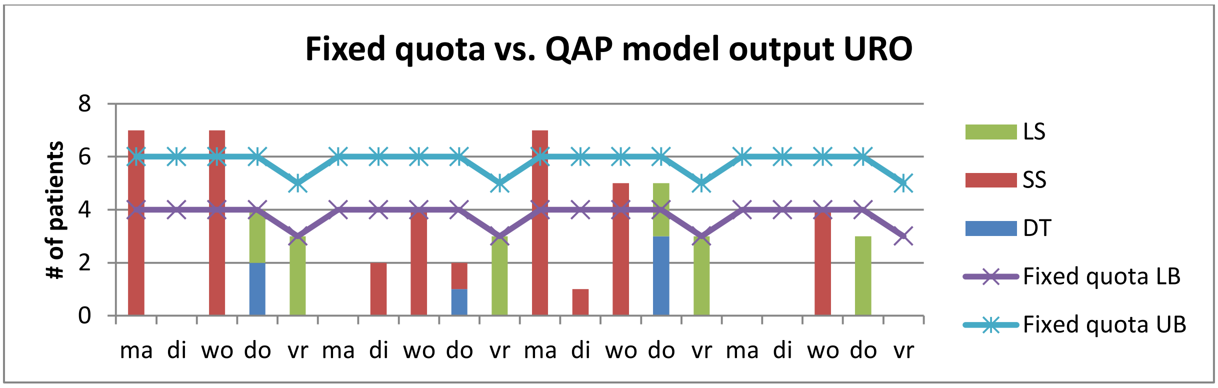

Figure 77: Case mix vs. fixed quota for URO during four weeks, source: QAP model & ORdashboard.

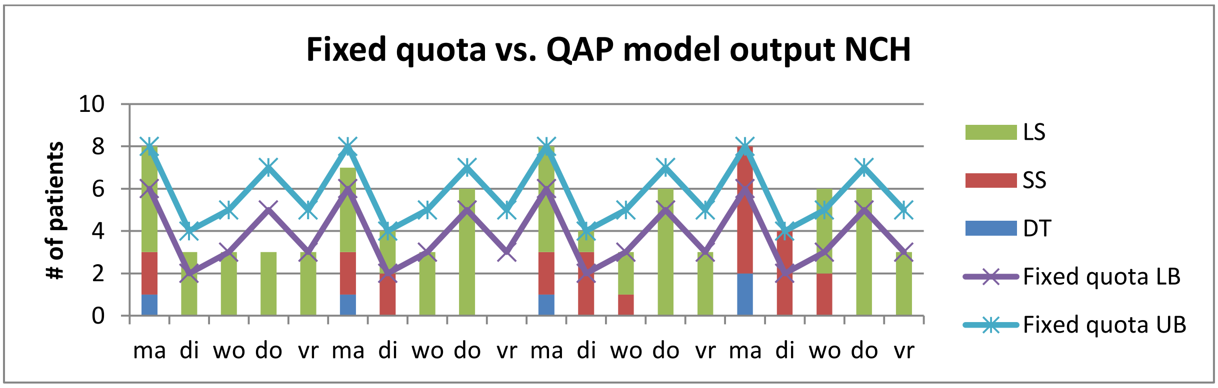

Figure 78: Case mix vs. fixed quota for NCH during four weeks, source: QAP model & ORdashboard.

