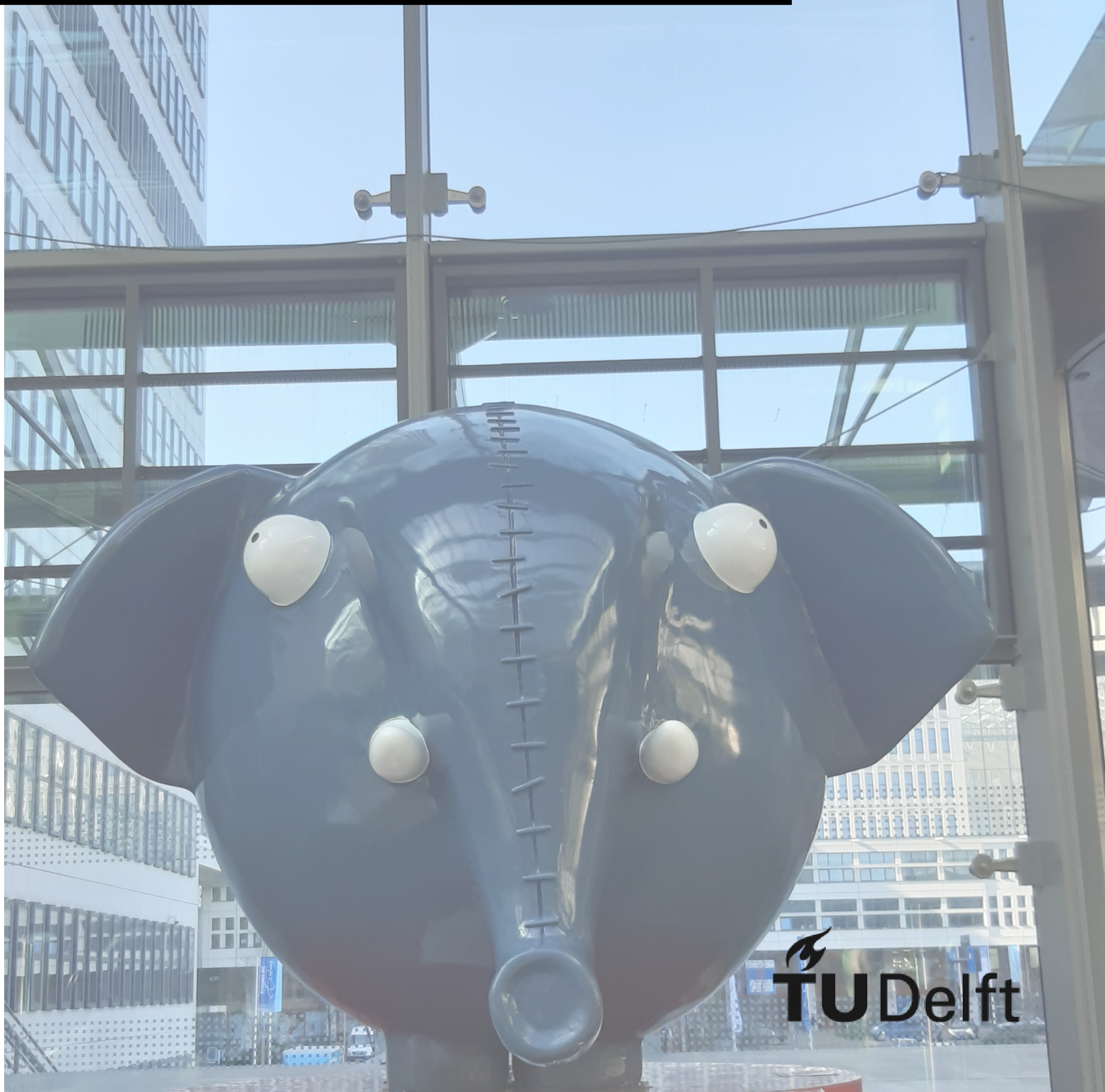
Optimising OR planning

Sequencing surgery groups while levelling bed occupancy

Kelly Vos



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Kelly Vos

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Preface

When I was a high school student, I visited the TU Delft during an Open Day. I was not planning to go to a presentation about applied mathematics, but there was a gap in my schedule and mathematics was the only available option, so I went anyway. This happy coincidence was the start of my eight years as an applied mathematics student at the TU Delft. During these years, I learned a lot both inside and outside the lecture hall.

During my studies, I preferred the applied courses and projects. Theresia was the lecturer of several of these courses. Therefore, I asked if she wanted to be my supervisor. Luckily, she was just starting a collaboration with the Sophia Children's Hospital, which resulted in this thesis. I want to express my gratitude to Theresia for her guidance. During our meetings, she helped me to stay on track and to apply the theory I learned during my studies. Next to that, I appreciate that she always took the time to give feedback on my writing.

I also want to thank the staff of the Sophia Children's Hospital. Both at the wards and in the OR, everybody made time in their busy schedules to provide insights on how things worked, such that I got a clear idea about the difficulties the hospital faces when planning surgeries. In particular, Lonneke, Bert, and René who were not only always open to answer questions, but also provided insights on how I can translate mathematical results into the real world.

Lastly, I want to thank my friends and family. They listened to all my stories about this graduation project, but also made sure that I took enough time to relax. I want to express my gratitude to some people in particular. Firstly, Vincent; thank you for all the times you calmed my nerves when I was doubting myself or stressing out in the middle of the night. Secondly, my parents; thank you for all your support and for believing in the choices I made during my time as a student. Thirdly, Pauline; thank you for the study sessions, which forced me to get out of bed and start the day early.

Kelly Vos
Delft, February 2023

Abstract

This research is conducted in collaboration with the Sophia Children's Hospital (SCH). The hospital wants to provide their patients with more detailed information about when a patient is approximately scheduled to have a surgery. The first step is to create a model which optimises the operation room (OR) schedule and indicates when different kinds of surgeries are planned. This information, combined with the waiting list, provides insight in when a surgery of a specific patient is scheduled.

In a hospital, different departments work together to treat the patient as good and efficient as possible. If a patient needs a surgery, not only an OR is needed, but also a bed at a ward which matches the patient's needs. The goal of this thesis is to use the different resources of the hospital as efficiently as possible. This is done by not only optimising the utilisation of the OR, but at the same time levelling the bed occupancy of the different wards. The levelling of the bed occupancy is done by minimising the maximum number of used beds at each ward. Because, if we minimise the maximum, we force that the patients are spread out more evenly over the day.

For each specialty, the patients are divided into patient groups based on historical data using a constrained k-means clustering algorithm. For each patient group, information is gathered about the length of stay (LoS) and the surgery duration of patients in this patient group. Next to that, the number of patients in a patient group indicates how often a patient group needs to be scheduled at least.

The probability distribution of the surgery duration is taken into account when deciding at which day, at what time, and in which OR a surgery is planned. A patient group can only be scheduled during OR shifts assigned to the corresponding specialty. At the same time, the levelling of the bed occupancy is taken into account.

After some constraints are linearised, this model can be formulated as a mixed integer linear program (MILP). However, the model has a large number of variables. Therefore, column generation is used to split the model into smaller subproblems per specialty. Some of the pricing subproblems take a lot of time to optimise. For that reason, we set some time limits both on the runtime of the pricing subproblems and the runtime of the entire algorithm. Column generation does not guarantee an optimal solution of our MILP. However, the objective value of our MILP improves over time, when new columns are added to the set of available columns. This indicates that column generation can be used to optimise our model.

In this thesis, several versions of the model are presented. For example, the schedule is different if the bed occupancy is calculated every hour or of every fifteen minutes. Next to that, the model can either be more focussed on maximising the OR utilisation or on levelling the bed occupancy.

List of Abbreviations

Abbreviation	Full form	Dutch
ICU	Intensive care unit	Intensive care (IC)
ILP	Integer linear program	-
OR	Operating room	Operatiekamer (OK)
LoS	Length of stay	Duur van het verblijf
LP	Linear program	-
LPM	Linear programming master	-
MCU	Medium care unit	Medium care (MC)
MILP	Mixed integer linear program	-
MSS	Master surgery schedule	Kameropenstellingsplan (KOP)
RLPM	Restricted linear programming master	-
SCH	Sophia Children's Hospital	Sophia Kinderziekenhuis
WS	Ward schedule	Beddenopenstellingsplan (BOP)

Contents

1 | Introduction

At the moment, there is a shortage of healthcare workers in the Netherlands, UWV (2019). This shortage results in longer waiting lists for patients. Moreover, it is predicted that the relative capacity of the healthcare system will only decrease, Plicht (2021). Training more people to work in healthcare would solve this problem. However, at the moment, there are not enough people interested in pursuing a career in healthcare to fulfil the country's needs.

Another solution exists, namely optimising the use of available resources. The focus of this thesis is on optimising the schedule for the operating rooms (ORs) at the Sophia Children's Hospital (SCH). This research specifically investigates optimising the order in which the surgical procedures are scheduled during a shift, while levelling the bed occupancy.

Section 1.1 provides some background information regarding the hospital where this research is conducted. Also, the motivation for this research is explained. This is followed by the problem description and research goals in Section 1.2. This chapter ends with an outline of the thesis in Section 1.3.

1.1 Sophia Children's Hospital

The Sophia Children's Hospital was founded in 1863. It started as a small independent hospital in Rotterdam. Nowadays, the hospital is part of the Erasmus University Medical Center and it is the largest children's teaching hospital in the Netherlands. Each year, around seven thousand surgical procedures are performed by eighteen different specialties using ten ORs.

When a patient is treated at the SCH, it is difficult to give a clear schedule for their treatment. Surgeons can give an average waiting time, but at the moment, it is difficult to give a good prediction. Hence, they have to tell the patient to go home, to wait until they get a call. The SCH started this research to provide more accurate waiting times between the different procedures a patient needs. The first step of this process is optimising the OR schedule. From this schedule, the surgeon could get an indication of when a certain surgical procedure will be performed.

1.2 Problem description and research goals

The goal of this research is to optimise the OR schedule for the SCH. As mentioned before, there are eighteen different specialties that need to share the available OR time. Each specialty has its own waiting list of elective surgeries. Surgical procedures are planned during the time slots reserved for their corresponding specialty. However, the different specialties use beds from the same wards for their patients. This could create issues if multiple specialties want to use the same beds at the same time.

For example, all scheduled patients (of the different specialties) on Monday have to stay more than two days after their surgery. There might not be any beds left for new patients on Tuesday or Wednesday. Therefore, all surgeries on these days would have to be cancelled. Next to that, all beds would be empty on Wednesday evening. However, during the day, we could not admit new patients, so the wards are empty this night. This example shows planning surgeries affects different departments in the hospital. Hence, if the aim is to optimise the OR schedule, all departments and needed resources have to be taken into account. Levelling the bed occupancy lowers the probability that surgeries have to be cancelled.

This is not the first research about optimising the OR schedule. The innovative part of this research is the combination of sequencing patients throughout the day, using the probability distribution of the surgery duration, while levelling the bed occupancy per time block and optimising the usage of the OR. This new approach could result in a better use of resources by, for example, allowing to schedule two patients at the same bed on the same day. This could be the case if patient A is released from the hospital in the morning and patient B has a procedure in the afternoon.

1.3 Research outline

Firstly, we give a description of the current situation at the SCH. In Chapter 2, both the current planning system and the route of a patient are discussed. Next, an overview of relevant literature is presented in Chapter 3, followed by relevant mathematical background in Chapter 4. Both are used to compose the mathematical model in Chapter 5. In Chapter 6, it is explained how this mathematical model can be solved. Information regarding the data that is used in this thesis is presented in Chapter 7. Chapter 8 contains the results that followed from the data and solving the model. Finally, Chapter 9 contains the conclusions and discussion.

2 | Current situation and desired changes

Firstly, this chapter describes the current planning strategy at the SCH in Section 2.1. Next to that, the drawbacks of the system are discussed. From this, the goal of this project is formed. Secondly, the route of a patient is discussed in Section 2.2, to get a better look at the bigger picture. There are a lot of different stages before and after a patient has surgery. All of these different stages have an effect on when a surgery can take place. Different members of the SCH contributed to this chapter, Slot et al. (2022).

2.1 Operating room planning

The hierarchical decomposition of the planning process for surgeries at the SCH is the same as in many other planning processes, Hans et al. (2012). The planning process is divided into three levels: strategic (Subsection 2.1.1), tactical (Subsection 2.1.2), and operational, split in offline and online (Subsection 2.1.3) .

2.1.1 Strategic planning

Firstly, at the strategic level some general decisions are made, e.g. the number of surgeries the different specialties are aiming to perform and the kind of surgeries this will be. Next to that, the hospital makes agreements with health insurance companies on how often certain surgeries are performed. These decisions and agreements result in a general idea about how much OR time the different specialties need, but also a general idea about how many beds are needed and available.

2.1.2 Tactical planning

Decisions made during the strategic planning are taken into account when planning at the tactical level. During the tactical planning meeting, both the master surgery schedule (MSS) and the ward schedule (WS) are evaluated and adjusted.

Master surgery schedule

The MSS states when which specialty may use which OR. This is a four week schedule that repeats itself. Some specialties have OR time each week, others only once every two or four weeks. Table 2.1 is an example of the MSS for one week, the abbreviations for the different specialties can be found in Table 2.2. We use the term OR day to refer to a specific OR on a specific day. Therefore, in general, there are multiple OR days at the same day.

Table 2.1: One week of the MSS.

	OR 1	OR 2	OR 3	OR 4	OR 5	OR 6	OR 7	OR 8	OR 9	OR 10	MRI
Mon	GYN	LOS	KIC		URO	PLC		ORT	CAS	NEC	RON
	GYN		FLEX		URO	PLC		ORT	CAS	NEC	RON
Tue	GYN	KNO	GAS		KNO		KIC	ORT		PLC	RON
	GYN	KNO	FLEX	NEU	KNO		KIC	ORT		PLC	
Wed	GYN			KNO	URO	KAA	KIC	ORT	CAS	PLC	
	GYN			KNO	URO	KAA	KIC	ORT	CAS	PLC	
Thu	GYN	LOS	KIC	ORT	URO	PLC	KIC	ORT		NEC	
	GYN		FLEX	ORT	URO	PLC	KIC	ORT		NEC	
Fri	GYN		KNO	OOG	URO	KIC	KIC	ORT		ORT	RON
	GYN		KNO	OOG	URO	FLEX	KIC	ORT		ORT	RON

Table 2.2: Abbreviations of specialties at the SCH.

Specialties	**Dutch Abbreviation**
Dental surgery	TAN
Dermatology	DER
Gastroenterology	GAS
Gynaecology	GYN
Maxillofacial surgery	KAA
Neurological surgery	NEC
Neurology	NEU
Ophthalmology	OOG
Orthopaedic surgery	ORT
Otorhinolaryngology	KNO
Paediatric cardiac surgery	CAS
Paediatric pulmonary disease	LOS
Paediatric surgery	KIC or HLK
Plastic surgery	PLC
Radiology	RON
Urology	URO

A few notes to get a better understanding of this example week of the MSS:

- FLEX is the only abbreviation that is not a specialty. This OR time is used for emergency surgeries.
- The OR is opened between 08:00 and 15:30. In general, the first shift is from 8:00 until 11:45 and the second shift is from 11:45 until 15:30.
- Although the MRI is not an OR, it is also in the MSS since children who need an MRI will get general anaesthesia. Therefore, an anaesthesiologist has to be present.
- Orthopaedic back surgeries are always performed in OR 8 on either Monday or Thursday.
- Plastic surgery is divided into two groups. Group one contains all the surgeries focused on the hand, and group two contains all the other surgeries. The first group performs surgeries on Monday (half of the weeks at one OR, and half of the weeks at two ORs). The rest of the OR time assigned to plastic surgery is used to perform the other surgeries.

- Some ORs have special equipment to perform certain surgeries.
  - OR 1 is always available for emergency caesarean sections.
  - OR 2 is used for airway surgeries.
  - OR 8 and 10 have better airflow for extra sterile surgeries, for example neurological, or orthopaedic surgery.
  - OR 9 is a cardiac catheterisation room, so it is not possible to perform other surgeries in this OR.
  - One OR is not in this schedule. This OR cannot be used for all types of surgeries, and is only used for caesarean sections. This OR is located at a different location from the other ORs.

The goal is to make changes in this schedule during the tactical planning meeting. For example, given the waiting list, a specialty needs more OR time. However, in practice this is difficult to accomplish. If one specialty gets more OR time, another specialty has to give up some OR time. None of the specialties are eager to give up "their" OR time. The exchange in OR time does happen within a specialty, however. If a certain surgery cannot take place, the aim is to replace it with a surgery from the same specialty, also if another surgeon performs this surgery. This could also happen if a surgeon knows in advance that they will not use a certain time slot. This research should provide more insight in the consequences of changes in the MSS, which could contribute to convincing the different specialties that some changes would optimise the usage of the total OR time and bed occupancy.

Ward schedule

The WS gives an overview of the available beds for every four weeks. It is important to note that a bed is not just the physical bed, but also the needed staff and equipment at the ward to treat the patient. From the strategic planning, the number of beds on each ward is known. However, sometimes there is not enough staff. During these weeks, there are less beds available. The main wards are the intensive care unit (ICU), medium care unit (MCU), and the daycare unit. There are also some wards for pregnant patients (SK4 and SP4) and newborn babies (neonatal intensive care unit (NICU)).

The ICU consists of four different units. Each unit is a hall with six beds and a nursing station. Some units also contain a separate room, which is used if a patient has for example an MRSA infection or if a patient dies. Unit 1 is called the short stay or the MC+. Patients who are on this unit are predicted to only stay one night at the ICU. Unit 2 and 3 are normal ICUs, where unit 2 is mostly used for cardiac and lung patients. Most patients at unit 3 are neurology patients or they have a congenital disorder. Lastly, unit 4 is called the high care. These patients do not need as much care as the patient on units 2 and 3, but they need to be monitored closely.

Not every patient at the ICU needs or has had surgery. These other patients do influence the number of available beds for the patients of elective surgeries. At the moment, each day, four elective patients from the OR are planned to get an ICU bed. Some specialties get assigned to a bed multiple times a week, others only a few times per month. However, sometimes there are too many emergency patients or other patients have to stay longer at the ICU. Therefore, it is not possible to free a bed for a new patient and a surgery has to be cancelled. Next to this, the goal is to have at least one empty bed at all times, in case it is needed for an emergency patient.

The MCU also consists of four different units. The specialties are divided between the different units. Only in case of an emergency, a patient can be placed on a unit from a different specialty, because the nurses at a ward are specialised to treat patients from certain specialties. The beds on a unit are not assigned to one specific specialty, so these can be exchanged between specialties that are assigned to the same unit.

- KCN (PDS North): neurology, neurological surgery, plastic surgery, otorhinolaryngology and maxillofacial surgery. This unit also has four "short-stay beds", which are only available from Monday morning until Saturday morning.
- KCZ (PDS South): paediatric surgery, urology and orthopaedic surgery.
- KTC (Paediatric thorax centre): paediatric cardiac surgery, paediatric pulmonary disease and sometimes paediatric surgery if the surgery is focused on the thorax.
- MCKG (Medium care paediatrics): non OR patients, for example haematology.

Almost all patients on the first three wards have had surgery.

Patients who do not have to stay overnight go to the daycare unit. This ward is opened on weekdays from 07:00 until 17:30. If a patient has to stay in the hospital, they have to be transferred to the MCU (or ICU if necessary). On this ward, the aim is to use the same bed for multiple patients on the same day (e.g. one patient in the morning, one in the afternoon).

The SCH provided how many beds are available on average for patients that need an elective surgery. We refer to this as the capacity. Note that, this is not the maximum number of beds available. The capacity of the different wards can vary per day or time slot. This information is in Appendix A, where we define weekdays to be from Monday 07:00 until Saturday 07:00 and weekend from Saturday 07:00 until Monday 07:00. There are two wards that have different time slots. Firstly, at the KCN, the capacity is different on Tuesday and Friday. Secondly, the daycare unit is only open on weekdays.

To give some more insight in the current ward occupancy, Figure 2.1 gives the ward occupancy of one MSS cycle. Note that, this is only an example of one cycle. Hence, we are not able to draw any conclusion from these figures.

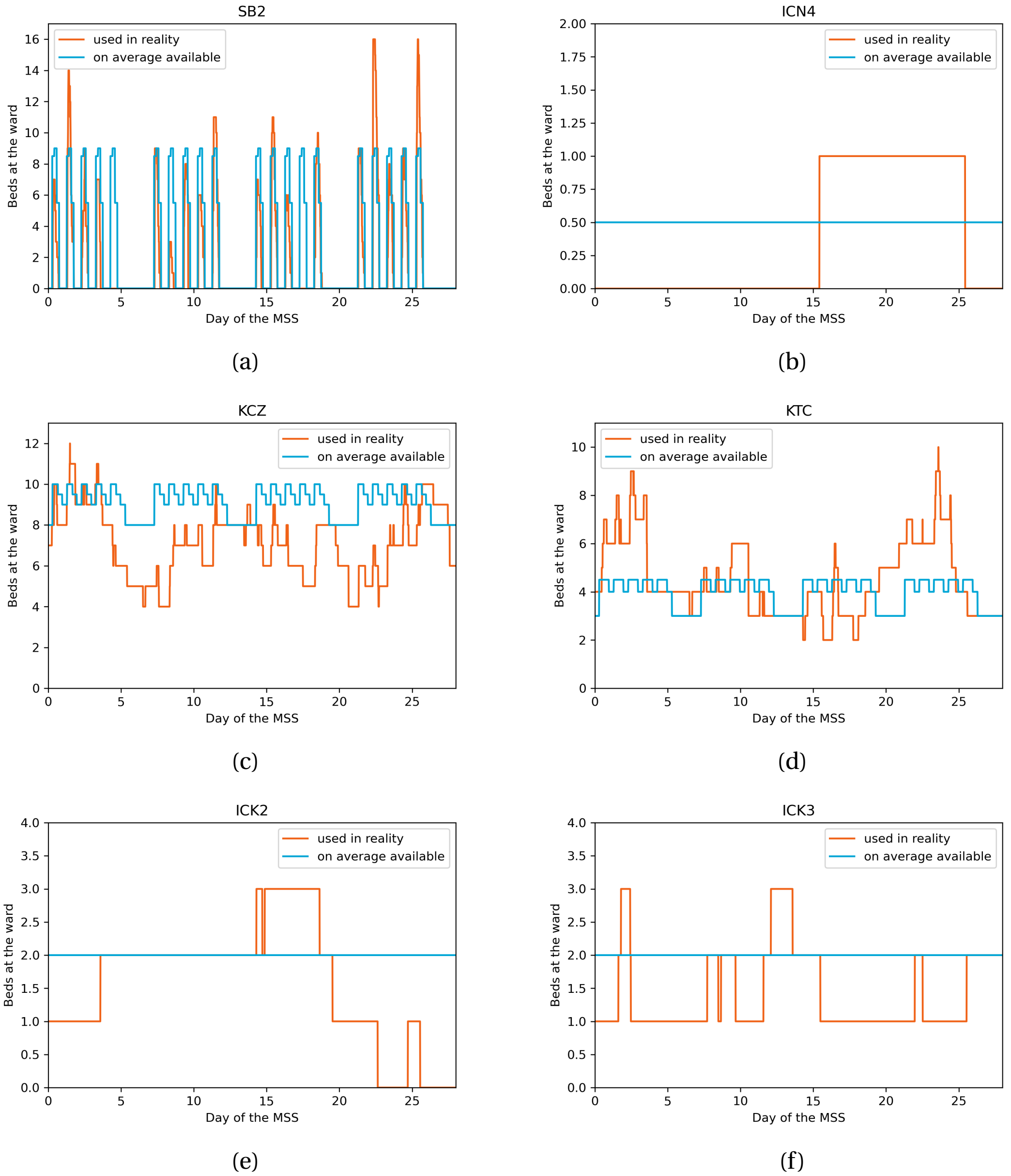


Figure 2.1: Ward occupancy of one MSS cycle, from April 23rd 2018 until May 20th 2018.

2.1.3 Operational planning

Next, admission planners schedule the actual surgeries. This is called offline operational planning. Not all the specialties plan in the same way, but in general they take into consideration:

- OR time slots assigned to their specialty (MSS);
- expected duration of the surgery;
- other specialties that are needed to perform the surgery;
- time a patient is on the waiting list;
- available beds (WS);
- expected length of stay (LoS) in the hospital.

For some specialties, the admission planners have to take into account that some surgeries have to be planned within one week. Hence, they have to leave some gaps in the schedule for these kinds of surgeries. The result is a schedule containing exactly when which patient is in surgery.

Once a week, this schedule is discussed with planners from different specialties and others, for example the people that monitor the number of patients at the ICU. Both the current and next week are discussed. This means that every week is discussed twice, because there might have been unforeseen changes in the meantime. During this meeting, it is evaluated if the planned surgeries can be executed. If there are for example not enough beds, because patients from last week are still there or too many specialties wanted to use the same beds, surgeries have to be cancelled or switched to another day or time.

The main focus of the admission planners is the MSS. They want to use their OR time as much as possible. This could however result in a fluctuating number of patients on the different wards. One of the goals of this research is to minimise the variation of the bed occupancy. This will be taken into account before the admission planners start scheduling surgeries, such that less surgeries have to be cancelled or rescheduled last minute. To achieve this, patients are divided into patient groups. Patients in one group are treated by the same specialty, and have a similar expected surgery duration and LoS on a specific ward. The MSS will be used to make a more specific schedule per specialty. It is not only decided when a specialty has OR time, but also how a certain OR slot is used. For example, firstly, a patient from group A, secondly, a patient from group B and lastly a patient from group A. The admission planners will still plan the individual patients, but they are given more guidance on which "kind" of patient this should be.

The last step is online operational planning. This is done by the anaesthesiologists. If there is an emergency surgery and the FLEX OR is full, they can make changes in the schedule to do this surgery. Other reasons for changes are e.g. the patient is too sick, the patient ate something or there is no bed available.

2.2 Route of a patient

Figure 2.2, provided by the SCH, gives an overview of the route of a patient within a hospital. Because the figure is from the SCH, it is in Dutch. Translation of the used words:

- Toegangstijd: access time.
- SEH: emergency department.
- Wachttijd: waiting time after their appointment.
- Diagnostiek: diagnostics.
- Behandeling: treatment.
- Poli: outpatient clinic.
- Verpleging: ward.

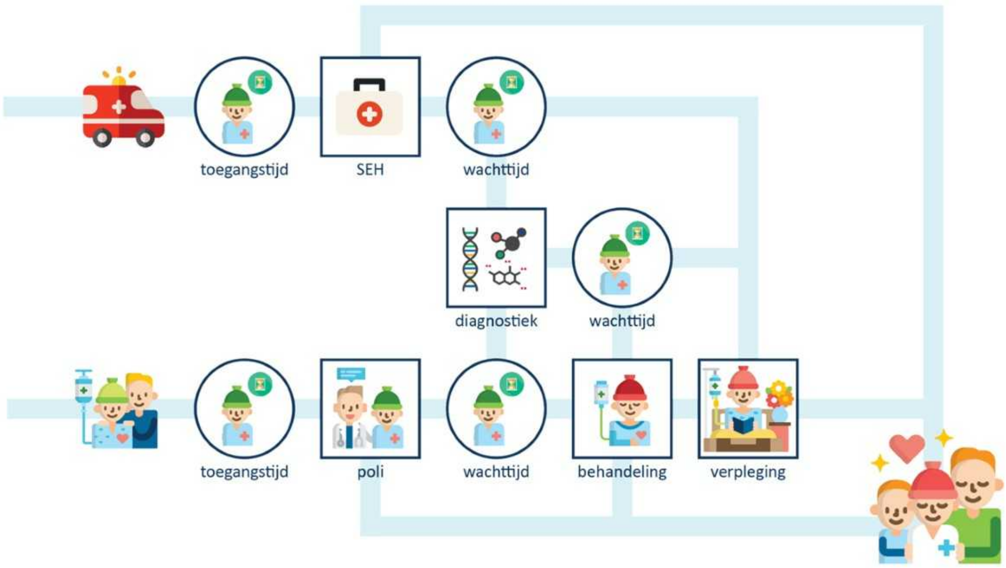


Figure 2.2: The route of a patient from entering the SCH until leaving the hospital.

In general, two categories of patients enter the hospital. Firstly, patients enter the hospital via the emergency department, because they need immediate care. Secondly, a patient plans to visit the hospital. There are three main reasons for this:

- a patient went to their general practitioner and was referred to a certain specialty at the hospital;
- a patient is referred to this hospital by another hospital, because the SCH can provide more specialised care;
- a patient is not even born yet, but during the pregnancy, it is discovered that the patient will need to be treated in a hospital after they are born.

In each of these cases, the patient calls to the hospital to make an appointment. Specifically, they call the outpatient department. Depending on the situation and the waiting list, the planners at the outpatient department set a date for this appointment. If a patient comes from a different hospital, this might go a little bit different, because the specialists at the SCH have to consult with the specialists from the other hospital.

All patients are examined by a specialist during their appointment. The specialist decides on how to proceed. Some patients do not have to come back after this first visit. Others are referred to a different specialty or hospital. Sometimes, it is not instantly clear what the problem is so a patient has to come back for more diagnostic tests and examinations (for example a CT scan). If the specialist decides that a patient needs a surgery, or some other treatment method, they place the patient on the waiting list. They also give a deadline for when the surgery should take place, such that the admission planners know when they need to schedule the patient. Depending on the deadline, the patient is called to make an appointment for the surgery or the surgery is directly scheduled. There are many different treatments, but because of the scope of this research, only surgery is discussed.

When a patient needs a surgery, there are some checks that need to happen beforehand. For example, whether the patient has any allergies or other medical complaints. These checks are done by the anaesthesiologist weeks before the surgery. One day before the surgery, the patient (or their parents) gets a call to discuss the last details.

At the day of the surgery, the patient arrives at the assigned ward approximately one hour before the surgery. A nurse does a few checks, e.g. if the patient has not eaten anything, and preps the patient for surgery. When the OR is ready, they notify the nurse, who brings the patient to the holding. The anaesthesiologist does another check at the holding (is it the right patient etcetera). In adult medicine, the holding is also used to give patients local anaesthesia or an IV line. In paediatrics, this is all done in the OR after the patient is brought under general anaesthesia. Before a patient enters the OR, the OR team does a final check (Who is the patient? What is the procedure? Do we have the right equipment? etcetera). After the surgery, a patient is brought to the post-anaesthesia care unit, where parents can visit their child. When a patient leaves the same day, the prescriptions for the needed medicine are arranged at this unit. If the child is awake again, they are brought back to the ward. When a patient needs an emergency surgery, this process is a little different. For example, the anaesthesiologist was not able to do the checks in advance, so these checks are performed before the surgery at the ward.

Sometimes a surgery gets cancelled. This can either happen before a patient enters the hospital or when the patient is already in the hospital. Some reasons for cancellation are:

- the patient is too sick to undergo the surgery;
- not enough staff is present to conduct the surgery;
- there is no bed for the patient.

The route described in this section is the "easy" route. It is also possible that a patient needs multiple treatments or surgeries or has to visit multiple specialties before they are cured. Especially in paediatric medicine, a lot of patients have to come back every few months/years, because their situation changes when they get older.

3 | Literature review

A lot of research has been done on OR planning. Section 3.1 gives an overview of earlier research on sequencing specialties or patient groups and leveling the bed occupancy. Section 3.2 specifically focuses on how patients can be clustered into different patient groups.

3.1 OR planning and bed occupancy

This thesis is not only focused on the OR schedule, but also on the effect of the OR schedule on the different wards. Wang et al. (2021) give an overview of research on this topic, including which departments are taken into account.

A lot of these, and other, articles focus on creating the MSS, i.e. the assignment of OR time to the different specialties. However, in Van Oostrum, van Houdenhoven, et al. (2008) the goal is similar to our goal. Each type of surgery is planned a certain number of times, while the workload on the wards is levelled. Contrary to our research, the starting point is not an MSS, but only OR opening times and some other capacity restrictions. They split the problem in two phases. Firstly, the goal to level the bed occupancy is ignored. They create a combination of feasible OR days. Combined, these OR days meet all the criteria regarding the frequency of the different procedures. This is done with an integer linear program (ILP), which is solved with column generation. Secondly, they assign the OR days to specific ORs on specific days, where the goal is to assign the days in such a way that the bed occupancy is levelled as much as possible.

Schneider et al. (2020) have a similar goal as our research and Van Oostrum, van Houdenhoven, et al. (2008), optimising the OR usage while minimising the variation at the different wards. They define a mixed integer program to schedule surgery groups. This is done using both a global approach and a local search heuristic.

In Choi and Wilhelm (2014), the focus is solely on using the ORs optimally, without looking at the effect on the wards. This research does however introduce another method to schedule surgical procedures. The MSS is used as a starting point and surgical procedures of the different specialties are divided into different groups, which they call sub-specialties. The goal is to find optimal surgical blocks for each sub-specialty and to plan these surgical blocks, such that the expected lateness and earliness costs are minimised. This block strategy is also used in Ghandehari and Kianfar (2022), where this strategy is used to both create the MSS and assign sub-specialties to optimal time blocks.

Kauwenbergh (2018) focuses on an entirely different part of the OR schedule. The research goal is also slightly different; minimising the number of beds that needs to be used on the different wards. The input of this research are patients (needing a specific procedure) which have to be treated on a certain OR and day. The outcome is the order in which these patients are scheduled at each OR day. This research is relevant to our research, because, unlike most researches, this research includes that patients stay for a certain number of minutes at a ward. Most researches assume that patients stay a certain number of days at the different wards. Therefore, this research could give a more realistic outcome about the bed occupancy during the day.

Our research differs from this research, because we do not know in advance which patients have to be treated on a specific OR day. We use the MSS as input and the probability distribution of the surgery duration to decide at which day, at what time, and on which OR a surgery is planned.

3.2 Clustering surgeries

There are different ways to cluster patients into patient groups. However, there are two things we demand from a clustering method. Firstly, all patients that need the same procedure are in the same patient group. Secondly, all patients in a patient group should be treated by a specialist from the same specialty. Hence, patient groups contain at most all patients from one specialty, and a patient group contains at least all patients that need the same procedure, Santibáñez et al. (2007). Next to that, Drupsteen (2013) emphasises that large patient groups with low variety result in a more realistic schedule.

In Schneider et al. (2020), the decision was made to first create patient groups based on the median LoS of the surgical procedures. Afterwards, these groups are split on the mean surgery duration of the procedures. They aimed for high precision for the different groups, i.e. a high percentage of the patients is assigned to the correct group.

k-means clustering is another option to divide a data set in multiple groups. This method is described in Yousefi et al. (2019). The goal of this method is to split a data set into k groups. Each group has a centre point. Starting, k data points are selected as initial centre points. Each data point is assigned to the group of the nearest centre point. Next, the average of each group is calculated and these averages are the new centre points. Again, for each data point it is evaluated which centre point is the nearest, and again the averages of the new groups are the new centre points. The algorithm stops if the centre points do not change. Note, this type of clustering does not have to be the optimal clustering of the data in k groups. Often, the sum of the distances from the data points to the corresponding centre points is used to evaluate how "good" a certain k-means clustering is. Different from Schneider et al. (2020), both the LoS and the surgery duration can be taken into account at the same time. However, we would need to scale the LoS and surgery duration. It is also possible to cluster first on the LoS, and second, on the duration of the surgery, or vice versa.

A "normal" k-means clustering algorithm, such as the algorithm described in Yousefi et al. (2019), cannot be used for our research, because we need to have a minimum number of surgeries within each cluster (i.e. patient group). However, a constrained k-means clustering, as described in Bradley et al. (2000), can be used. In addition to the "normal" k-means clustering algorithm, this method also takes into account the minimum number of data points a cluster should contain.

A different method, which is also based on the distance between the mean of different groups and the data points, is used in Van Oostrum, Parlevliet, et al. (2008). This is called Ward's hierarchical cluster method, Ward (1963). Contrary to Yousefi et al. (2019), it is not needed to decide in advance on how many clusters the data set should be clustered. At the start, each individual data point, in this case each surgical procedure, is a cluster. The cost of a cluster is the error sum of squares (ESS):

$$ESS_{\text{one cluster}} = \sum_{i=1}^{n} x_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right)^2, \tag{3.1}$$

with x_i the distance from a data point to the mean of the corresponding cluster. Hence, at the start, the total cost is zero. Next, two clusters are combined, for which holds that the combination of these two clusters would increase the total costs with the least amount (compared to all the other possible combinations of clusters). This continues until there is one cluster left; the cluster containing all data points. Depending on the goal, a "best" number of clusters can be selected. Again, this method could cluster on both the LoS and the surgery duration at the same time, or one after another.

4 | Mathematical background

This chapter gives relevant background information on the mathematical techniques that are used in this thesis. Firstly, linear problems and their duals are introduced in Section 4.1. This is needed to explain how column generation works in Section 4.2. Finally, in Section 4.3, some relevant concepts from probability theory are introduced.

4.1 Linear programming

A linear program (LP) is an optimisation problem without integer variables and both the objective function and the constraints are linear. The general form, i.e. canonical form, of an LP is given by Murota (2019):

$$\begin{aligned} \min_{\mathbf{x}} \quad & \mathbf{c}^\top \mathbf{x} \\ \text{subject to} \quad & A\mathbf{x} \geq \mathbf{b} \\ & \mathbf{x} \geq \mathbf{0} \end{aligned} \tag{4.1}$$

The goal is to find values for variables $\mathbf{x} \in \mathbb{R}^n$, such that the objective function $\mathbf{c}^\top \mathbf{x}$ (with $\mathbf{c} \in \mathbb{R}^n$) is minimised, while the constraints $A\mathbf{x} \geq \mathbf{b}$ (with $A \in \mathbb{R}^{m \times n}$ and $\mathbf{b} \in \mathbb{R}^m$) and $\mathbf{x} \geq \mathbf{0}$ are met.