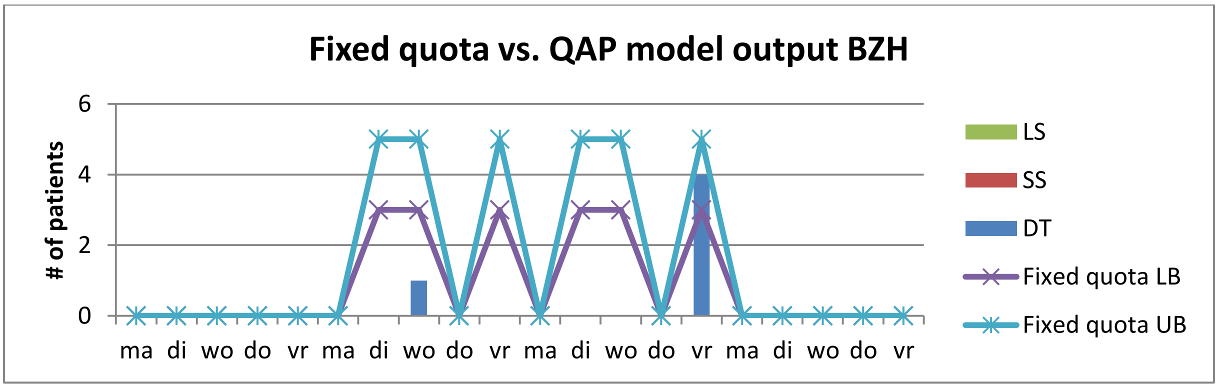

Figure 79: Case mix vs. fixed quota for BZH during four weeks, source: QAP model & ORdashboard.

Appendix H: Distributions for LoS and surgery duration

Distributions per patient type for the simulation model with μ and σ in seconds.

Table 23: Overview of lognormal distribution per special type for the simulation study.

Patient type	Distribution LoS	Distribution surgery duration
1	Lognormal with (μ=29099 ,σ=18431)	Lognormal with (μ=3448,σ=1336)
2	Lognormal with (μ=41449,σ=30299)	Lognormal with (μ=3322,σ=1325)
3	Lognormal with (μ=58191,σ=40603)	Lognormal with (μ=3301,σ=1371)
4	Lognormal with (μ=41212,σ=25693)	Lognormal with (μ=2771,σ=1147)
5	Lognormal with (μ=23335,σ=7645)	Lognormal with (μ=3108,σ=910)
6	Lognormal with (μ=32320,σ=30201)	Lognormal with (μ=2604,σ=797)
7	Lognormal with (μ=38358,σ=30992)	Lognormal with (μ=3810,σ=1644)
8	Lognormal with (μ=42664,σ=28803)	Lognormal with (μ=2672,σ=682)
9	Lognormal with (μ=57849,σ=37962)	Lognormal with (μ=3167,σ=1079)
10	Lognormal with (μ=22394,σ=7786)	Lognormal with (μ=6545,σ=2616)
11	Lognormal with (μ=96600,σ=5615)	Lognormal with (μ=3760,σ=1226)
12	Lognormal with (μ=91750,σ=25370)	Lognormal with (μ=4893,σ=1631)
13	Lognormal with (μ=93953,σ=30985)	Lognormal with (μ=5891,σ=2352)
14	Lognormal with (μ=91846,σ=14883)	Lognormal with (μ=6289,σ=3740)
15	Lognormal with (μ=23335,σ=7645)	Lognormal with (μ=3108,σ=910)
16	Lognormal with (μ=91912,σ=19992)	Lognormal with (μ=4292,σ=1697)
17	Lognormal with (μ=94354,σ=17058)	Lognormal with (μ=5800,σ=2141)
18	Lognormal with (μ=98739,σ=18722)	Lognormal with (μ=3451,σ=1421)
19	Lognormal with (μ=107940,σ=16250)	Lognormal with (μ=5678,σ=2789)
20	-	-
21	Lognormal with (μ=472196,σ=387428)	Lognormal with (μ=9317,σ=3640)
22	Lognormal with (μ=816806,σ=954070)	Lognormal with (μ=8744,σ=4568)
23	Lognormal with (μ=252021,σ=136101)	Lognormal with (μ=6427,σ=3438)
24	Lognormal with (μ=290918,σ=174245)	Lognormal with (μ=6893,σ=3498)
25	-	-
26	Lognormal with (μ=490682,σ=338935)	Lognormal with (μ=6641,σ=2009)
27	Lognormal with (μ=479393,σ=500627)	Lognormal with (μ=9844,σ=6157)
28	Lognormal with (μ=552708,σ=538823)	Lognormal with (μ=9856,σ=8100)
29	Lognormal with (μ=352563,σ=309624)	Lognormal with (μ=7859,σ=5952)
30	-	-

Appendix I: Flowcharts simulation model

This part describes different departments by using flowcharts. These flowcharts consist of the most important decisions for the transportation of patient through MST.