Some additional notes:

- Problem (4.1) is a minimisation problem, but an LP could also be a maximisation problem. In that case, the constraints are of the form: $A\mathbf{x} \leq \mathbf{b}$.
- If all variables are integers, the problem is called an integer linear program (ILP). In this thesis, we use a mixed integer linear program (MILP) to optimise the more specific version of the MSS. This is a linear optimisation problem for which some, but not all, variables are integer variables.
- $\bar{\mathbf{x}}$ is called a feasible solution of LP (4.1) if all the constraints are met. Note, this solution does not have to be optimal.

The dual of primal problem (4.1) is:

$$\begin{aligned} \max_{\mathbf{y}} \quad & \mathbf{b}^\top \mathbf{y} \\ \text{subject to} \quad & A^\top \mathbf{y} \leq \mathbf{c} \\ & \mathbf{y} \geq \mathbf{0} \end{aligned} \tag{4.2}$$

Each objective function value of a feasible solution to the dual problem gives a lower bound on the objective function value of the primal problem. Next to that, it can be shown that, if an optimal solution $\mathbf{y}^*$ of the dual problem (4.2) exists, there exists an optimal solution $\mathbf{x}^*$ of the primal problem, with $\mathbf{c}^\top\mathbf{x}^* = \mathbf{b}^\top\mathbf{y}^*$. Finally, if we have a feasible solution to our primal problem, there are two options: the corresponding dual solution is either feasible or not feasible. If the corresponding dual solution is feasible, the primal solution and the corresponding dual solution are optimal. However, if the corresponding dual solution is not feasible, the primal solution is not optimal. The proofs of the previous statements are given in Thie and Keough (2008).

To illustrate this, we show an example. We define the primal (4.3).

$$\begin{array}{rlllll} \min\limits_{\mathbf{x}} & 4x_1 & + & 3x_2 & & \\ \text{subject to} & 8x_1 & + & 6x_2 & \geq & 7 \\ & x_1 & + & 2x_2 & \geq & 5 \\ & x_1, x_2 \geq 0 & & & & \end{array} \tag{4.3}$$

And, the dual (4.4) of the primal (4.3).

$$\begin{array}{rlllll} \max\limits_{\mathbf{x}} & 7\pi_1 & + & 5\pi_2 & & \\ \text{subject to} & 8\pi_1 & + & \pi_2 & \leq & 4 \\ & 6\pi_1 & + & 2\pi_2 & \leq & 3 \\ & \pi_1, \pi_2 \geq 0 & & & & \end{array} \tag{4.4}$$

Combining the two constraints of the primal (4.3) results in a linear combination (4.5), with π_1 times the first constraint and π_2 times the second constraint. This linear combination is rewritten to Equation (4.6), which implies a lower bound on the primal (4.3) if $4 \geq 8\pi_1 + \pi_2$ and $3 \geq 6\pi_1 + 2\pi_2$. This results in inequality (4.7), which is the objective value of the primal problem.

$$7\pi_1 + 5\pi_2 \leq (8x_1 + 6x_2)\pi_1 + (x_1 + 2x_2)\pi_2 \tag{4.5}$$
$$= (8\pi_1 + \pi_2)x_1 + (6\pi_1 + 2\pi_2)x_2 \tag{4.6}$$
$$\leq 4x_1 + 3x_2 \tag{4.7}$$

4.2 Column generation

The general idea of column generation is splitting a large LP into smaller subproblems, which together help solve the master problem, Wolsey (1998). We explain column generation using the relaxation of the Dantzig-Wolfe reformulation (4.9) of ILP (4.8).

$$\begin{array}{rllll} \max\limits_{\mathbf{x}} & \sum\limits_{k=1}^{K} \mathbf{c}_\mathbf{k}^\top \mathbf{x}_\mathbf{k} & & & \\ \text{subject to} & \sum\limits_{k=1}^{K} A_k \mathbf{x}_\mathbf{k} & = & \mathbf{b} & \\ & D_k \mathbf{x}_\mathbf{k} & \leq & \mathbf{d}_\mathbf{k} & \forall k \in \{1, \dots, K\} \\ & \mathbf{x}_\mathbf{k} \in \mathbb{Z}_+^{n_k}, \quad \forall k \in \{1, \dots, K\} & & & \end{array} \tag{4.8}$$

$$\begin{array}{llll} \max\limits_{\mathbf{x}} & \sum_{k=1}^{K}\sum_{t=1}^{T_k}\left(\mathbf{c_k^\top x_{kt}}\right)\lambda_{kt} & & \\ \text{subject to} & \sum_{k=1}^{K}\sum_{t=1}^{T_k}\left(A_k\mathbf{x_{kt}}\right)\lambda_{kt} & = & \mathbf{b} \\ & \sum_{t=1}^{T_k}\lambda_{kt} & = & 1 \quad \forall k\in\{1,\dots,K\} \end{array} \tag{4.9}$$

$$\text{With, } \lambda_{kt}\geq 0, \quad \forall k\in\{1,\dots,K\} \quad \forall t\in\{1,\dots,T_k\}.$$

$$\text{And, } \mathbf{x_k}=\sum_{t=1}^{T_k}\mathbf{x_{kt}}\lambda_{kt},\ \mathbf{x_{kt}}\in\mathbb{Z}_+^{n_k} \text{ and } D_k\mathbf{x_{kt}}\leq\mathbf{d_k}, \quad \forall k\in\{1,\dots,K\}, \quad \forall t\in\{1,\dots,T_k\}.$$

Problem (4.9) describes the relaxation of Problem (4.8). Here, we assume that all feasible solutions are in the set $\{x_{k1},\dots,x_{kT_k}\}$ for each $k\in\{1,\dots,K\}$. If λ_{kt} would be binary, it would ensure that exactly one $\mathbf{x_{kt}}$, for which the constraints hold, is selected for each $k\in\{1,\dots,K\}$. However, λ_{kt} is not binary. Therefore, the model can select a combination of different variables.

Next, we define the linear programming master (LPM), as the optimisation problem below.

$$\max_{\mathbf{x}} \quad \sum_{k=1}^{K}\sum_{t=1}^{T_k}\left(\mathbf{c_k^\top x_{kt}}\right)\lambda_{kt} \tag{4.10}$$

$$\text{subject to} \quad \sum_{k=1}^{K}\sum_{t=1}^{T_k}\left(A_k\mathbf{x_{kt}}\right)\lambda_{kt} = \mathbf{b} \qquad (\pi) \tag{4.11}$$

$$\sum_{t=1}^{T_k}\lambda_{kt} = 1 \quad \forall k\in\{1,\dots,K\} \quad (\mu_k) \tag{4.12}$$

$$\lambda_{kt}\geq 0, \quad \forall k\in\{1,\dots,K\}, \quad \forall t\in\{1,\dots,T_k\}$$

Constraints (4.12) ensure that for each $k\in\{1,\dots,K\}$ a combination of variables $\mathbf{x_{kt}}$, i.e. columns, is chosen. Constraint (4.11) is called the joint constraint.

During column generation, we solve the LPM using only a restricted set of columns. This version of the problem is called the restricted linear programming master (RLPM). The RLPM is solved with an initial set of columns. This set contains at least one column for each $k\in\{1,\dots,K\}$, and together these columns need to form a feasible solution to the LPM. Because not all columns are available, it could occur that for a $k\in\{1,\dots,K\}$ the optimal value for $\mathbf{x_k}$ is not in the set of available columns. In that case, the optimal solution to the RLPM is not the optimal solution to the LPM. Next, it is explained how we check if the optimal solution of the RLPM is also the optimal solution of the LPM.

As mentioned in Section 4.1, a solution to the primal problem is optimal, only if the corresponding dual solution is feasible and the objective function of the primal and dual problem are equal. The dual of the LPM is:

$$\begin{array}{llll} \min\limits_{\pi,\mu} & \pi\mathbf{b}+\sum_{k=1}^{K}\mu_k & & \\ \text{subject to} & \pi A_k\mathbf{x_{kt}}+\mu_k & \geq & \mathbf{c_k^\top x_{kt}} \quad \forall k\in\{1,\dots,K\}, \quad \forall t\in\{1,\dots,T_k\} \end{array} \tag{4.13}$$

$$\pi^\top\in\mathbb{R}^m, \mu_k\in\mathbb{R}, \quad \forall k\in\{1,\dots,K\}$$

Hence, a feasible solution to the primal problem is feasible to the dual of the LPM if $\pi A_k \mathbf{x_{kt}} + \mu_k \geq \mathbf{c_k^\top x_{kt}}$, i.e. $\left(\mathbf{c_k^\top} - \pi A_k\right)\mathbf{x_{kt}} - \mu_k \leq 0$, for all $k \in \{1,\ldots,K\}$ and $t \in \{1,\ldots,T_k\}$. Hence, an optimal solution of the RLPM is the optimal solution of the LPM if this constraint is met. This feasibility can be checked separately for each $k \in \{1,\ldots,K\}$. This is used in the next step of column generation.

For each $k \in \{1,\ldots,K\}$, we define a pricing subproblem (4.14). If the optimal value of the objective function of a subproblem is bigger than zero, the dual solution of the RLPM is not feasible for each $k \in \{1,\ldots,K\}$ and $t \in \{1,\ldots,T_k\}$ and the column corresponding to this solution has positive reduced costs, i.e. adding this column to our set of available columns to the master problem could improve the objective value of the RLPM.

$$\begin{aligned} \max_{\mathbf{x_k}} \quad & \left(\mathbf{c_k^\top} - \pi A_k\right)\mathbf{x_k} - \mu_k \\ \text{subject to} \quad & D_k \mathbf{x_k} \leq \mathbf{d_k} \\ & \mathbf{x_k} \in \mathbb{Z}_+^{n_k} \end{aligned} \tag{4.14}$$

Next, the RLPM is solved using the new extended set of columns. Again, the renewed dual variables and the pricing subproblems are used to determine if the solution is dual feasible for the LPM. This process repeats itself until $\left(\mathbf{c_k^\top} - \pi A_k\right)\mathbf{x_{kt}} - \mu_k = 0$ for each subproblem. If this is the case, we found an optimal solution to the LPM.

The final step is to use the selected columns to find a solution to the original ILP (4.8). One of the options is to use a branch and price algorithm, where you can also use that the LPM gives a lower bound to the ILP.

4.3 Probability theory

In this section, two concepts from probability theory are explained. Firstly, the expectation of a random variable is defined. Secondly, the definition and some notation regarding convolutions of probability distributions is introduced.

The expectation of a random variable X, with a finite number of possible outcomes $x_1, x_2, \ldots, x_n$ is defined as

$$\mathbb{E}(X) = x_1 \cdot \mathbb{P}(X = x_1) + x_2 \cdot \mathbb{P}(X = x_2) + \ldots + x_n \cdot \mathbb{P}(X = x_n). \tag{4.15}$$

Let X and Y be two independent discrete random variables, corresponding to the probability distributions $\mathscr{X}$ and $\mathscr{Y}$, respectively. Let $\mathscr{Z}$ be the probability distribution of the convolution of $\mathscr{X}$ and $\mathscr{Y}$, with the corresponding discrete random variable Z. This probability distribution $\mathscr{Z}$, is defined by Equations (4.16).

$$\mathbb{P}(Z = z) = \sum_{(x,y)\in K_z} \mathbb{P}(X = x) \cdot \mathbb{P}(Y = y), \qquad \forall z \in \mathbb{Z}, \tag{4.16}$$

where K_z is the set of all possible combinations of x and y that add up to z. The notation of this convolution is

$$\mathscr{Z} = \mathscr{X} * \mathscr{Y}. \tag{4.17}$$

Next, we introduce two forms of notation. Let $\mathscr{X}_0, \mathscr{X}_1, \ldots, \mathscr{X}_n$ be independent probability distributions. The convolution of all of the probability distributions is given by

$$\mathscr{X}_0 * \mathscr{X}_1 * \ldots * \mathscr{X}_n = \mathop{\Huge *}_{i=0}^{n} \mathscr{X}_i = \mathop{\Huge *}_{i\in I} \mathscr{X}_i, \tag{4.18}$$

where $I = \{0, 1, \ldots, n\}$.

5 | Mathematical model

The goal of this project is to create and use a model to make a more specific version of the MSS. To create this more specific version, we take a closer look at scheduling the surgical procedures into the already fixed specialty blocks of the MSS and the influence of these procedures on the different wards. This chapter starts with the problem description in Section 5.1. In this section, the problem is explained in more detail and the different parameters are introduced. The problem formulation can be found in Section 5.2. This chapter concludes with an overview of the mathematical model in Section 5.3.

5.1 Problem description

To make a more detailed version of the MSS, the total time of one MSS cycle is divided into time blocks of equal length. The set T is the set containing all time blocks $t \in T$. Next to that, we want to look into specific days of the MSS cycle. Therefore, we use a second notation to describe the total time of one MSS cycle, where $\mathscr{D}$ is the set of all the days $d \in \mathscr{D}$ in one MSS cycle and $\mathscr{Z}$ the set of time blocks $z \in \mathscr{Z}$ per day. We define h as the number of time blocks per day:

$$h = \frac{\text{number of minutes in one day}}{\text{length of one time block in minutes}} = \frac{1440}{\text{length of one time block in minutes}}. \tag{5.1}$$

Hence, it holds that $t = z + d \cdot h$, with $z \in \mathscr{Z}$, $d \in \mathscr{D}$ and $t \in T$. To speed up the model, we define two other sets. Firstly, $D \subset \mathscr{D}$ which contains all days $d \in \mathscr{D}$ on which the OR is opened for elective surgeries (all weekdays). Secondly, $Z \subset \mathscr{Z}$ which contains all the time blocks $z \in \mathscr{Z}$ during the opening times of the OR on day $d \in D$.

To make the model more readable, we let $D = \{d_0, d_1, \ldots, d^*\}$. This implies, that set D contains $d^* + 1$ elements. Similar notation is used for each of the sets.

As mentioned in Subsection 2.1.2, the SCH provided how many beds are on average available for patients that need an elective surgery. Let W the set of all wards. The parameter q_{tw} denotes the number of beds at ward $w \in W$ that are available for elective OR patients during time block $t \in T$. Note that, this is not the maximum number of beds available.

When scheduling surgeries of different patient groups, we have to take into account the MSS. The set O is the set containing all ORs at the SCH, and the set S is the set containing all the specialties. The MSS specifies exactly when specialty $s \in S$ can use OR $o \in O$. This is translated to the model with parameter $m_{dosz} \in [0,1]$, which indicates the fraction of time of OR $o \in O$ that can be used by specialty $s \in S$ at time $z \in Z$ on day $d \in D$. This parameter is one in general, but for example at the end of the OR day, we allow some overtime. We define t^{OT} as the number of time blocks during which we allow some overtime. This is explained in Section 7.5. Next to that, $z_{do}^{open} \in Z$ and $z_{do}^{close} \in Z$ indicate the opening and closing time, respectively, of OR $o \in O$ at day $d \in D$.

As mentioned in Subsection 2.1.2, we use patient groups to create a more detailed version of the MSS. Therefore, elective patients are clustered in patient groups based on the surgical procedure they need and historical data about this procedure, see Section 7.4. We define G to be the set of all patient groups. The MSS divides the available OR time between the different specialties. Hence, we introduce $G_s \subseteq G$ as the set of patient groups belonging to specialty $s \in S$. The new schedule is more specific, because we plan a certain patient group $g \in G_s$ at a certain time during OR time assigned to specialty $s \in S$. To do this, we use the following information regarding the different patient groups.

- The parameter $p_{g\tau} \in [0,1]$ which gives the probability that a surgery on a patient from patient group $g \in G$ takes $\tau \in T$ time blocks.
- The parameter n_g indicates the fraction of surgeries performed by specialty $s \in S$ which are in patient group $g \in G_s$, see Equation (5.2).

$$n_g = \frac{\text{number of patients in patient group } g \in G_s}{\text{total number of patients treated by specialty } s \in S} \tag{5.2}$$

Multiple surgeries can be scheduled in the same OR $o \in O$ on the same day $d \in D$. The set V describes the possible positions of these surgeries, in other words, the order of the surgeries. The order of the surgeries is important, because it influences when a patient uses a bed at a ward. For example, if a patient has a surgery that takes thirty minutes and has to stay six hours at the daycare unit after their surgery, then, if this patient is planned at the end of the OR day, the daycare unit closes before the patient can be discharged. Hence, the patient needs to be moved to the MCU. Therefore, it might have been better to schedule this patient at the start of the OR day.

We use four indicators to refer to a unique surgery in the schedule:

- The day $d \in D$ during which the surgery is performed.
- The patient group $g \in G$ to which the patient who has the surgery belongs.
- The OR $o \in O$ in which the surgery is performed.
- The position $v \in V$ of the surgery.

Next to information about surgeries, the patient groups contain information about the LoS of the patients at the different wards.

Before we introduce the corresponding variables, it is important to note that the SCH uses a cyclic MSS schedule. Therefore, we decided to make our more specific schedule cyclic as well. For example, when a patient has to stay in the hospital for three days, with the first day of their stay being the last day of the cycle, then the patient is also in the hospital the first and second day of the cycle. Next to that, because the schedule is cyclic, a patient can use multiple beds at the same time in a schedule. This is the case, if a patient stays for more than one MSS cycle at the hospital, this patient uses more than one bed during one time block $t \in T$ in our cyclic schedule. Therefore, we define the set $X = \{0, \ldots, \text{maximum number of cycles a patient stays at a ward}\}$.

The parameter $k_{g\tau wx} \in [0,1]$ indicates the probability that a patient from patient group $g \in G$ uses $x \in X$ beds at ward $w \in W$ during time block $\tau \in T$, with the start time of the surgery at $\tau = 0$. Next to that, at the moment, a patient is always assigned to a ward, even when the patient is in surgery. Even though the patient is not physically at a ward during the surgery, there is an empty bed reserved for the patient.

5.2 Problem formulation

This section contains the explanation of the different variables and constraints. Subsection 5.2.1 is focused on the restrictions related to the OR and Subsection 5.2.2 is focused on the restrictions related to the wards. After that, some general restrictions and the objective function are introduced in Subsection 5.2.3.

5.2.1 Restrictions regarding the OR

We start off with the binary variable f_{dgov}, which is one if a patient from patient group $g \in G$ is the $v \in V$-th surgery in OR $o \in O$ on day $d \in D$ and zero otherwise. In other words, the $v \in V$-th surgery on day $d \in D$ in OR $o \in O$ performed on a patient from patient group $g \in G$ only exists if f_{dgov} is equal to one.

Constraints (5.3) are used to ensure (with the binarity of f_{dgov}) that only one patient group can be scheduled as the $v \in V$-th surgery in OR $o \in O$ on day $d \in D$.

$$\sum_{g \in G} f_{dgov} \leq 1, \qquad \forall d \in D, \forall o \in O, \forall v \in V \tag{5.3}$$

To indicate the start time of a surgery, we use the variable $b_{dgovz} \in [0,1]$. This variable gives the probability that the $v \in V$-th surgery on day $d \in D$ in OR $o \in O$ performed on a patient from patient group $g \in G$ starts at time $z \in Z$. The start time is a probability, because the start time of surgery depends on the end time of the previous surgery. To calculate the end time, we need the duration of the surgery. The probability that this previous surgery takes a certain number of time blocks is given by parameter $p_{g\tau}$.