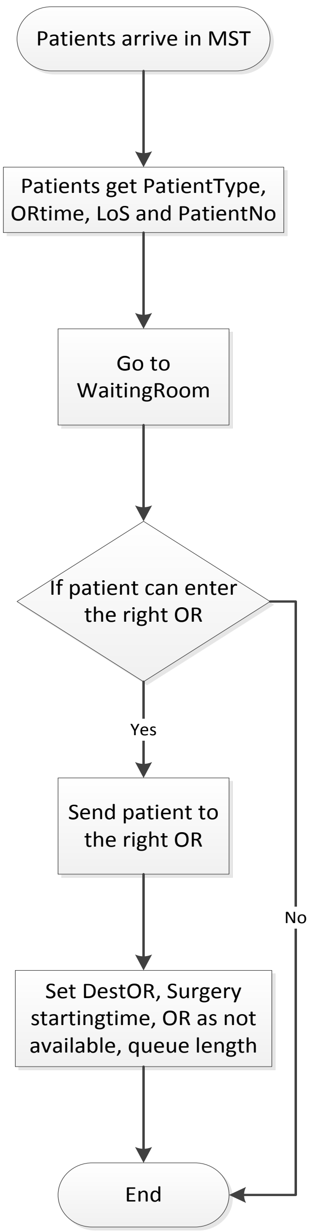

Figure 80: Flowchart of the NOU

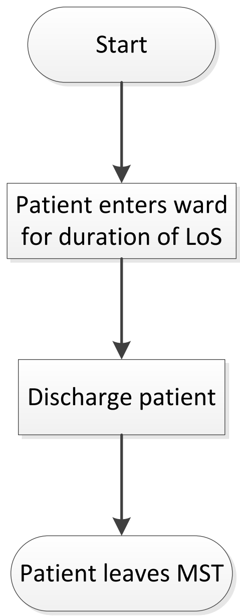

Figure 81: Flowcharts of the wards

Flowchart of the NOU creates patients and gives the patients some characteristics. The patient is referred to the waiting room when the right OR is available. If the OR is available, the patient transfers to the OR and data values are saved. The flowchart of the wards receives patients out of the OR and the patient will be discharged if LoS is over.

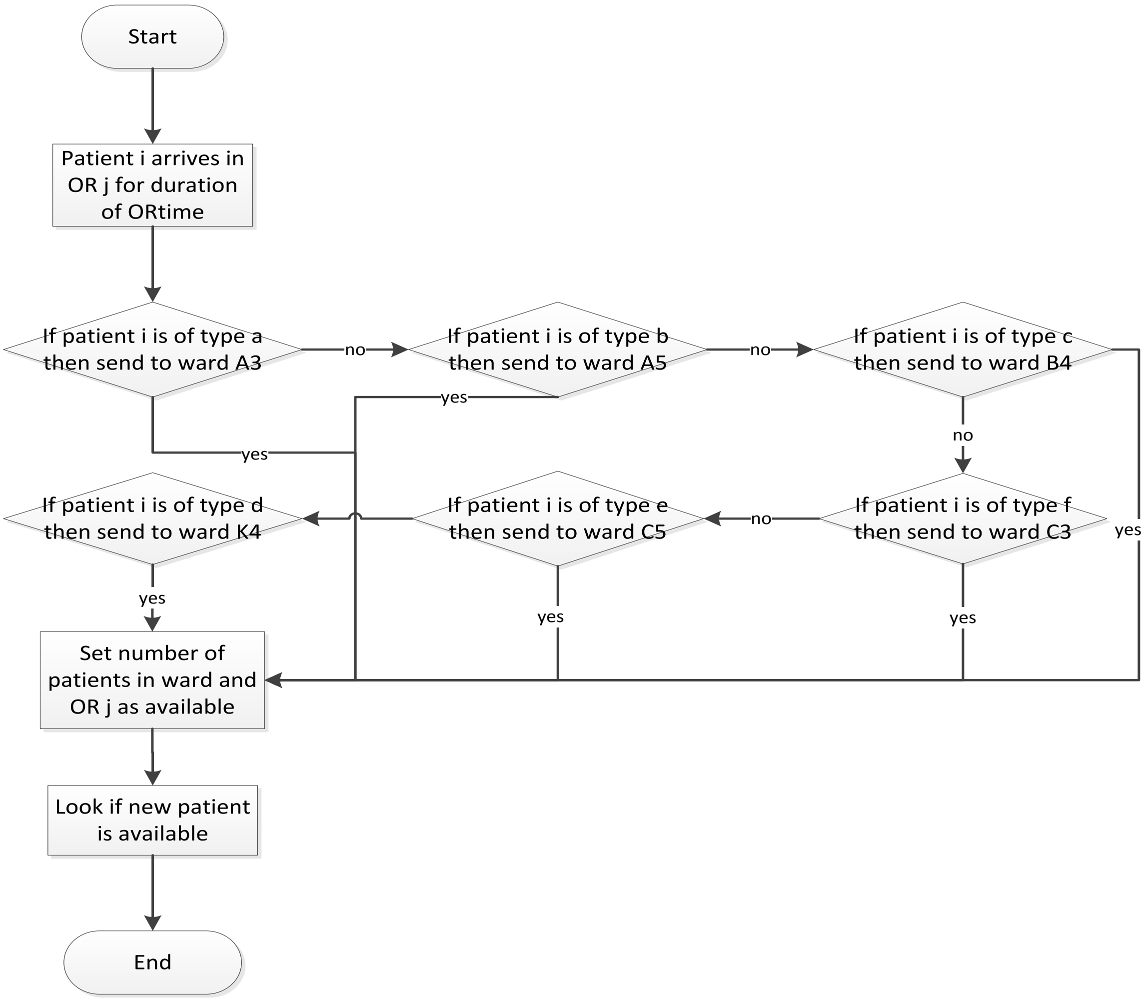

Figure 82: Flowchart of the ORs

The flowchart of the ORs is the most complex one. This part of the process receives a patient in one of the twelve ORs. After surgery, the patient is sent to the corresponding ward. A new patient will be called for surgery if the OR is empty.

Appendix J: Calculation experiment design

Determine warm-up period by using Welch for A3 and C3.