Constraints (5.4) ensure that if f_{dgov} is equal to zero, b_{dgovz} is equal to zero for all possible start times. And, if f_{dgov} is equal to one, the total probability that the start time exists should be equal to one.

$$\sum_{z \in Z} b_{dgovz} = f_{dgov}, \qquad \forall d \in D, \forall g \in G, \forall o \in O, \forall v \in V \tag{5.4}$$

We decided to start the first surgery of the day immediately if the OR opens. This is enforced with Constraints (5.5).

$$b_{dgo0z_{do}^{open}} = f_{dgo0}, \qquad \forall d \in D, \forall g \in G, \forall o \in O \tag{5.5}$$

The variable $e_{dgovz} \in [0,1]$ gives the probability that the $v \in V$-th surgery on day $d \in D$ in OR $o \in O$ performed on a patient from patient group $g \in G$ ends at time $z \in Z$. This is determined using a similar strategy as Kauwenbergh (2018). The end time of a surgery depends on both the start time and the length of a surgery. Let $\zeta \in Z$ be the start time, and $\tau \in T$ the length of the surgery. If it holds that $\tau + \zeta = z$, then the combination of this start time and length of surgery gives the desired end time, which occurs with the probability: $p_{g\tau} \cdot b_{dgov\zeta}$. However, there could be more combinations that give the same end time: $\tau = 1$ and $\zeta = z-1$, $\tau = 2$ and $\zeta = z-2, \ldots, \tau = z$ and $\zeta = z-\tau$. The sum of the probabilities that these combinations occur is the probability that a surgery ends at time $z \in Z$. This is enforced with Constraints (5.6).

$$e_{dgovz} = \sum_{\tau=1}^{z-z_0} p_{g\tau} \cdot b_{dgov(z-\tau)}, \qquad \forall d \in D, \forall g \in G, \forall o \in O, \forall v \in V, \forall z \in Z \tag{5.6}$$

We assume that we want to plan as much surgeries as possible. This is the case if a surgery starts directly after the previous surgery is finished. However, the OR also needs to be cleaned after a surgery and prepared for the next surgery, which takes one time block if the two surgeries are performed by the same specialty, and two time blocks if the surgeries are performed by different specialties. This is ensured by Constraints (5.7), while taking into account that there is also the probability that we do not want to schedule another surgery.

$$b_{dgovz} \leq \sum_{j \in G_s} e_{djo(v-1)(z-1)} + \sum_{j \notin G_s} e_{djo(v-1)(z-2)}, \qquad \forall d \in D, \forall o \in O, \forall v \in V \backslash \{0\}, \forall s \in S, \forall g \in G_s, \forall z \in Z \backslash \{z_0, z_1\} \tag{5.7}$$

These constraints also ensure that there can only be a second surgery if there is a first surgery, that there can only be a third surgery if there is a second surgery, and so on. Constraints (5.7) do not apply if $v = 0$, because in that case there is no previous surgery. These constraints do also not apply if $z = z_0$ or if $z = z_1$, because this would result in a non-existing end times.

The $v \in V$-th surgery on day $d \in D$ in OR $o \in O$ performed on a patient from patient group $g \in G$ is only allowed to start during OR time assigned to the corresponding specialty. This is given by Constraints (5.8).

$$\sum_{g \in G_s} \sum_{v \in V} b_{dgovz} \leq m_{dosz}, \qquad \forall d \in D, \forall o \in O, \forall s \in S, \forall z \in Z \tag{5.8}$$

Next to that, we want to ensure that a surgery is not scheduled if there is a high probability that this surgery is not finished before the OR has to close. As mentioned before, we allow some overtime at the end of an OR day, namely t^{OT} time blocks. Before the OR is closed, the OR needs to be cleaned. This takes one extra time block. Combined, this results in Constraints (5.9), which assure that there is at least a 90% chance that the $v \in V$-th surgery on day $d \in D$ in OR $o \in O$ performed on a patient from patient group $g \in G$ is finished during time block $z^{close}_{do} + t^{OT} - 1 \in Z$.

$$\sum_{z \in \{z_0, \dots, z^{close}_{do} + t^{OT} - 1\}} e_{dgovz} \geq 0.9 \cdot f_{dgov}, \qquad \forall d \in D, \forall o \in O, \forall s \in S, \forall g \in G_s, \forall v \in V \backslash \{0\} \tag{5.9}$$

This constraint does not apply to the first surgery of an OR day, because there are patient groups for which only one surgery takes already more time than the maximum amount of OR time at one day. By not applying this constraint to the first surgery of an OR day, these surgeries can also be scheduled, but only at the beginning of the OR day and without any other surgeries scheduled on the same day in the same OR.

5.2.2 Restrictions regarding the wards

In this section, it is explained how the bed occupancy is taken into account in our model. Firstly, the probability distribution $\mathscr{R}_{tw}$ of the bed occupancy at ward $w \in W$ at time $t \in T$ is defined. Secondly, it is explained why it is needed to use a linearisation of this probability distribution and this linearisation is given.

As a reminder, we defined the parameter $k_{g\tau wx} \in [0,1]$ as the probability that a patient from patient group $g \in G$ uses $x \in X$ beds at ward $w \in W$ during time block $\tau \in T$, with the start time of the surgery at $\tau = 0$. This parameter is used to define the probability distribution, $\mathscr{K}_{g\tau w}$, of the number of beds a patient from patient group $g \in G$ needs at ward $w \in W$ during time block $\tau \in T$, if the surgery started at $\tau = 0$. This probability distribution is defined by Equations (5.10), where $K_{g\tau w}$ is the discrete random variable corresponding to this distribution.

$$\mathbb{P}(K_{g\tau w} = x) \quad = \quad k_{g\tau wx}, \qquad \forall g \in G, \forall \tau \in T, w \in W \tag{5.10}$$

Secondly, let $\mathscr{B}_{dgovz}$ be the probability distribution describing if the $v \in V$-th surgery on day $d \in D$ in OR $o \in O$ performed on a patient from patient group $g \in G$ starting at time $z \in Z$ is planned or not. The discrete probability distribution $\mathscr{B}_{dgovz}$ is given by Equations (5.11) and (5.12), where B_{dgovz} is the discrete random variable corresponding to this distribution.

$$\begin{aligned} \mathbb{P}\left(B_{dgovz}=1\right) &= b_{dgovz}, && (5.11)\\ & \forall d \in D, \forall g \in G, \forall o \in O, \forall v \in V, \forall z \in Z \\ \mathbb{P}\left(B_{dgovz}=0\right) &= 1-b_{dgovz}, && (5.12)\\ & \forall d \in D, \forall g \in G, \forall o \in O, \forall v \in V, \forall z \in Z \end{aligned}$$

Subsequently, we define $\overline{\mathscr{B}}_{dgz}$, which is the probability distribution of the number of surgeries which start at time $z \in Z$ on day $d \in D$ performed on patients from patient group $g \in G$. This probability distribution is given by Equations (5.13).

$$\overline{\mathscr{B}}_{dgz} = \mathop{\ast}_{o\in O} \mathop{\ast}_{v \in V} \mathscr{B}_{dgovz}, \qquad \forall d \in D, \forall g \in G, \forall z \in Z \tag{5.13}$$

Next, we define $\mathscr{H}_{dgtwz}$, as the probability distribution of the number of patients at ward $w \in W$ during time block $t \in T$ from patient group $g \in G$, who have had a surgery that started at time $z \in Z$ on day $d \in D$. This probability distribution is defined by Equations (5.14), where H_{dgtwz} is the discrete random variable corresponding to this distribution. Note that, $K_{g\tau w}$ and $\overline{B}_{dgz}$ are the discrete random variables corresponding to probability distributions $\mathscr{K}_{g\tau w}$ and $\overline{\mathscr{B}}_{dgz}$, respectively. This is done in a similar way as for Constraints (5.6).

$$\begin{aligned} \mathbb{P}\left(H_{dgtwz}=h\right) &= \sum_{(\overline{b},x)\in V_h} \mathbb{P}\left(\overline{B}_{dgz}=\overline{b}\right) \cdot \mathbb{P}\left(\mathscr{K}_{g((t-(z+d\cdot h)) \bmod (t^*+1))w}=x\right), && (5.14)\\ & \forall g \in G, \forall h \in \{0,\ldots,x^* \cdot \overline{b}^*\}, \forall t \in T, \forall w \in W, \end{aligned}$$

where V_h is the set of all possible combinations of $\overline{b}$ and x for which hold $\overline{b} \cdot x = h$.

Subsequently, we define $\overline{\mathscr{H}}_{gtw}$, as the probability distribution of the number of patients at ward $w \in W$ during time block $t \in T$ from patient group $g \in G$. This probability distribution is defined by Equations (5.15).

$$\overline{\mathscr{H}}_{gtw} = \mathop{\ast}_{d\in D} \mathop{\ast}_{z \in Z} \mathscr{H}_{dgtwz}, \qquad \forall g \in G, \forall t \in T, \forall w \in W \tag{5.15}$$

Lastly, the probability distribution $\mathscr{R}_{tw}$ of the number of patients at ward $w \in W$ at time $t \in T$ is defined by Equations (5.16).

$$\mathscr{R}_{tw} = \mathop{\ast}_{g\in G} \overline{\mathscr{H}}_{gtw} \tag{5.16}$$

5.2.3 Objective function

As stated in Section 5.1, the parameter n_g gives the fraction of surgeries performed by specialty $s \in S$ that are in patient group $g \in G_s$. When planning the surgeries, we want to plan the patients groups according to these fractions. For example, if there is a specialty with two patient groups, A and B, with $n_A = 0.8$ and $n_B = 0.2$, we do not want to schedule exactly 0.8 patients from group A and 0.2 patients from group B, but if we schedule four patients from group A, we want to schedule one patient from group B. Therefore, we use the non-negative variable α_s in Constraints (5.17) to maintain the same ratio between the different patient groups $g \in G_s$ and plan as many surgeries as possible from specialty $s \in S$. α_s is maximised in the objective function.

$$\sum_{d\in D} \sum_{o\in O} \sum_{v\in V} f_{dgov} \geq \alpha_s \cdot n_g, \qquad \forall s \in S, \forall g \in G_s \tag{5.17}$$

Sometimes, there is not enough OR time to schedule another surgery of one of the patient groups, but it could be possible that there is enough time left to schedule a surgery of one of the other patient groups. For example, assume that the surgery duration of patient group A is exactly three time blocks and the surgery duration of patient group B is exactly eight time blocks. If there are eight consecutive time blocks left, there are two options, schedule two patients from group A (using six time blocks in total) or schedule one patient from group B (using eight time blocks in total). We want to use as much OR time as possible, but if we would optimise the total number of planned surgeries the model would select the first option. To ensure that we use the OR time as much as possible,

$$\sum_{d\in D}\sum_{g\in G}\sum_{o\in O}\sum_{v\in V} f_{dgov}\cdot\mathbb{E}(p_g) \tag{5.18}$$

is maximised in the objective function. The maximisation of planning the individual surgeries is scaled in such a way that the extra surgeries are only planned if it is not possible to plan surgeries according to their assigned fractions.

Next to maximising the usage of the OR, the goal is to minimise the variation of the bed occupancy. This can be done by minimising the maximum of $\mathscr{R}_{tw}$ at each ward. Because, if we minimise the maximum, we force that the patients are spread out more evenly over the day. However, the number of available beds fluctuates. For example, during the weekends there is less capacity at the wards. Therefore, the fraction of the beds available for elective OR patients that is used at each ward $w \in W$ during each time block $t \in T$ is used in Constraints (5.19).

$$\frac{\mathscr{R}_{tw}}{q_{tw}} \leq \theta_w, \qquad \forall t \in T, \forall w \in W \tag{5.19}$$

With the objective function (5.20), the fraction of the beds available for elective OR patients that is used at each ward is minimised. Also, the variables α_s and the number of planned surgeries should be maximised. The weight $\omega \in \mathbb{R}^+$ is added, such that the model can be either focussed more on the OR utilisation or levelling the ward occupancy.

$$\min \quad \sum_{w\in W}\theta_w - \omega\cdot\sum_{s\in S}\alpha_s - \omega\cdot\frac{1}{200}\sum_{d\in D}\sum_{g\in G}\sum_{o\in O}\sum_{v\in V}\left(f_{dgov}\cdot\mathbb{E}(p_g)\right) \tag{5.20}$$

5.3 Overview

This section provides an overview of the optimisation problem. All information given is explained in the previous sections.

Table 5.1: Sets

Set	Description
T	Time blocks.
W	Wards.
D	Days on which the OR is opened for elective surgeries.
Z	Time blocks during which the OR is opened.
O	ORs.
S	Specialties.
G	Surgery groups.
G_s	Surgery groups from specialty $s \in S$.
X	The possible number of cycles a patient stays at a ward.
V	The possible positions of a surgery $s \in S$ on a day $d \in D$.

Table 5.2: Parameters

Parameter	Description
q_{tw}	The number of beds at ward $w \in W$ that are available for elective OR patients during time block $t \in T$.
m_{dosz}	Parameter between zero and one, which indicates the fraction of OR $o \in O$ that can be used by specialty $s \in S$ at time $z \in Z$ on day $d \in D$.
$p_{g\tau}$	The probability that a surgery on a patient from patient group $g \in G$ takes $\tau \in T$ time blocks.
n_g	The fraction of surgeries performed by specialty $s \in S$ which are in patient group $g \in G_s$.
$k_{g\tau wx}$	The probability that a patient from patient group $g \in G$ uses $x \in X$ beds at ward $w \in W$ during time block $\tau \in T$, with the start time of the surgery at $\tau = 0$.
ω	The non-negative parameter indicating if the model is either focussed more on the OR utilisation (high value) or on levelling the ward occupancy (low value).

Table 5.3: Variables

Variable	Description
f_{dgov}	Binary decision variable, which is one if a patient from patient group $g \in G$ is the $v \in V$-th surgery in OR $o \in O$ on day $d \in D$ and zero otherwise.
b_{dgovz}	Variable that takes values in $[0,1]$, which gives the probability that the $v \in V$-th surgery on day $d \in D$ in OR $o \in O$ performed on a patient from patient group $g \in G$ starts at time $z \in Z$.
e_{dgovz}	Variable that takes values in $[0,1]$, which gives the probability that the $v \in V$-th surgery on day $d \in D$ in OR $o \in O$ performed on a patient from patient group $g \in G$ ends at time $z \in Z$.
$\mathscr{R}_{tw}$	Probability distribution of the number of patients at ward $w \in W$ at time $t \in T$.
α_s	Non-negative variable, which indicates how often each patient group $g \in G_s$ of specialty $s \in S$ is minimally planned during one cycle of the MSS.
θ_w	Non-negative variable, which gives the maximum fraction of the beds available for elective OR patients that is used at each ward $w \in W$ during a time block $t \in T$.

The optimisation problem:

$$\min \quad \sum_{w\in W}\theta_w - \omega\cdot\sum_{s\in S}\alpha_s - \omega\cdot\frac{1}{200}\sum_{d\in D}\sum_{g\in G}\sum_{o\in O}\sum_{v\in V}\left(f_{dgov}\cdot\mathbb{E}(p_g)\right)$$

subject to

$$\sum_{g\in G} f_{dgov} \leq 1 \qquad \forall d\in D, \forall o\in O, \forall v\in V$$

$$\sum_{z\in Z} b_{dgovz} = f_{dgov} \qquad \forall d\in D, \forall g\in G, \forall o\in O, \forall v\in V$$

$$b_{dgo0z^{open}_{do}} = f_{dgo0} \qquad \forall d\in D, \forall g\in G, \forall o\in O$$

$$e_{dgovz} = \sum_{\tau=1}^{z-z_0} p_{g\tau}\cdot b_{dgov(z-\tau)} \qquad \forall d\in D, \forall g\in G, \forall o\in O, \forall v\in V, \forall z\in Z$$

$$b_{dgovz} \leq \sum_{j\in G_s} e_{djo(v-1)(z-1)} + \sum_{j\notin G_s} e_{djo(v-1)(z-2)} \qquad \forall d\in D, \forall o\in O, \forall v\in V\setminus\{0\}, \forall z\in Z\setminus\{z_0, z_1\}, \forall s\in S, \forall g\in G_s$$

$$\sum_{g\in G_s}\sum_{v\in V} b_{dgovz} \leq m_{dosz} \qquad \forall d\in D, \forall o\in O, \forall s\in S, \forall z\in Z$$

$$0.9\cdot f_{dgov} \leq \sum_{z\in\{z_0,\ldots,z^{close}_{do}+t^{OT}-1\}} e_{dgovz} \qquad \forall d\in D, \forall o\in O, \forall s\in S, \forall g\in G_s, \forall v\in V\setminus\{0\}$$

$$\alpha_s\cdot n_g \leq \sum_{d\in D}\sum_{o\in O}\sum_{v\in V} f_{dgov} \qquad \forall s\in S, \forall g\in G_s$$

$$\theta_w \geq \frac{\mathcal{R}_{tw}}{q_{tw}} \qquad \forall t\in T, \forall w\in W$$

$$f_{dgov}\in\{0,1\}, \quad \forall d\in D, \forall g\in G, \forall o\in O, \forall v\in V$$

$$b_{dgovz}, e_{dgovz}\in[0,1], \quad \forall d\in D, \forall g\in G, \forall o\in O, \forall v\in V, \forall z\in Z$$

$$r_{tw}\in\mathbb{R}^+, \quad \forall t\in T, \forall w\in W$$

$$\alpha_s\in\mathbb{R}^+, \quad \forall s\in S$$

$$\theta_w\in\mathbb{R}^+, \quad \forall w\in W$$

6 | Solution method

In this chapter, we discuss how the model described in Section 5.3 can be solved. Firstly, we explain how we linearise the model in Section 6.1. Secondly, in Section 6.2, it is explained why, and how, a constraint is slightly relaxed. Thirdly, the model consists of a lot of variables and constraints. In Section 6.3, it is given how the number of variables is reduced. However, even after this reduction of the number of variables, it takes too much memory to create the model at once. In Section 6.4, column generation is used to split the model into smaller subproblems.

6.1 Linearisation of the model

When the probability distribution $\mathscr{R}_{tw}$ is calculated, the variables b_{dgovz} are multiplied. To linearise our model, we define the non-negative parameter $k_{g\tau w} \in \mathbb{R}$ as the expectation of the number of beds at a certain ward $w \in W$ a patient from patient group $g \in G$ uses during time block $t \in T$, with the start time of the surgery at $\tau = 0$. This results in the following definition of this parameter.

$$k_{g\tau w} = \mathbb{E}\left(K_{g\tau w}\right) \tag{6.1}$$

$$= 0 \cdot \mathbb{P}(K_{g\tau w} = 0) + 1 \cdot \mathbb{P}(K_{g\tau w} = 1) + \ldots + x^* \cdot \mathbb{P}(K_{g\tau w} = x^*) \tag{6.2}$$

Hence, the non-negative variable r_{tw} is defined as the expectation of the number of beds that is used at ward $w \in W$ during time block $t \in T$ by Constraints (6.3).

$$r_{tw} = \sum_{d\in D}\sum_{g\in G}\sum_{o\in O}\sum_{v\in V}\sum_{z\in Z}\left(k_{g((t-(z+d\cdot h)) \bmod (t^*+1))w} \cdot b_{dgovz}\right), \qquad \forall t \in T, \forall w \in W \tag{6.3}$$

The variable r_{tw} replaces $\mathscr{R}_{tw}$ for each $t \in T$ and $w \in W$ when the model is implemented.

6.2 Relaxation of a constraint

When the model is implemented, we run into a problem concerning Constraints (5.4). This problem is caused by two things. Firstly, for some patient groups, there is a really small chance that the surgery duration of a patient group is longer than the number of time blocks in Z. Secondly, when the probability b_{dgovz} is calculated, some rounding errors could occur. Both of these situations could result in the same problem: $\sum_{z\in Z} b_{dgovz}$ is not exactly equal to one even though f_{dgov} (a patient from patient group $g \in G$ is the $v \in V$-th surgery in OR $o \in O$ on day $d \in D$) is one. This is solved by replacing Constraints (5.4) by Constraints (6.4) and (6.5).

$$\sum_{z\in Z} b_{dgovz} \geq 0.9999 \cdot f_{dgov} \qquad \forall d \in D, \forall g \in G, \forall o \in O, \forall v \in V \tag{6.4}$$

$$\sum_{z\in Z} b_{dgovz} \leq f_{dgov} \qquad \forall d \in D, \forall g \in G, \forall o \in O, \forall v \in V \tag{6.5}$$

6.3 Reducing the number of variables

An obvious method to reduce the size of the model is reducing the number of variables. In Section 5.1, the sets D and Z are introduced to take a first step in reducing the number of variables. However, this can be extended. The $v \in V$-th surgery on day $d \in D$ in OR $o \in O$ can only be performed on a patient from patient group $g \in G_s$ if specialty $s \in S$ has an OR shift on day $d \in D$ in OR $o \in O$. Therefore, f_{dgov}, b_{dgovz}, and e_{dgovz} are only defined for all $d \in D$, $g \in G_s$, $o \in O$, $v \in V$, and $z \in Z$, if specialty $s \in S$ has an OR shift on day $d \in D$ in OR $o \in O$.

6.4 Column generation

When using column generation, there are two options to solve this model: columns can be generated per specialty or per day. We decided to generate columns per specialty, because in that case some of the original objective function is in the objective function of the pricing subproblem.

There is a downside to this decision. This downside occurs when two specialties two specialties use the same OR at the same day, one specialty has OR time in the morning and the other specialty has OR time in the afternoon. The start times of the surgeries in the afternoon are influenced by the surgeries performed in the morning. However, if the columns are generated per specialty this is no longer taken into account. Therefore, it is necessary to check afterwards if this does not cause any issues for our model.

Firstly, we introduce the binary variable λ_s^c, which is one if we use schedule $c \in C_s$ for specialty $s \in S$, and zero otherwise. We introduce Ψ_{cstw}, with $s \in S$, $c \in C_s$, $t \in T$ and $w \in W$, as

$$\Psi_{cstw} = \frac{1}{q_{tw}} \sum_{g \in G_s} \sum_{d \in D} \sum_{z \in Z} \sum_{o \in O} \sum_{v \in V} \left(b^c_{dgovz} \cdot k_{g((t-(z+d \cdot h)) \bmod (t^*+1))w} \right) \tag{6.6}$$

to improve readability of the model.

Next, we define the master problem with one new constraint to ensure that we choose a schedule $c \in C_s$ for each specialty $s \in S$. Next to that, some constraints are combined to make column generation possible.

$$\min \quad \sum_{w \in W} \theta_w - \omega \cdot \sum_{s \in S} \sum_{c \in C_s} \alpha_s^c \cdot \lambda_s^c - \omega \cdot \frac{1}{200} \sum_{s \in S} \sum_{c \in C_s} \sum_{d \in D} \sum_{g \in G_s} \sum_{o \in O} \sum_{v \in V} \left(f^c_{dgov} \cdot \mathbb{E}(p_g) \cdot \lambda_s^c \right)$$

$$\begin{aligned}
\text{subject to} \quad & \sum_{s \in S} \sum_{c \in C_s} \lambda_s^c \cdot \Psi_{cstw} \leq \theta_w \qquad && \forall t \in T, \forall w \in W \quad (\pi_{tw}) \\
& \sum_{c \in C_s} \lambda_s^c = 1 && \forall s \in S \qquad (\mu_s)
\end{aligned}$$

$$\lambda_s^c \geq 0, \quad \forall s \in S, \forall c \in C_s$$

$$\theta_w \in \mathbb{R}^+, \quad \forall w \in W$$

Lastly, we define the pricing subproblems.

$$\min \quad -\omega \cdot \alpha_s - \omega \cdot \frac{1}{200} \sum_{d \in D} \sum_{g \in G_s} \sum_{o \in O} \sum_{v \in V} \left(f_{dgov} \cdot \mathbb{E}(p_g)\right) - \sum_{t \in T} \sum_{w \in W} (\pi_{tw} \cdot \Psi_{stw}) - \mu_s$$

$$\begin{array}{llll}
\text{subject to} & \sum_{g \in G_s} f_{dgov} \leq 1 & & \forall d \in D, \forall o \in O, \forall v \in V \\
& \sum_{z \in Z} b_{dgovz} = f_{dgov} & & \forall d \in D, \forall g \in G_s, \forall o \in O, \forall v \in V \\
& b_{dgo0z^{open}_{do}} = f_{dgo0} & & \forall d \in D, \forall g \in G_s, \forall o \in O \\
& e_{dgovz} = \sum_{\tau=1}^{z-z_0} p_{g\tau} \cdot b_{dgov(z-\tau)} & & \forall d \in D, \forall g \in G_s, \forall o \in O, \forall v \in V, \forall z \in Z \\
& \sum_{g \in G_s} b_{dgovz} \leq \sum_{j \in G_s} e_{djo(v-1)(z-1)} & & \forall d \in D, \forall o \in O, \forall v \in V \setminus \{0\}, \forall z \in Z \setminus \{z_0, z_1 + 1\} \\
& \sum_{g \in G_s} \sum_{v \in V} b_{dgovz} \leq m_{dosz} & & \forall d \in D, \forall o \in O, \forall z \in Z \\
& \sum_{z \in \{z_0, \dots, z^{close}_{do} + t^{OT} - 1\}} e_{dgovz} \geq 0.9 \cdot f_{dgov} & & \forall d \in D, \forall o \in O, \forall g \in G_s, \forall v \in V \setminus \{0\} \\
& \alpha_s \cdot n_g \leq \sum_{d \in D} \sum_{o \in O} \sum_{v \in V} f_{dgov} & & \forall g \in G_s
\end{array}$$

$$\begin{aligned}
f_{dgov} &\in \{0,1\}, && \forall d \in D, \forall g \in G_s, \forall o \in O, \forall v \in V \\
b_{dgovz}, e_{dgovz} &\in [0,1], && \forall d \in D, \forall g \in G_s, \forall o \in O, \forall v \in V, \forall z \in Z \\
\Psi_{stw} &\in \mathbb{R}^+, && \forall s \in S, \forall t \in T, \forall w \in W \\
\alpha_s &\in \mathbb{R}^+
\end{aligned}$$

As explained in Section 4.2, we apply column generation to an LP. Hence, when solving the RLPM, we assume $\lambda_s^c \in [0,1]$ for all $s \in S$ and $c \in C_s$. Once we finished generating new columns, we find a solution to the ILP by selecting one column for each specialty $s \in S$, i.e. we optimise the RLPM with λ_s^c binary for all $s \in S$ and $c \in C_s$. Note that this solution does not have to be optimal for the ILP.

7 | Data

This chapter describes a lot of the decisions and assumptions we made regarding the model and the data. These decisions and assumptions were made in consultation with the SCH. Prior to working with the data, we describe some assumptions made regarding our model in Section 7.1. In this thesis, we use anonymised data provided by the SCH. This data set contains patient information from 2018 up to and including 2021. This data set is described in Section 7.2. Almost all of this information is entered manually, which causes inconsistencies. In Section 7.3, it is explained which assumptions were made to deal with these inconsistencies. Next, in Section 7.4, the cleaned data is used to create patient groups of elective OR patients with similar features. Lastly, in Section 7.5, it is described how other data was used to set some of the parameters of the mathematical model.

7.1 Assumptions

Several assumptions, regarding for example the cycle duration or the allowed overtime at the OR, are explained in this section.

As described in Chapter 5, the total time of an MSS cycle is divided into time blocks $t \in T$. We made some decisions regarding these time blocks. Firstly, the MSS repeats itself after four weeks. Hence, the more specific MSS should also repeat itself after four weeks (28 days). Secondly, the time blocks $t \in T$ are fifteen minutes. These two assumptions, implicate the following sets:

- $T = \{0, \ldots, 2687\}$: where time block $t = 0$ starts on day one of the MSS cycle at 00:00 and ends at 00:15 the same day. The last time block of a cycle $t = 2687$ starts on day 28 of the MSS cycle at 23:45, and ends at 00:00 on day 1 of the new cycle.
- $\mathscr{D} = \{0, \ldots, 27\}$: the days $d \in \mathscr{D}$ in one cycle of the schedule.
- $\mathscr{Z} = \{0, \ldots, 95\}$: the time blocks $z \in \mathscr{Z}$ per day.
- $D = \{0, 1, 2, 3, 4, 7, 8, 9, 10, 11, 14, 15, 16, 17, 18, 21, 22, 23, 24, 25\}$:
  days $d \in D$ on which the OR is opened for elective surgeries.
- $Z = \{30, \ldots, 74\}$: indicating the time blocks $z \in Z$ during which an OR $o \in O$ could be open at day $d \in D$.

And, the number of time blocks per day

$$h = \frac{1440}{\text{length of one time block}} = \frac{1440}{15} = 96. \tag{7.1}$$

The used data is from four years. The first three years are used to define representative clusters, i.e. the first three years form the training data. The fourth year is used to test if these clusters are also representative for future surgeries, i.e. the data from the fourth year is the test data. The length of an MSS cycle is four weeks. A year contains approximately 52 weeks. Hence, the MSS cycle is repeated $\frac{52}{4} = 13$ times per year. Therefore, the training data contains information of 39 MSS cycles. Each cluster should occur at least once during each cycle. Therefore, a cluster in the training data should contain at least 39 individual surgeries. This implies that during each cycle in the historical data, we were able to plan each cluster at least once.

Officially, the OR is opened for elective surgeries between 08:00 and 15:30. In practice some overtime is allowed as mentioned in Section 5.1. Therefore, in consultation with the SCH, 25% of the ORs may have overtime until 16:15. The other 75% has to finish at 15:30. This also includes the cleaning time of the OR after the last surgery.

A surgery takes at least one time block, but when the cleaning time is also included, the minimum time for a surgery is two time blocks. The OR opens no earlier than 08:00, and closes not later than 16:15 (including cleaning time). Consequently, there are at most sixteen surgeries at one day $d \in D$ in OR $o \in O$. So, we define the set $V = \{0, \ldots, 15\}$.

In the model, we do not take into account that there is only a limited number of available beds. We do not expect this to be a problem, because the goal is to level the bed occupancy. This should prevent big spikes in the bed occupancy.

Lastly, we do not take into account that in practice a patient is normally not discharged in the middle of the night. This does not effect the number of available beds for elective OR patients during the day, because in practice this patient is discharged first thing in the morning, and the bed can be used by another patient during the day. This does slightly effect the percentage of beds used during the night, because in practice the patient stays a little longer. However, we do not expect that this significantly influences the results.

7.2 Data description

The patient information consists of two data sets. The two data sets are linked by the admission number of the patient. The first data set is a list with all the surgeries that are performed during the given time period and information regarding each of these surgeries. This information is provided by different properties of a surgery, such as the specialty that treated the patient, when the surgery started, when the surgery ended. The second data set is a list of all bed switches that have taken place during the given time period.

In total, there are 28,339 surgeries and 124,150 bed switches in these data sets with 96 and 68 properties, respectively. A small example of this data is shown in Table 7.1 and Table 7.2.

Table 7.1: Data set 1: Surgeries.

Admission number	**Specialty**	**Start time of the surgeon**	**End time of the surgeon**
1	KAA	2018-01-05 14:27	2018-01-05 16:02
2	ORT	2018-01-08 08:19	2018-01-08 16:59
3	KIC	2018-01-09 15:51	2018-01-09 16:53
⋮	⋮	⋮	⋮

Table 7.2: Data set 2: Bed switches.

Admission number	Ward	Start time	End time
1	SB2	2018-01-05 07:33	2018-01-05 17:48
2	KCZ	2018-01-07 20:30	2018-01-08 16:35
2	ICK4	2018-01-08 16:35	2018-01-09 11:39
3	SB2	2018-01-09 07:44	2018-01-09 17:45
2	KCZ	2018-01-09 11:39	2018-01-14 11:45
3	KCN	2018-01-09 17:45	2018-01-09 19:39
⋮	⋮	⋮	⋮

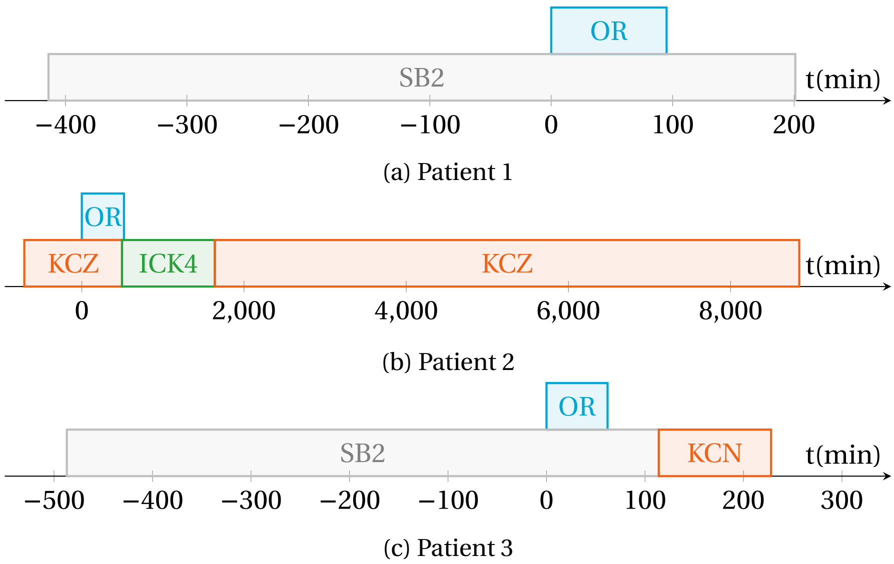


Figure 7.1: Examples of paths of different patients during their stay at the SCH.

A visualisation of the paths of these patients is shown in Figure 7.1.
For this thesis, we need the following information regarding the elective OR patients.

- Whether or not the patient was an elective OR patient.
- When the patient was on which ward, and the resulting LoS for each of the different wards the patient visited.
- The specialty that treated the patient. Sometimes a patient is treated by different specialties at the same time, but there is always one "main-specialty". If this is the case, the surgery is planned during OR time of this "main-specialty". Therefore, this is the specialty that we assign to the surgery.
- The type of surgery, i.e. procedure, the patient needed.
- The start and end time of the surgery, and the resulting surgery duration (end time minus start time).

7.3 Cleaning patient data

The cleaning of the data is done in two steps. Firstly, in Subsection 7.3.1, the duration of the surgery is checked and if necessary adjusted. Followed by some information regarding other irregularities in the OR data that required some adjustments. Secondly, in Subsection 7.3.2, the OR data is matched with the ward data, which also leads to some adjustments, and it is explained how the data is used. The adjustments in this section are a result of different assumptions and decisions made in consultation with the SCH.

7.3.1 Surgery duration

We start with the OR data, specifically for the elective surgeries. The following data is used (if available) to clean the data. These times are in chronological order.

- Start time of the surgery (the moment the patient enters the OR)
- Start time of the induction (the moment the anaesthesiologist starts the anaesthesia)
- Start time of the surgeon
- End time of the surgeon
- End time of the surgery (the moment the patient leaves the OR)
- Arrival time at the recovery

The start and end time of the surgery are needed to calculate the surgery duration. If the start time of the surgery is missing, there are two possibilities.

- If the start time of the induction is known, we assume that the start time of the surgery is five minutes earlier than the start time of the induction.
- If the start time of the induction time is unknown, it is not possible to give a good prediction of the start time of the surgery. Therefore, this data entry cannot be used.

If the end time of the surgery is missing, there are also two possibilities.

- If the arrival time at the recovery is known, we assume that the end time of the surgery is five minutes earlier than the time the patient arrives at the recovery.
- If the arrival time at the recovery is unknown, it is not possible to give a good prediction of the end time of the surgery. Therefore, this data entry cannot be used.

After these adjustments, 1.5% of the data entries is deleted, because either the begin time of the surgery and the begin time of the induction are missing, the end time of the surgery and the arrival time at the recovery are missing, or all four of these properties are missing.

Next, it is checked if the end date of the surgery is not before the start date of the surgery. The following two assumptions are only used if the end date of the surgery is before the start date of the surgery, and solve all of these errors in our data set:

- If the start time of the induction is known and the start time of the induction is before the end time of the surgery, change the date of the start time of the surgery to the date of the start time of the induction.
- If the end time of the surgeon is after the end time of the surgery, change the date of the end time of the surgery to the date of the end time of the surgeon.

Thirdly, sometimes either the start or end date is not correct, even though the end date is not before the start date. Most often, this occurs if a surgery was performed around midnight. The following three (similar) assumptions help to fix this problem.

- If the difference between the start time of the surgery and the start time of the induction is more than three hours, there are two possible fixes:
    1. If the date of the start of the surgery is not the date of the start of the induction and the following results in a surgery duration larger than zero, change the date of the start of the surgery to the date of the start of the induction.
    2. If (1) does not result in a surgery duration larger than zero, the date of the start of the surgery is not one day before the date of the start of the induction and the following results in a surgery duration larger than zero, change the date of the start of the surgery to the date before the start of the induction.
- If the start time of the induction is unknown and the difference between the start time of the surgery and the start time of the surgeon is more than four hours, there are two possible fixes:
    1. If the date of the start of the surgery is not the date of the start of the surgeon and the following results in a surgery duration larger than zero, change the date of the start of the surgery to the date of the start of the surgeon.
    2. If (1) does not result in a surgery duration larger than zero, the date of the start of the surgery is not one day before the date of the start of the surgeon and the following results in a surgery duration larger than zero, change the date of the start of the surgery to the date before the start of the surgeon.
- If the end time of the surgeon is known and the difference between the end time of the surgery and the end time of the surgeon is more than three hours, there are two possible fixes:
    1. If the date of the end of the surgery is not the date of the end of the surgeon and the following results in a surgery duration larger than zero, change the date of the end of the surgery to the date of the end of the surgeon.
    2. If (1) does not result in a surgery duration larger than zero, the date of the end of the surgery is not one day before the date of the end of the surgeon and the following results in a surgery duration larger than zero, change the date of the end of the surgery to the date before the end of the surgeon.