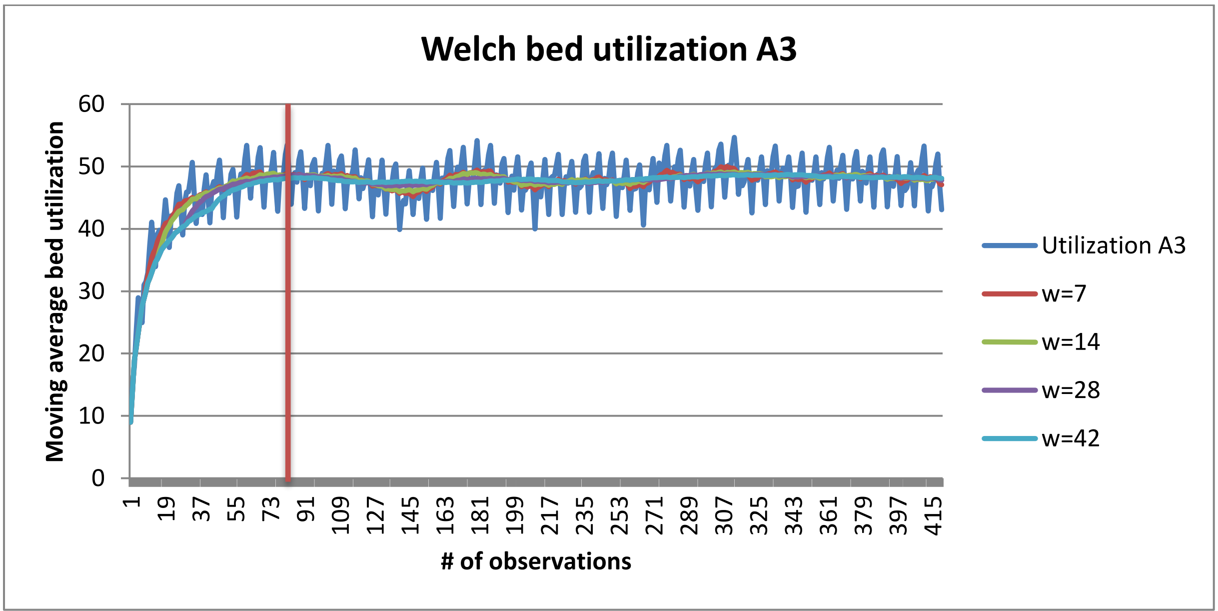

Figure 83: Bed utilization in A3 according to the simulation model and by using Welch. The red line is the end of the warm-up period.

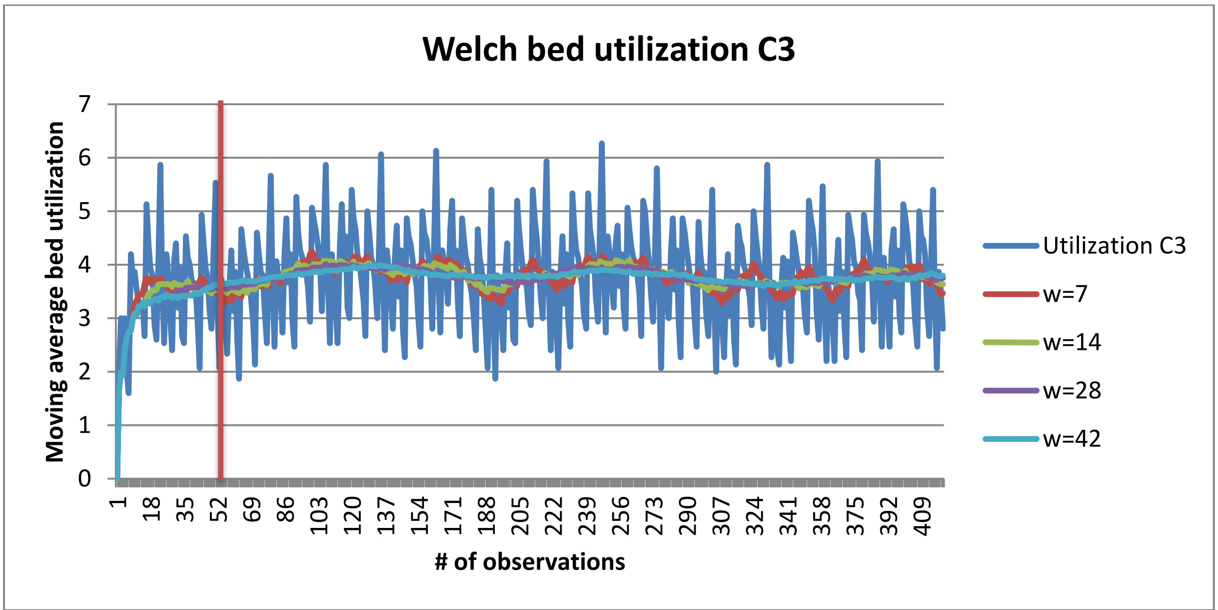

Figure 84: Bed utilization in C3 according to the simulation model and by using Welch. The red line is the end of the warm-up period.

Appendix K: Ward utilization

Ward utilization in six wards based on the realized situation of quarter one in 2014, QAP model and simulation model.

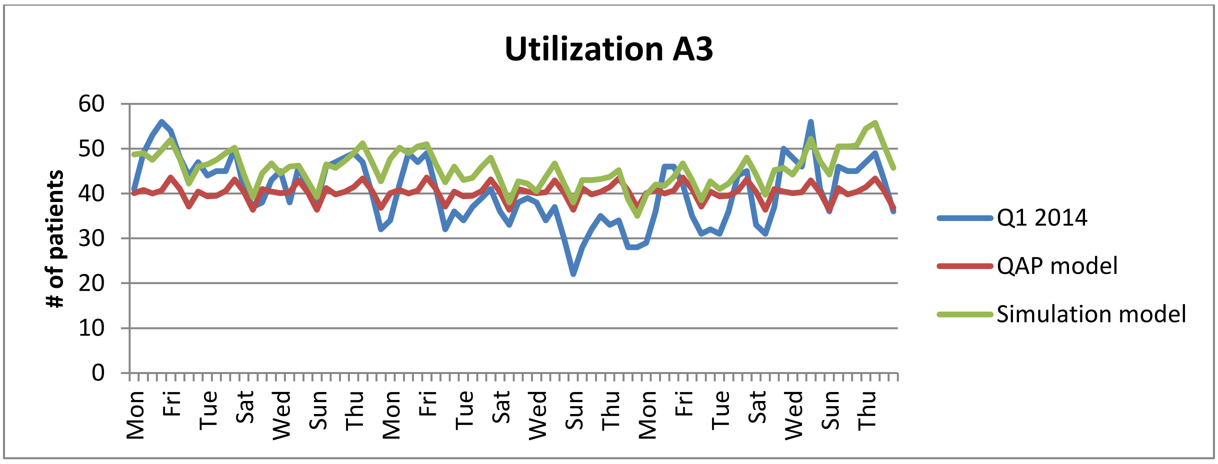

Figure 85: Utilization of A3 during one quarter, source: Xcare and ORsuite & QAP model & Simulation model.

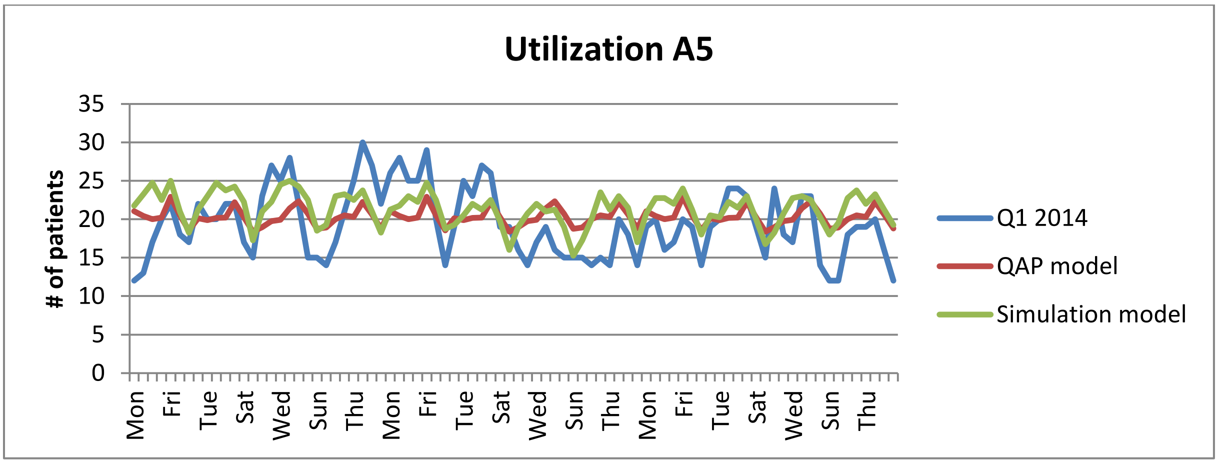

Figure 86: Utilization of A5 during one quarter, source: Xcare and ORsuite & QAP model & Simulation model.