Fourthly, sometimes the start and end time are on the same date, but the surgery ends before it starts. We use three possible fixes, together these fixes solve all of the cases for which the surgery ends before it starts.

- If the start time of the surgery is before the arrival time at the recovery, change the end time of the surgery to five minutes before the patient arrives at the recovery.
- If the start time of the induction is before the end time of the surgery, change the start time of the surgery to five minutes before the start time of the induction.
- If the difference between the start time of a surgery and the end time of the surgery is more than twenty hours, this is most likely a mistake in the date of the start or end time of the surgery. If the last two steps were not able to solve the problem, we add one day to the end time of the surgery.

Lastly, we check the order of different steps during the surgery.

- If the start time of the surgery is after both the induction, and the start time of the surgeon and the start time of the surgeon is after the induction; change the start time of the surgery to five minutes before the induction.
- If the end time of the surgery is after both the end time of the surgeon, and the time the patient arrives at the recovery, and the following results in a surgery duration larger than zero; change the end time of the surgery to five minutes before the patient arrives at the recovery.
- If the end time of the surgery is before both the end time of the surgeon, and the time the patient arrives at the recovery, and the following results in a surgery duration larger than zero; change the end time of the surgery to five minutes before the patient arrives at the recovery.

At this point, an entry either looks like a realistic surgery or we are not able to recover representative data from the available data. This is the case for some surgeries that take over twenty hours, so these entries are deleted. Entries are also deleted if an admission number, specialty code or the procedure a patient needs is missing. Without this information, a surgery can either not be linked to information regarding the patient on the ward or cannot be clustered into a specific patient group. We only select the patients that entered the SCH after the first of January 2018 and left before the 1st of January 2022. In this way, we have the entire treatment path of the patients that went to the OR.

Lastly, sometimes, a surgery occurs multiple times in the data set or there are multiple specialties linked to the same surgery, which is the case if multiple specialties perform a surgery on the same patient during one OR session. There is always one "main specialty", which (in general) is the specialty that performs the longest or most intensive surgery. Therefore, this is the specialty where we assign the surgery to.

7.3.2 Combining the OR and ward data

When combining the OR and ward data, it stands out that the specialty linked to the patient on the ward is not always the same as the specialty linked to the same patient on the OR. We use the specialties given by the OR data, because this is also the time slot that is used in the OR. There are some other adjustments or assumptions that need to be made to use the ward data.

Firstly, if it is not known on which ward a patient stayed or the admission number is not registered, this data entry is deleted, because both the information regarding the OR and the ward is needed to cluster the patient.

Secondly, some patients need multiple different surgeries (which are not executed at the same time). We decided to split the paths of these patients, as if it would be multiple individual patients, and look at them as individual surgeries. Here, we assume that the groups are planned regularly, such that it is possible to have all the needed surgeries within one stay.

Lastly, if a patient has a surgery, we assume that the patient has to be in the hospital at least one hour before the start of the surgery. Similarly, we assume that the patient also has to stay at the hospital for at least one hour after the surgery. When this is not the case for a data entry, the time at the ward is extended such that this is true.

Note that, the word "surgery" is used to refer to a specific surgery performed on a patient, and the term "(surgical) procedure" is used to refer to the type of surgery a patient needs. For example, there are multiple surgeries during which the surgeon had to do a "skin - biopsy" (the procedure).

Preferably, we want to cluster the surgeries during which the same procedure is performed in the same patient group. As mentioned before, the data is entered manually. Hence, the same procedures are written down in many different ways. For example:

Bone – remove osteosynthesis material,
Bone: remove plates and screws.

On the other hand, there are also procedures which look alike on first glance but the LoS and/or surgery duration could differ a lot. Together with the SCH, we looked at different methods to recognise if two procedures were the same even though they were written down different. One of the options is checking the declaration codes. This does not link the correct procedures. Checking the procedures manually was too big of a task. Therefore, the decision was made to only define procedures as the same surgery if the description was exactly the same.

7.4 Clustering elective OR patients

The goal is to cluster elective OR patients into different patient groups, using the cleaned data from Section 7.3. For each individual surgery, it is known how long the surgery took, and how long the patient, on whom the surgery was performed, had to stay in the hospital. When clustering the patients, we do not take into account on which ward a patient stayed during their stay in the hospital, only their LoS.

The first method we used to split the procedures of a specialty into patient groups, is described in Subsection 7.4.1 and has a similar approach as Schneider et al. (2020). Some suggestions for improvement are discussed at the end of this section. Because of the run time of this first method, the method of Bradley et al. (2000) is used in Subsection 7.4.2 to create patient groups. This is the method we ended up using for the results of this thesis. This method is also used for radiology, but the data is modified differently, which is explained in Subsection 7.4.3.

Lastly, for some specialties, it is not possible to split the patient into patient groups, which is discussed in Subsection 7.4.4.

7.4.1 Clustering using the accuracy

The goal of this method is to cluster elective OR patients into four patient groups per specialty. For some specialties, it is not possible to create four clusters. However, for some of these specialties, it is possible to split the patients in two patient groups. Both cases are discussed in this section.

Clustering - four patient groups

In consultation with the SCH, we decided that we want to create four different patient groups (clusters) per specialty. There are six specialties for which it is possible to divide the procedures into four groups: paediatric surgery, otorhinolaryngology, urology, orthopaedic surgery, plastic surgery, and neurological surgery. The four different patient groups are described in Table 7.3. The goal is to define these patient groups such that most surgeries are assigned to the correct patient group. There are multiple ways to split the patients into the four patient groups, but for this method, we use a similar approach as Schneider et al. (2020).

Firstly, we need to make a decision on the order in which we are going to split the surgical procedures. Option one, firstly, split the procedures on the LoS, and secondly, on the surgery duration. For example, procedures for which patients are expected to stay four days or less

Table 7.3: Different patient groups

	Short surgery	Long surgery
Short LoS	I	III
Long LoS	II	IV

in the hospital are defined to be short stay procedures. Procedures for which the patients are expected to stay for more than four days are defined to be long stay procedures. Next, we only look at the short stay procedures and split this group in short and long surgery duration. Lastly, we only look at the long stay procedures and split these procedures in short and long surgery duration. These splits do not have to be after the same amount of time. Hence, this results in three thresholds:

1. the LoS on which the procedures are divided into short and long stay procedures;
2. the surgery duration on which the short stay procedures are divided into short and long procedures;
3. the surgery duration on which the long stay procedures are divided into short and long procedures.

Option two, firstly, split the procedures on the surgery duration, and secondly, split on the LoS. This also results in three thresholds:

1. the surgery duration on which the patients are divided into short and long procedures;
2. the LoS on which the short procedures are divided into short and long LoS;
3. the LoS on which the long procedures are divided into short and long LoS;

Most procedures have been executed multiple times in the past. From this historical data, the mean and median of the OR and LoS can be calculated for the different procedures. Together with the different possibilities for the thresholds, this results in eight different combinations. For all of these of these combinations, the corresponding thresholds are calculated using Algorithm 1. Note that, this algorithm is written down for one option (split firstly, on the mean surgery duration, and secondly, on the median LoS), but the algorithm is similar for the other combinations.

We define the best combinations, as the combination for which the corresponding thresholds result in the highest accuracy. This accuracy is calculated in multiple steps per specialty:

1. For the given thresholds, it is determined in which patient group a procedure is placed based on either its mean/median surgery duration or LoS.
2. For each individual surgery, it is determined in which patient group the surgery would be placed based on its surgery duration or LoS.
3. The accuracy is the number of individual surgeries that is placed in the correct patient group (determined in 1.) divided by the total number of individual surgeries performed by a specialty.

After testing the different combinations of possibilities, it is concluded that we get the highest accuracy if we split firstly, on the mean surgery duration, and secondly, on the median LoS.

Algorithm 1 Creating patient groups

Input: Historical data containing the surgery duration and the LoS of elective patients from the past four years of a certain specialty $s \in S$
Output: Thresholds that result in the highest accuracy

minimum group size ← 39.
Divide the data in training and test data, until mentioned otherwise only the training data is used.
I_{df} ← the mean surgery duration and median LoS per procedure performed by specialty $s \in S$.
ot_{list} ← list of all possible surgery duration thresholds.
if ot_{list} is empty **then**
    return "No possible threshold"
else
    $acc_{best} \leftarrow 0$
    $acc_{list} \leftarrow []$
    for ot in ot_{list} **do**
        IS_{df} ← rows of I_{df} for which holds mean surgery duration $\leq ot$
        wst_{list} ← possible LoS thresholds for procedures in the category short surgery duration.
        IL_{df} ← rows of I_{df} for which holds mean surgery duration $> ot$
        wlt_{list} ← possible LoS thresholds for procedures in the category long surgery duration.
        if wst_{list} or wlt_{list} is empty **then**
            return "No possible threshold"
        else
            $wst_{best} \leftarrow 0$
            $awst_{best} \leftarrow 0$
            for wst in wst_{list} **do**
                acc_{wst} ← accuracy of short surgeries using wst
                if $acc_{wst} > awst_{best}$ **then**
                    $wst_{best} \leftarrow wst$
                    $awst_{best} \leftarrow acc_{wst}$
                end if
            end for
            $wlt_{best} \leftarrow 0$
            $awlt_{best} \leftarrow 0$
            for wlt in wlt_{list} **do**
                acc_{wlt} ← accuracy of long surgeries using wlt
                if $acc_{wlt} > awlt_{best}$ **then**
                    $wlt_{best} \leftarrow wlt$
                    $awlt_{best} \leftarrow acc_{wlt}$
                end if
            end for
            acc ← accuracy of all surgeries using ot, wst_{best} and wlt_{best}
            if $acc > acc_{best}$ **then**
                $acc_{best} \leftarrow acc$
                $acc_{list} \leftarrow [ot, wst_{best}, wlt_{best}]$
            end if
        end if
    end for
    acc_{test} ← accuracy of the test data using the values in acc_{list}
    return acc_{best}, acc_{test}
end if

Clustering - two patient groups

There are five specialties for which it is not possible to find four (good) clusters, but it is possible to find two clusters.

Firstly, maxillofacial surgery, performs mainly two procedures (one is 50% of the total number of performed surgeries, the other 25%, and the remaining 25% consists of different procedures). The surgery duration and the LoS of these procedures and the other procedures make it impossible to create four groups of at least 39 patients.

Next to that, it is possible to create four different patient groups for gastroenterology, gynaecology, ophthalmology and paediatric cardiac surgery. However, less than 50% of the surgeries in the test data is assigned to the correct patient group. Therefore, these specialties are also divided into two instead of four patient groups.

In the case of two patient groups, a specialty is only split on either the surgery duration or the LoS. But, there are a lot of similarities with splitting a specialty in four patient groups.

- Both groups have to contain at least 39 individual surgeries.
- A threshold is called "the best threshold" if the accuracy (number of individual surgeries assigned to the correct group, divided by the total number of surgeries performed by this specialty) is the highest.
- It is checked if either the median or the mean is a better indicator if surgeries are performed multiple times.

We get the best threshold if the surgeries are split based on their LoS, and using the median if surgeries are performed multiple times. The algorithm to find the best threshold is also similar to Algorithm 1.

As an example, the accuracy at different thresholds for gastroenterology is shown in Figure 7.2.

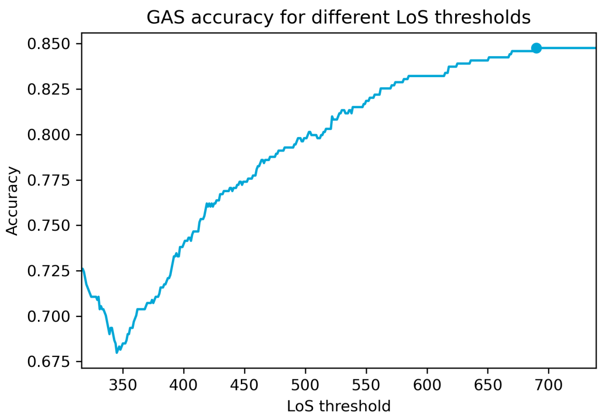


Figure 7.2: Example of the accuracy of the gastroenterology data set with different thresholds, using the median LoS.

Suggestions for improvement

Next, we give two suggestions to improve the patient groups.

Firstly, the specialties that are split into two patient groups. At the moment, these patient groups are made based on their LoS. If we make these patient groups based on surgery duration, it might be possible to schedule more surgeries, because the variance of the surgery duration in the groups would be lower. If it is possible, it is an option to split a specialty into three groups instead of two.

Secondly, the specialties that are split into four groups. These specialties consist of many different procedures. Therefore, splitting on the LoS can still be useful. However, to schedule more surgeries, it could help to split the procedures into more groups based on their surgery duration. This can be done by first splitting the data based on the LoS of the procedures, and secondly, divide these groups into multiple groups based on the surgery duration.

There is one main downside to making patient groups by this method. Our implementation takes a lot of time to find the best thresholds, because we loop over all possible combinations of the thresholds for both the surgery duration and the LoS. If we want to improve the groups using the suggestions given above, it would take even more time to find the best thresholds.

7.4.2 Constrained k-means clustering

For the second method, we use the algorithm described in Bradley et al. (2000). This constrained k-means clustering algorithm contains two steps. Firstly, we define some variables, such that we can look into this algorithm in more detail.

- $\{x_1, \ldots, x_m\}$ the set of data points we want to cluster;
- k the number of desired clusters;
- $\{C_{1t}, \ldots, C_{kt}\}$ the set of cluster centres during iteration t;
- the variables T_{ih} for all $i = 1, \ldots, m$ and $h = 1, \ldots, k$, which are equal to one, if data point x_i is closest to centre C_h, and zero otherwise;
- $\tau_h > 0$ is the minimum size of cluster h for all $h = 1, \ldots, k$;
- the distance between a data point and a centre is calculated with the Euclidean norm.

Next, randomly select cluster centres $C_{10}, \ldots, C_{k0}$, and, repeat the following two steps until C_{ht} is equal to $C_{h(t+1)}$ for all $h = 1, \ldots, k$.

1. Let T_{ih} for all $i = 1, \ldots, m$ and $h = 1, \ldots, k$ be the optimal solution of:

$$
\begin{aligned}
\min_{\mathbf{T}} \quad & \sum_{i=1}^{m} \sum_{h=1}^{k} T_{ik} \cdot \frac{1}{2} ||x_i - C_h||_2^2 & & \\
\text{subject to} \quad & \sum_{h=1}^{k} T_{ih} = 1 & & i = 1, \ldots, m \\
& \sum_{i=1}^{m} T_{ih} \geq \tau_h & & h = 1, \ldots, k \\
& T_{ih} \in \{0, 1\} & & i = 1, \ldots, m, h = 1, \ldots, k
\end{aligned}
\tag{7.2}
$$

2. In this step, we update the cluster centres.

$$C_{h(t+1)} = \frac{\sum_{i=1}^{m} T_{ih} \cdot x_i}{\sum_{i=1}^{m} T_{ih}} \tag{7.3}$$

When we use this algorithm for our data set, we need to make some adjustments and assumptions.

- Just as in Subsection 7.4.1, we use the mean of the surgery duration and the median of the LoS, if a procedure is multiple times in the data set.
- It is possible to use both the LoS and the surgery duration at the same time when the clusters are formed. However, this would imply that we need to assign weights to the LoS and the surgery duration, because of their different order of magnitude. To avoid this, we run the algorithm separately on the LoS and the surgery duration.
- One of the downsides of our first method was the high variation in surgery duration. Therefore, if a patient group was previously split into two groups, we split the data into clusters based on the surgery duration (instead of the LoS). If a patient group was previously split into four groups, we firstly, split the data into two sets based on the LoS, and secondly, we split the resulting clusters in at most four groups based on the distribution of the surgery duration.
- We increase the minimum number of patients in a patient group. Before, the minimum size of a patient group was 39 surgeries, such that, each patient group would occur at least once during each MSS cycle. However, if the waiting list of a specialty is short, a small patient group has a higher chance of having no patients to plan. Next to that, we want to decrease the difference in the number of patients per group per specialty. Therefore, the minimum size of a patient group $g \in G_s$ is the maximum of 78 and 10% of the number of surgeries performed by specialty $s \in S$ in the training data.

Before we are able to use the algorithm, the set of data points we want to cluster needs to be defined. We start with an empty set. If we cluster on LoS, we add the median LoS of each procedure X times to this set, where X is the number of times a procedure occurs in the training data. For example, the first procedure is performed four times and the median LoS of the procedure is 45. In this case, the set is $\{45, 45, 45, 45\}$. Next, the second procedure occurs only once in the training data and the median LoS of this procedure is 67. The set is updated to $\{45, 45, 45, 45, 67\}$, and so forth.

Now, we are able to create patient groups for each specialty. The list of procedures per patient group are given in Appendix B.

If a patient needs a procedure that is not in the list, the surgeon or planner needs to predict to which group the procedure would belong.

It is important to note that, the implementation of constrained k-means clustering algorithm is much faster than our implementation of the first method.

7.4.3 Clustering radiology

Radiology performs a lot of scans. However, 94% of these scans has a general description, which indicates that the patient needs an MRI. A lot of the other procedures are only performed once. We decided not to group this specialty per procedure. Instead we split all the individual surgeries based on their surgery duration into two groups, using the algorithm given in Subsection 7.4.2. This results in the patients groups given in Table B.44 and Table B.45. Some procedures can occur in both patient groups, because the patient groups were created without clustering the procedures first. If this is the case, the mean surgery duration and the median LoS of these procedures are only based on the surgeries of that procedure which are assigned to the corresponding patient group.

7.4.4 Specialties without clusters

There are multiple specialties which are not split into different patient groups, for different reasons. The information in this section is based on the combination of both the training and test data. Remember that,an MSS cycle is repeated 13 times per year. In total, the training and test data contains information from four years. Therefore, the training and test data together contain information of 52 MSS cycles. Therefore, a patient group needs to contain at least 52 surgeries in total.

Firstly, there are a few specialties which do not perform enough surgeries to split the data in different patient groups. In other words, there are less than 104 surgeries of these individual specialties in the training data. This is the case for dermatology (22 surgeries) and neurology (68 surgeries).

Secondly, there are a few specialties which perform almost exclusively one type of surgery. Therefore, there are not enough remaining surgeries to form a second patient group with at least 52 individual surgeries.

- Dental surgery: 95% of the surgeries are patients redirected by a foundation that helps children who cannot be treated by a regular dentist, for example, because of a physical/mental disability or fear from a previous treatment. In total, the training data contains 106 surgeries performed by this specialty. Hence, there are only five other surgeries, which is less than 52.

- Orthopaedic surgery - spinal: 98% of the surgeries are spondylolysis, a procedure where they attach multiple vertebrae to each other. In total, the training data contains 289 surgeries performed by this specialty. Hence, there are only nine other surgeries, which is less than 52.