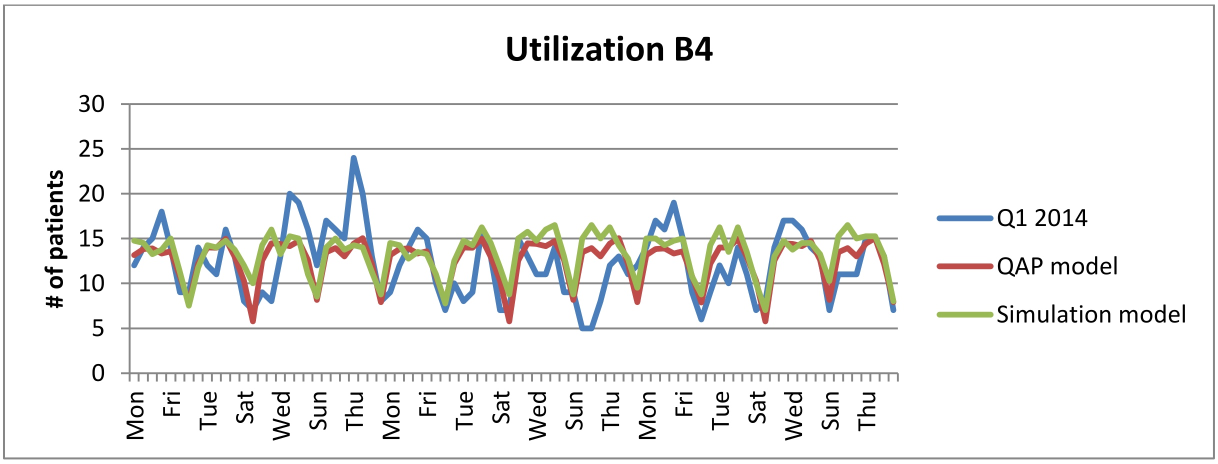

Figure 87: Utilization of B4 during one quarter, source: Xcare and ORsuite & QAP model & Simulation model.

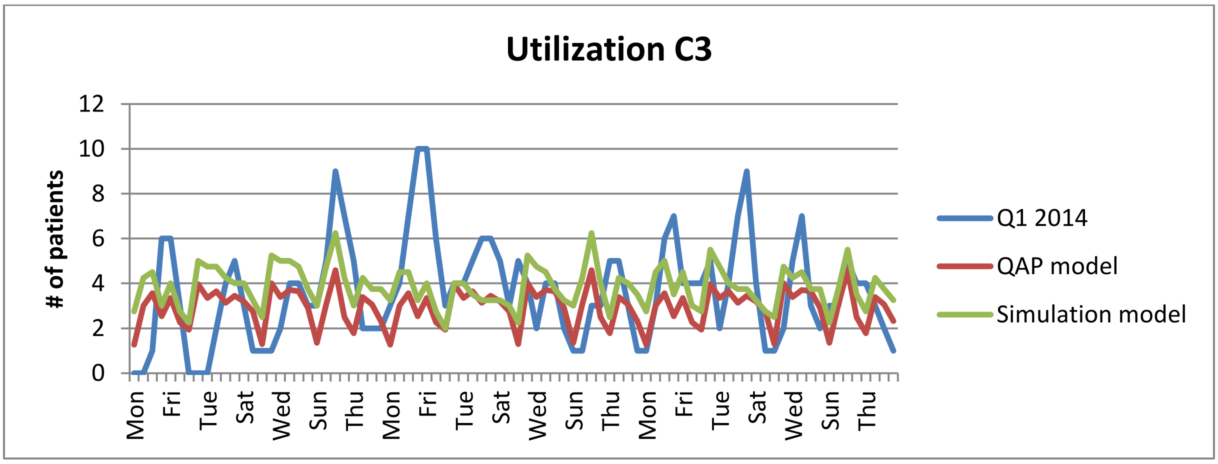

Figure 88: Utilization of C3 during one quarter, source: Xcare and ORsuite & QAP model & Simulation model.