- Paediatric pulmonary disease: 88% of the surgeries are bronchoalveolaire lavages, a procedure to retrieve some fluid from the pulmonary alveoli for examination. In total, the training data contains 296 surgeries performed by this specialty. Hence, there are only 37 other surgeries, which is less than 52.

Next to that, the hand surgeries of plastic surgery are not split into patient groups. In total, there are only 192 surgeries, where during almost half of these surgeries, the same procedure is performed. This does not always cause a problem. However, in this case, both the surgery duration and the time spend on the ward are in the middle compared to the other procedures. Therefore, there is always a group left with not enough surgeries (less than 52).

The lists of procedures performed by these specialties can be found in Appendix B.

7.5 Parameters

This section explains how the information for the different parameters is gathered.

For q_{tw}, the number of beds at ward $w \in W$ that are on average available for elective OR patients during time block $t \in T$, a combination of the historical data and the information provided by the staff of the SCH resulted in the number of beds that are available for elective OR patients. These numbers are given in Appendix A. The daycare unit is the only ward that is only opened during set hours. To enforce that the daycare unit is only used during these hours, the parameter q_{tw} is set to 0.01 for the daycare unit during time blocks that the daycare unit is closed.

The parameter m_{dosz} (the fraction of OR $o \in O$ that can be used by specialty $s \in S$ at time $z \in Z$ on day $d \in D$) is derived using the OR opening times from Section 7.1 and the MSS. From this same section, we get that we allow some overtime during the last three time blocks, hence $t^{OT} = 3$.

There are four possibilities for the parameter m_{dosz}:

$$m_{dosz} = \begin{cases} 1 & \text{If } z \neq z^{close}_{do} - 1 \text{ and specialty } s \in S \text{ has OR time in OR } o \in O\text{, on day } d \in D\text{, at time } z \in Z. \\ 0.25 & \text{If } z \in \{z^{close}_{do} - 1, z^{close}_{do}, z^{close}_{do} + 1\} \text{ and specialty } s \in S \text{ has OR time in OR } o \in O\text{, on day } d \in D\text{, at time } (z^{close}_{do} - 1) \in Z. \\ 0.1 & \text{If } z \in \{z^{close}_{do} + 2, \dots, z^*\} \text{ and specialty } s \in S \text{ has OR time in OR } o \in O\text{, on day } d \in D \\ 0 & \text{Otherwise.} \end{cases}$$

Here, $(z^{close}_{do} - 1) \in Z$ indicates the last time block of an OR shift. From this time block on, we allow 25% overtime. The overtime starts at $(z^{close}_{do} - 1) \in Z$ instead of $z^{close}_{do} \in Z$, because we need one time block to clean the OR at the end of the day. For the same reason, the last surgery has to end during time block $(z^{close}_{do} + 1) \in Z$. Lastly, we assumed that there can be a 10% chance that a surgery is not finished after $z^{close}_{do} + t^{OT} - 1 \in Z$.

The final parameters are related to the patient groups. Some of this data was used as training data and some of the data as test data. Now, all data is used to derive these parameters. After deriving the different patient groups $g \in G$, the number of surgeries per group is determined, which results in the parameter n_g (the fraction of patients from specialty $s \in S$ which are in patient group $g \in G_s$).

Next, each surgery is categorised per patient group $g \in G$. The duration of the surgeries is used for parameter $p_{g\tau}$ (the probability that a surgery on a patient from patient group $g \in G$ takes $\tau \in T$ time blocks). The parameters $p_{g\tau}$ are initialised for all $g \in G$ and $\tau \in T$ by the following steps.

1. Let $p_{g\tau} = 0$, for all $g \in G$ and $\tau \in T$.
2. For each patient in the data set:
   a) get the patient group $g \in G$ the patient is in;
   b) let $\tilde{\tau}$ be the number of time blocks the surgery takes;
   c) Add one to $p_{g\tilde{\tau}}$.
3. For all $g \in G$ and $\tau \in T$, divide $p_{g\tau}$ by the number of patients in patient group $g \in G$.

Previously, only the total time a patient stayed on the different wards was used. Now, to derive the parameter $k_{g\tau wx}$ (the probability that patients from patient group $g \in G$ use $x \in X$ beds at ward $w \in W$ during time block $\tau \in T$, with the start time of the surgery at $\tau = 0$), we check to which ward $w \in W$ a patient was assigned during each time block $t \in T$ the patient was in the hospital. We rewrite this information into tuples $\Delta_1, \ldots, \Delta_n$ per patient, with n the number of wards the patient visited, where the tuple Δ_i is formed by three elements:

- $w \in W$, the i-th ward the patient stayed at.
- $\delta_a \in \mathbb{Z}$, the number of time blocks between the start time of the surgery and the time the patient arrived at the i-th ward. If the start time of the surgery is after the patient arrived at the ward, δ_a is negative. For example, if the patient arrived at the ward eight hours before the surgery $\delta_a = -32$.
- $\delta_d \in \mathbb{Z}$, the number of time blocks between the start time of the surgery and the time the patient left the i-th ward. If the start time of the surgery is after the patient left the ward, δ_d is negative. For example, if the patient left the ward exactly three days after the surgery $\delta_d = 288$.

Note that, both δ_a and δ_b could be more than the length of one MSS-cycle before or after the surgery, i.e. δ_a and δ_b could be larger than t^* or smaller than $-t^*$.

Next, the parameters $k_{g\tau wx}$ are initialised for all $g \in G, \tau \in T, w \in W$, and $x \in X$ by the following steps:

1. Let $k_{g\tau wx} = 0$, for all $g \in G, \tau \in T, w \in W$ and $x \in X$.
2. For each patient in the data set:
   a) Get the patient group $g \in G$ the patient is in.
   b) Define the tuples $\Delta_1, \ldots \Delta_n$.
   c) For each tuple $\Delta_i = (w, \delta_a, \delta_d)$:
      i) Calculate the total number of time blocks a patient spent at the i-th ward $w \in W$: $\delta_{\text{tot}} = \delta_d - \delta_a$
      ii) Define $\tilde{x} = \left\lfloor \frac{\delta_{\text{tot}}}{t^* + 1} \right\rfloor$, the number of entire MSS cycles the patient stayed at the i-th ward.
      iii) If $(\delta_a \bmod (t^* + 1)) \leq (\delta_d \bmod (t^* + 1))$:
         - $\forall \tau \in \{(\delta_a \bmod (t^* + 1)), \ldots, (\delta_d \bmod (t^* + 1))\}$ add 1 to $k_{g\tau w(\tilde{x}+1)}$.
         - $\forall \tau \notin \{(\delta_a \bmod (t^* + 1)), \ldots, (\delta_d \bmod (t^* + 1))\}$ add 1 to $k_{g\tau w\tilde{x}}$.

         If $(\delta_a \bmod t^* + 1) > (\delta_d \bmod (t^* + 1))$:
         - $\forall \tau \in \{(\delta_a \bmod (t^*+1)), \ldots, t^*\} \cup \{0, \ldots, (\delta_d \bmod (t^*+1))\}$ add 1 to $k_{g\tau w(\tilde{x}+1)}$.
         - $\forall \tau \notin \{(\delta_a \bmod (t^* + 1)), \ldots, t^*\} \cup \{0, \ldots, (\delta_d \bmod (t^* + 1))\}$ add 1 to $k_{g\tau w\tilde{x}}$.
3. Divide $k_{g\tau wx}$ by the number of patients in patient group $g \in G$, for all $g \in G, \tau \in T, w \in W$ and $x \in X$.

The modulo function is not always defined in the same way for negative numbers. We define: $0 \leq (x \bmod y) < y$, where it does not matter if x is negative or positive.

8 | Results

In this chapter, the results following from the historical data and the model are discussed in Section 8.3 and Section 8.4. Before we are able to discuss these results, the probability distributions regarding the OR utilisation and overtime at the OR are defined in Section 8.1. Next to that, in Section 8.2, it is investigated if adding Equation (6.3) to the objective function indeed results in scheduling more surgeries, while it is prioritised that the surgeries are planned according to the given fractions.

We used Python to implement the model. Next to that, Gurobi Optimization, LLC (2023) is used to solve our model and Delft High Performance Computing Centre (DHPC) (2022) to run the model.

8.1 Probability distribution of the OR utilisation

In this section, two probability distributions are defined: the probability distribution of the number of OR days with overtime and the probability distribution of the OR utilisation.

An OR day is a day in the MSS during which a specialty has OR time. Note that not each OR is used on each weekday in the MSS. In total, there are 173 OR days in the MSS. Firstly, for each of these OR days, we determine the probability that the last surgery is finished after the closing time of the OR. This probability distribution is determined after the model is optimised. Hence, for all OR days, we let $g_{do} \in G$ be the patient group of the last surgery performed on day $d \in D$ in OR $o \in O$ and v_{do} the position of this surgery. This implies that $e_{dg_{do}ov_{do}z}$ is the probability that the last surgery performed on day $d \in D$ in OR $o \in O$ ends at time $z \in Z$. Now, let $\mathscr{E}_{do}$ be the probability distribution describing if the last surgery performed on day $d \in D$ in OR $o \in O$ ends after $z_{do}^{close} \in Z$ or not. The discrete probability distribution $\mathscr{E}_{do}$ is given by Equations (8.1) and (8.2), where E_{do} is the discrete random variable corresponding to this distribution. Note that, an OR day is finished before closing time if the cleaning of the OR is also finished before the closing time.

$$\mathbb{P}(E_{do} = 1) = 1 - \sum_{z=z_{do}^{open}}^{z_{do}^{close}-1} e_{dg_{do}ov_{do}z} \qquad \forall d \in D, \forall o \in O \tag{8.1}$$

$$\mathbb{P}(E_{do} = 0) = \sum_{z=z_{do}^{open}}^{z_{do}^{close}-1} e_{dg_{do}ov_{do}z} \qquad \forall d \in D, \forall o \in O \tag{8.2}$$

Subsequently, we define $\overline{\mathscr{E}}$, which is the probability distribution of the number of OR days with overtime during one MSS cycle. This probability distribution is given by Equations (8.3).

$$\overline{\mathscr{E}} = \mathop{\ast}_{d \in D} \mathop{\ast}_{o \in O} \mathscr{E}_{do} \tag{8.3}$$

Next, we define $\mathscr{U}_{do}$ as the probability distribution of the number of time blocks OR $o \in O$ is used on day $d \in D$, in between the start and end time of the OR day. We define an OR as in use, if a surgery is performed or the OR is cleaned in between surgeries or at the end of the OR day. The discrete probability distribution $\mathscr{U}_{do}$ is given by Equations (8.4), (8.5), and (8.6), where U_{do} is the discrete random variable corresponding to this distribution.

$$\mathbb{P}(U_{do} = 0) = 0 \qquad \forall d \in D, \forall o \in O \tag{8.4}$$

$$\mathbb{P}(U_{do} = c) = e_{dg_{do}ov_{do}(z_{do}^{open}+c-1)} \qquad \forall d \in D, \forall o \in O, c \in \{1, \ldots, z_{do}^{close} - z_{do}^{open}\} \tag{8.5}$$

$$\mathbb{P}\left(U_{do} = z_{do}^{close} - z_{do}^{open}\right) = 1 - \sum_{z=z_{do}^{open}}^{z_{do}^{close}} e_{dg_{do}ov_{do}z} \qquad \forall d \in D, \forall o \in O \tag{8.6}$$

Subsequently, we define $\overline{\mathscr{U}}$, which is the probability distribution of the number of time blocks the ORs use in total during one MSS cycle. This probability distribution is given by Equations (8.7).

$$\overline{\mathscr{U}} = \mathop{\ast}_{d \in D} \mathop{\ast}_{o \in O} \mathscr{U}_{do} \tag{8.7}$$

8.2 Maximising the usage of the OR

Remember, to maximise the utilisation of the OR, Equation (6.3) was added to the objective function. To check if this indeed increases the utilisation of the OR, while prioritising scheduling surgeries according to the fractions n_g, we solve two versions of our model in which the ward occupancy is not taken into account. The objective function of the pricing subproblems of the first version is maximising

$$\alpha_s, \tag{8.8}$$

and the objective of the second version is maximising

$$\alpha_s + \frac{1}{200} \sum_{d \in D} \sum_{g \in G_s} \sum_{o \in O} \sum_{v \in V} \left(f_{dgov} \cdot \mathbb{E}\left(p_g\right)\right). \tag{8.9}$$

Firstly, we take a look at the OR utilisation. The total number of available time blocks in our MSS is 4036 time blocks. The probability distribution $\overline{\mathscr{U}}$ gives the probability that a certain number of time blocks is used during one MSS. Combining this information results in the probability that a certain percentage of the total OR time is used, see Figure 8.1. From these probability distributions, we conclude that the OR utilisation increases if Equation (8.9) is used as the objective function instead of Equation (8.8).

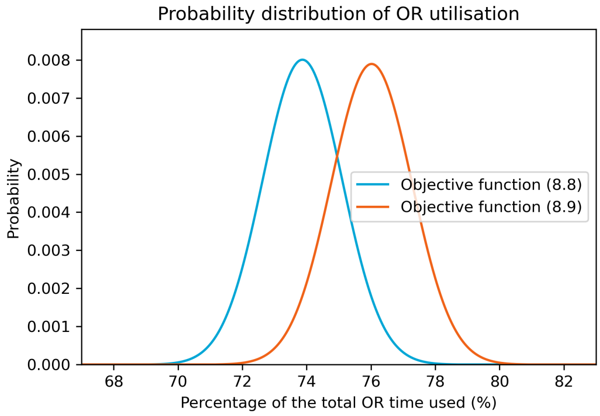
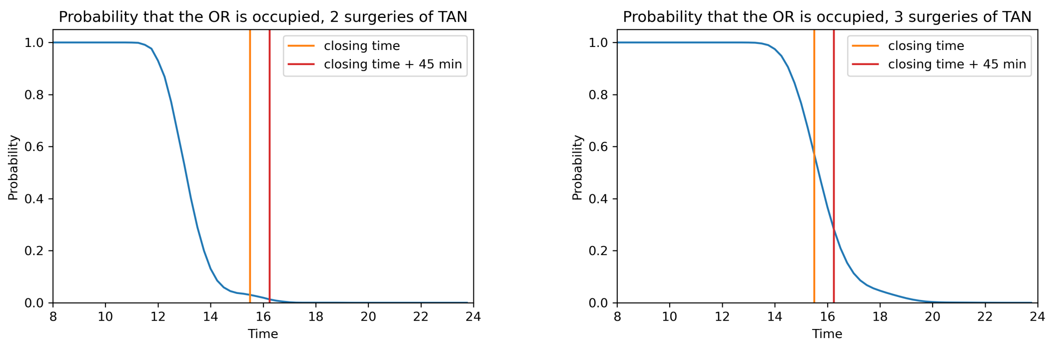


Figure 8.1: Comparison of the OR utilisation for scheduling surgeries with or without adding Equation (6.3).

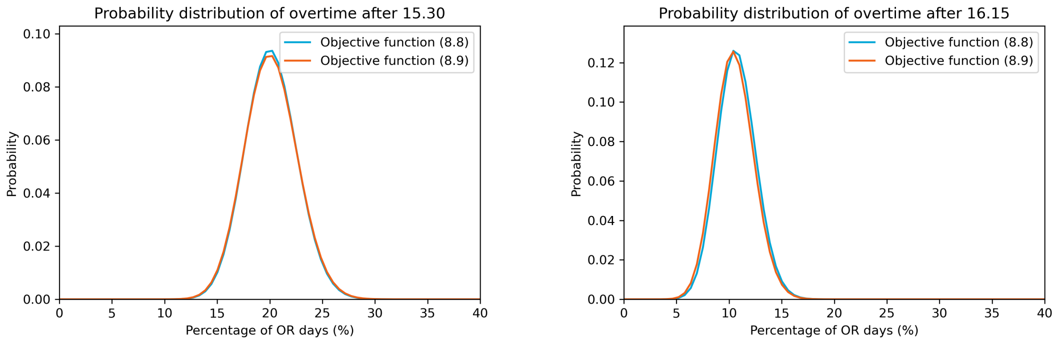
However, the number of scheduled surgeries does not increase for every specialty. One of those specialties is dental surgery. This specialty has only one OR shift in the MSS cycle. We use the probability distribution $\mathscr{U}_{do}$, indicating the probability that a certain the number of time blocks is used at OR $o \in O$ on day $d \in D$, and the start time $z_{do}^{open} \in Z$ to plot the probability that the OR is still used at a certain time. In Figure 8.2, we compare scheduling either two or three surgeries. If we plan only two surgeries, there is a lot of OR time unused. However, if we plan three surgeries there is a high risk of overtime. In Constraint (5.9), we assumed that 90% of a surgery has to be finished two time blocks after the OR is closed. Hence, we can only plan two surgeries.



(a) (b)

Figure 8.2: Probability that the OR is occupied at a certain time, when a certain number of surgeries is scheduled.

Next to that, we look at the percentage of OR days with overtime. In total, there are 173 OR days and we use the probability distribution $\overline{\mathscr{E}}$, which indicates the number of OR days with overtime during one MSS cycle, to calculate the percentage of OR days with overtime. In Figure 8.3, the overtime of the different scenarios is shown. From these figures, we conclude that, even though we planned more surgeries, the percentage of OR days that have overtime does not increase.



(a) (b)

Figure 8.3: Comparison of the overtime for scheduling surgeries with or without adding Equation (6.3).

As mentioned before, in Constraint (5.9), we assumed that 90% of a surgery has to be finished one time block before the OR is closed. However, this does not apply to the first surgery of an OR day, because some surgeries could otherwise not be scheduled. This holds for the orthopaedic spinal surgeries, see Figure 8.4.

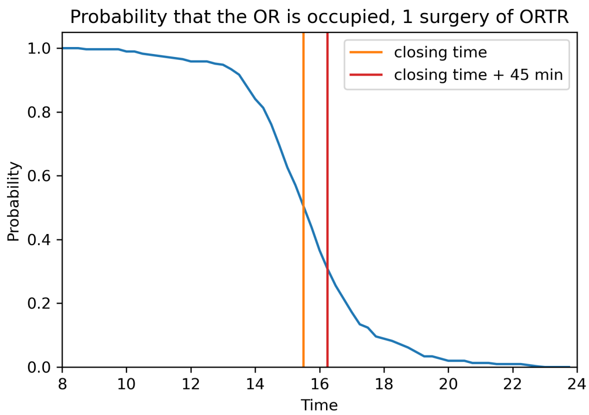
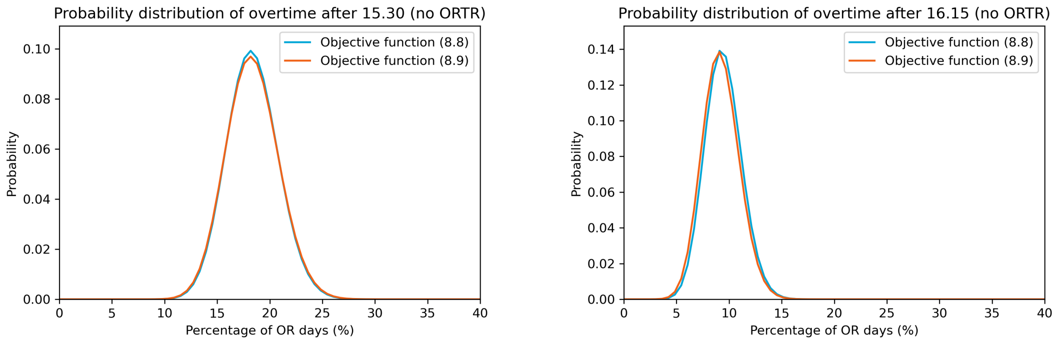


Figure 8.4: Probability that the OR is occupied at a certain time.