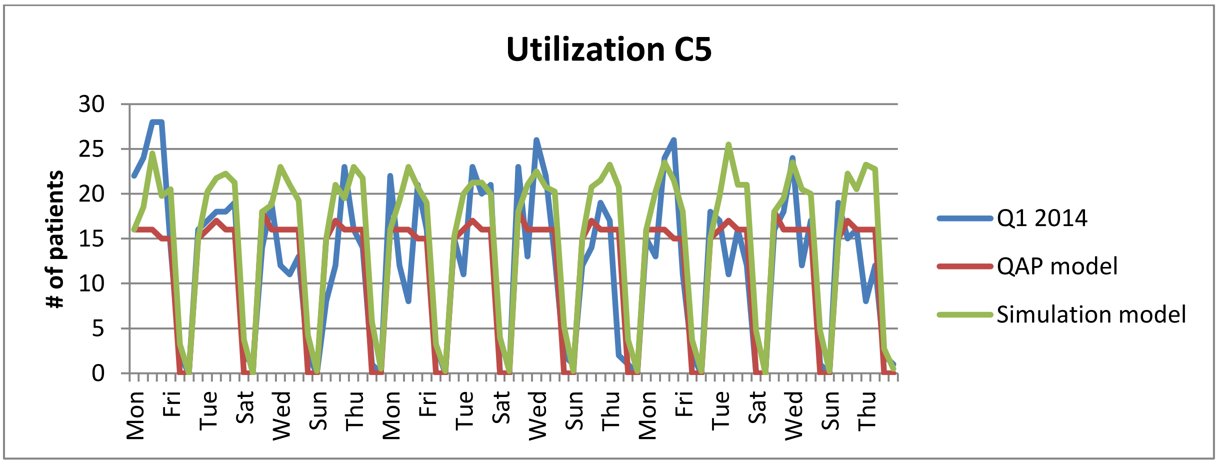

Figure 89: Utilization of C5 during one quarter, source: Xcare and ORsuite & QAP model & Simulation model.

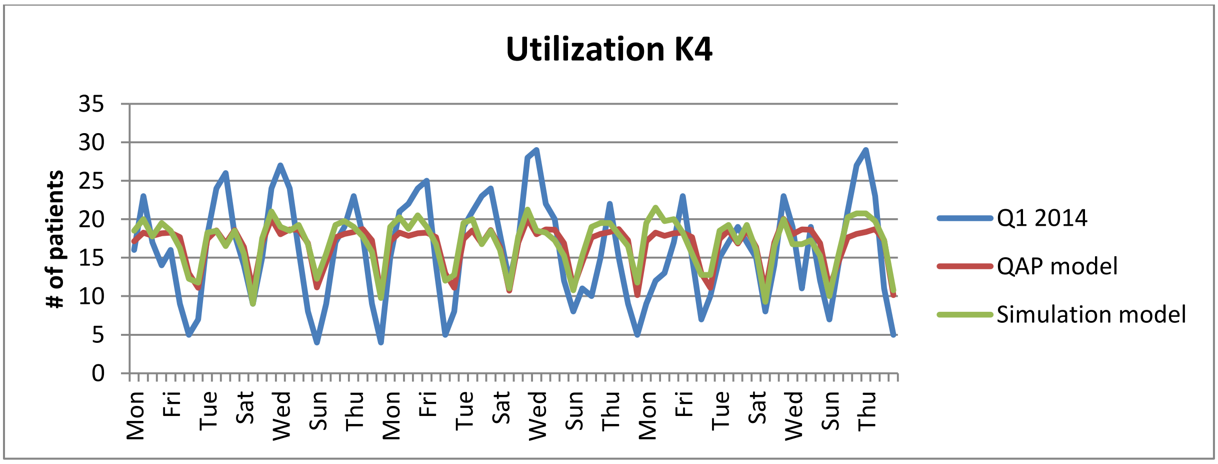

Figure 90: Utilization of K4 during one quarter, source: Xcare and ORsuite & QAP model & Simulation model.