In Figure 8.5, we look at the percentage of the OR days with overtime without the orthopaedic spinal surgeries. In this case, the total number of OR days is 165. As expected, the percentage of OR days with overtime is lower if the spinal surgeries are not taken into account.

From the above, we get that the OR utilisation increased when Equation 8.9 is used as objective function instead of Equation 8.8. Next we check if scheduling surgeries according to the fractions n_g is prioritised over maximising the OR utilisation. The variables α_s are the same for both versions, i.e. scheduling surgeries according to the fractions n_g is prioritised over maximising the OR utilisation. The values of these variables are given in Table 8.1.

Hence, we conclude that using Equation (6.3) as the objective function of the pricing subproblems gives the desired results. In the future, we refer to this model as the model without taking bed occupancy into account. For short, we use "no ward" to refer to this model in figures and tables.



(a) (b)

Figure 8.5: Comparison of the overtime for scheduling surgeries using the either Equation (6.3), without the orthopaedic spinal surgeries.

8.3 Performance of the initial model

In this section, we compare three different versions of our model. Each version of the model starts with the same set of initial columns, namely the columns that indicate that there are no surgeries planned at all. The difference between the different versions of the model is the value we assign to the non-negative parameter ω, namely 1, 0.5 and 0.1. The results of the different versions of the model are not only compared with one another, but also with the results from the previous section and historical data. To decrease the runtime of the algorithm, we decided to only add columns for which the objective function value of the corresponding subproblem rounded to three decimal places is negative. However, still all of the three different versions take a very long time to run. There are two main reasons why this takes so long.

- For some specialties, it takes a long time to find the optimal solution to the corresponding pricing subproblem. Although the number of variables is reduced, as explained in Section 6.3, some of the pricing subproblems still consist of a lot of variables. Especially, if a specialty has a lot of different OR slots and patient groups.

- As explained in Section 6.2, we relaxed one constraint. This causes that, if for two solutions of the same pricing subproblem the variables f_{dgov} are the same for all $d \in D$, $g \in G$, $o \in o$ and $v \in V$, the variables b_{dgovz} can differ a little bit. Because this effects the bed occupancy, the model adds columns that would not be different in the original version of the model.

Firstly, we compare the OR utilisation of the different versions of the model in Figure 8.6. Remember, ω indicates if the focus is on the OR utilisation or on levelling the ward occupancy. When the value assigned to ω is decreased, the focus of the model shifts more to the levelling of the ward occupancy. This aligns with the information represented in Figure 8.6.

Secondly, we compare the values assigned to α_s for all $s \in S$ by the different models, this information is provided in Table 8.1. When we compare the model without taking the bed occupancy into account and the version of the model with $\omega = 1$, it stands out that for most specialties $s \in S$ the values of α_s are almost the same. However, this is not the case for the specialty ophthalmology. In Appendix C, the exact schedule for both of these models is given. Here, it shows that the difference between the two models is that the model with $\omega = 1$ does not schedule any ophthalmology surgeries on the first Friday of the MSS. When we analyse the results of the model with $\omega = 0.5$, it stands out that for some specialties there are no surgeries planned at all. This stands out even more for the model with $\omega = 0.1$.

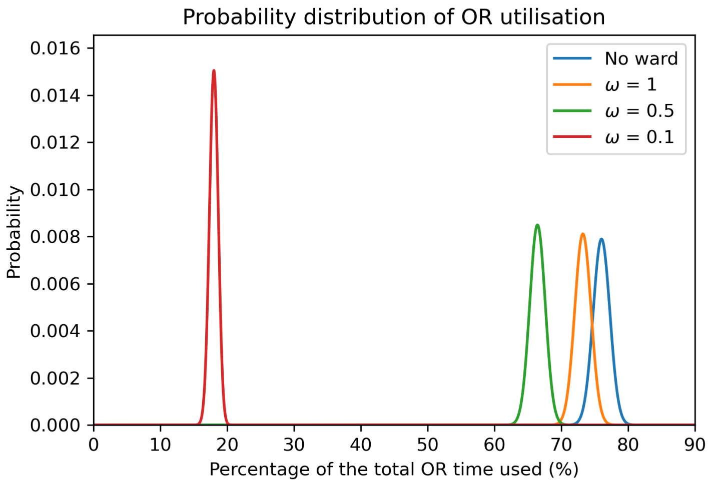


Figure 8.6: Comparison of the OR utilisation for different versions of the model.

Table 8.1: Variables α_s for all specialties $s \in S$, of different versions of the model.

Specialty (s)	**Data**	**No ward**	$\omega = 1$	$\omega = 0.5$	$\omega = 0.1$
KIC	56.63	62.24	60.23	59.51	0.00
KNO	56.55	51.75	50.82	45.79	0.00
RON	48.39	55.76	55.76	55.76	0.00
URO	44.00	46.99	46.85	46.28	0.00
ORTO	37.57	28.30	28.30	28.30	0.00
PLCO	31.61	17.62	17.62	17.62	0.00
GYN	21.02	18.87	18.87	18.87	17.85
GAS	11.92	9.48	9.48	9.48	0.00
CAS	12.55	19.43	19.43	19.43	17.49
NEC	13.02	10.46	10.35	10.35	10.35
KAA	11.53	7.30	7.30	5.47	0.00
OOG	6.43	8.63	5.75	0.00	0.00
LOS	5.88	8.00	8.00	8.00	5.00
ORTR	6.51	8.00	8.00	8.00	8.00
PLCH	3.76	12.00	12.00	0.00	0.00
TAN	2.43	2.00	2.00	0.00	0.00
NEU	1.25	3.00	3.00	3.00	2.00
DER	3.76	4.00	4.00	4.00	2.00

Thirdly, we compare the values assigned to θ_w (the non-negative variable, which gives the maximum fraction of the beds available for elective OR patients that is used at each ward $w \in W$ during a time block $t \in T$) for all $w \in W$ by the different models, which are given in Table 8.2. It stands out that on average the values for θ_w are about a hundred times bigger for the daycare unit (SB2) than for the other wards. The reason for this is that the daycare unit is the only unit that is only opened during set hours on weekdays. The parameter q_{tw} is equal to 0.01 during the time blocks that the daycare unit is closed. Therefore, the results in Table 8.2 concerning the daycare unit can be translated to the expected maximum number of patients that has to be moved from the daycare to the medium care at the end of the day using Constraints (5.19)

$$\max_{t \in T} r_{tw} \quad = \quad \theta_w \cdot q_{tw} = \quad \theta_w \cdot 0.01. \tag{8.10}$$

Hence, if we do not take into account the levelling of the bed occupancy we expect that a maximum of $196.84 \cdot 0.01 \approx 2$ patients has to be moved from the daycare unit to a medium care unit per day. If we look at the model with $\omega = 1$, this is expected to be at most $81.89 \cdot 0.01 \approx 1$ patient per day.

When we compare the model without taking the bed occupancy into account and the model with $\omega = 1$, the value assigned to θ_w for the daycare unit is almost halved, whereas the values assigned to θ_w for the other wards did not decrease as much.

Note that, because the schedule created by our model differs from the historical data, the values θ_w cannot be compared one-to-one. Next to that, it is possible that the values are bigger than one, because q_{tw} indicates the beds that are on average available, it is not a fixed maximum.

Table 8.2: Variables θ_w for all wards $w \in W$, of different versions of the model.

Ward (w)	**Data**	**No ward**	$\omega = 1$	$\omega = 0.5$	$\omega = 0.1$
ICK1	0.91	0.94	0.89	0.90	0.46
ICK2	0.91	1.14	1.08	1.10	0.54
ICK3	0.81	1.00	0.90	0.93	0.29
ICK4	0.95	1.15	1.11	1.09	0.52
ICKT	0.91	0.98	0.96	0.95	0.03
ICN1	0.78	0.86	0.79	0.78	0.20
ICN2	0.77	0.86	0.82	0.81	0.10
ICN3	0.75	0.73	0.70	0.70	0.06
ICN4	1.04	1.09	1.02	1.02	0.17
SB2	38.46	196.84	81.89	64.73	1.75
KCN	1.13	1.40	1.15	1.12	0.44
KCZ	0.83	1.51	1.52	1.45	0.29
KTC	0.99	1.48	1.40	1.39	0.89
MCKG	0.96	1.27	1.23	1.20	0.17
SK4	1.14	1.21	1.11	1.18	0.98
SP4	1.09	1.08	1.07	1.04	0.78

8.4 Performance of the adjusted model

From the previous section, we learned that there are some flaws in our model. In this section, the model is improved and tested for different values of the non-negative weight ω.

Firstly, the order of magnitude difference between θ_w of the daycare unit and the other wards. As mentioned before, for most of the wards $w \in W$ the value of θ_w is between 0.1 and 1.6, but for the daycare unit this number is about a hundred times as big. Therefore, θ_w of the daycare unit is scaled by dividing only this value by a hundred in the objective function. This causes the model to focus less on the daycare unit.

Secondly, because the model takes a long time to finish, we decided to run the model for a maximum of five days. Next to that, for each pricing subproblem, after half an hour, we check if the current objective function value is negative. If this is the case, we add the corresponding column to the set of available columns, although this column does not correspond to the optimal solution of the pricing subproblem. If the objective function value of the pricing subproblem is not negative after half an hour, this same check is performed during every iteration of the Gurobi solver. However, after two hours, the optimisation of the pricing subproblem is stopped. If at that moment the objective function value is not negative, we do not add a new column to the set of available columns.

Thirdly, we reduce the number of variables, by only checking the expectation of the number of patients at ward $w \in W$ every hour and not every time block. Therefore, the constraints that hold for all $t \in T$ will now hold for all $t \in \{0, 4, 8, \dots, t^* - 3\}$. Next to that, Ψ_{cstw}, given in Equation (6.6), is now defined for all $s \in S$, $c \in C_s$, $t \in \{0, 4, 8, \dots, t^* - 3\}$ and $w \in W$. Note that, we calculate the expectation of the number of patients every hour, we do not take the average of the bed occupancy of the last hour.

Lastly, we change the initial set of columns to the columns resulting from the model without taking into account the bed occupancy.

Table 8.3 gives an overview of the model we compare in this section.

Table 8.3: Different versions of the model

	$\omega = 0.5$	$\omega = 0.1$
r_{tw} is defined for all $t \in T$	Model A	Model C
r_{tw} is defined for all $t \in \{0, 4, 8, \dots, t^* - 3\}$	Model B	Model D

Since, models A and C contain more variables than models B and D, it is expected that it takes more time to create the pricing subproblems of models A and C than the time needed to create the pricing subproblems of models B and D. From Table D.1, it can be concluded that this is indeed the case.

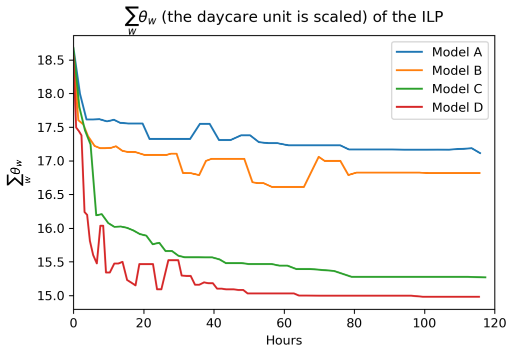
Next, after an iteration of the column generation algorithm, the MILP was solved using only the columns available at that moment. In Figure 8.7, we separately compare the components of the objective function of the resulting solution of the MILP. From the objective function given by Equation (5.20), we know that the goal is to minimise

$$\sum_{w \in W} \theta_w \tag{8.11}$$

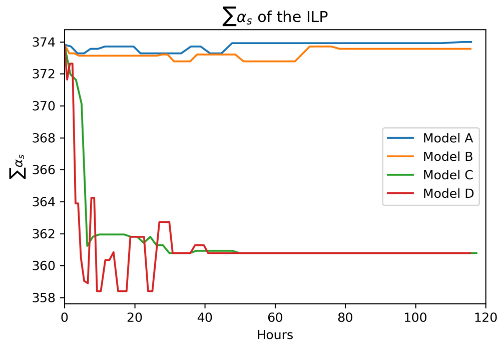
and to maximise

$$\omega \cdot \sum_{s \in S} \alpha_s \quad + \quad \omega \cdot \frac{1}{200} \sum_{d \in D} \sum_{g \in G} \sum_{o \in O} \sum_{v \in V} \left(f_{dgov} \cdot \mathbb{E}(p_g) \right). \tag{8.12}$$

Hence, the results shown in Figure 8.7 match our expectation. Firstly, models A and B focus more on maximising the OR utilisation than models C and D. Therefore, Equations (8.12) have higher values for models A and B, than for models C and D. Secondly, models A and B focus less on levelling the bed occupancy (which we want to minimise) than models C and D. Therefore, Equation (8.11) has a higher value for models A and B, than for models C and D.



(a)



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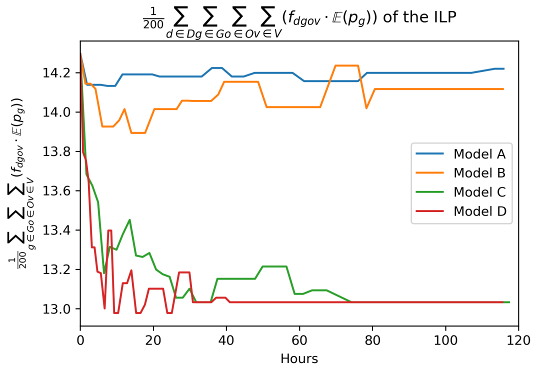

(c)

Figure 8.7: Comparison of different parts of the objective function value at different moments during the column generation algorithm.

Subsequently, we take a look at the objective function value of both the RLPM and MILP at different moments during the column generation algorithm given in Figure 8.8. During column generation, the goal is to solve the LP using the pricing subproblems and the RLPM. Hence, the focus is on solving the LP instead of the MILP. Therefore, it could be the case that our model adds columns to the set of available columns which do not improve the objective function value of our MILP. From Figure 8.8, we get that, in general, the columns added to the set of available columns do also influence the outcome of our MILP.

Next to that, two other observations stand out:

- although it takes less time to create the pricing subproblems of models A and C than the models B and D, the different models take approximately the same time to converge to the final objective function value;
- from Figure 8.8a, we get that the objective function value of the model still improves just before the algorithm is terminated, which indicates that the objective function would maybe improve even more if the algorithm was not terminated.

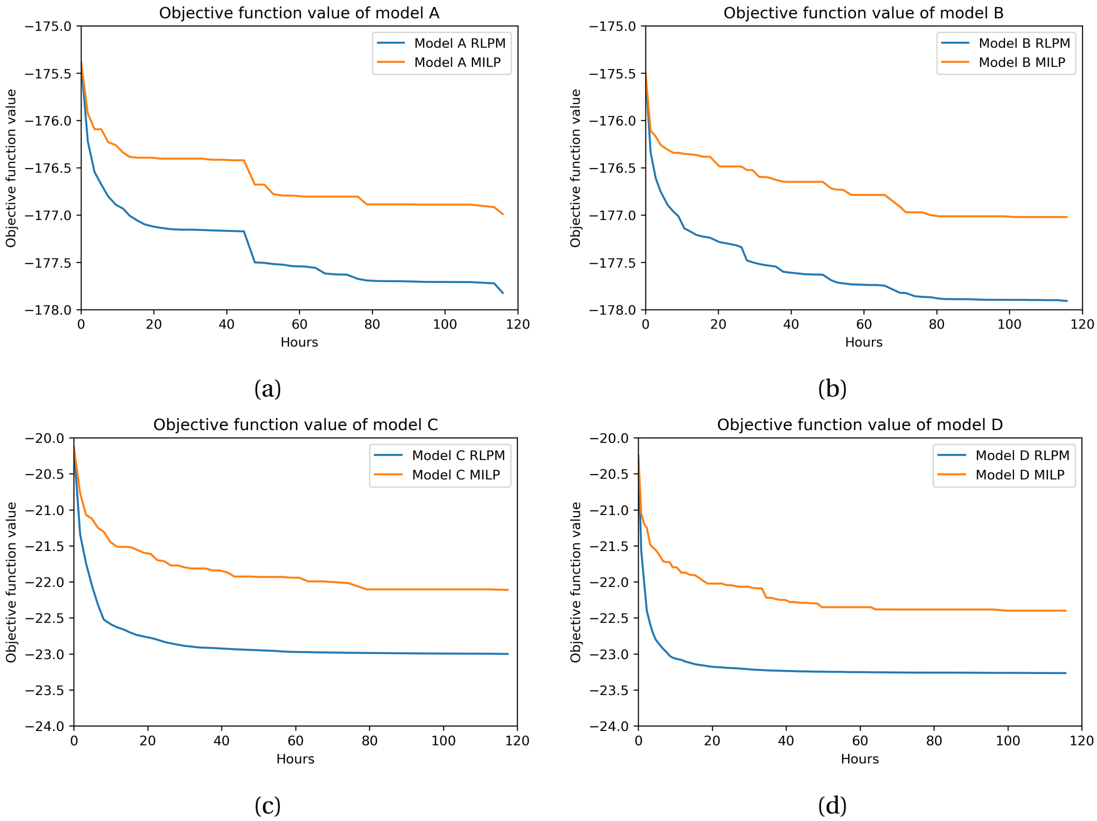

Figure 8.8: Comparison of the objective function value of both the RLPM and MILP at different moments during the column generation algorithm.

Lastly, the solutions of models A and B do not converge to the same solution, the same holds for models C and D. Reducing the variables could be the cause of this. Remember, from Equation Equation 5.19, θ_w gives the maximum fraction of the beds available for elective OR patients that is used at each ward $w \in W$ during a time block $t \in T$. Because we do no longer calculate r_{tw} for all $t \in T$ for every $w \in W$, but only at the whole hour, it could be that the highest value of $\frac{r_{tw}}{q_{tw}}$ is not calculated. Hence, another lower value of $\frac{r_{tw}}{q_{tw}}$ will then be the maximum value θ_w. To be able to compare the different methods, we calculate r_{tw} for every $t \in T$ for every ward $w \in W$, to get the maximum expectation θ_w of the final solution.

Something we have not mentioned up until now, is there are two days in our MSS on which two different specialties have OR time. On both days, ophthalmology has OR time from 8:00 until 11:45 and dermatology had OR time from 11:45 until 15:30. During column generation, the columns were generated per specialty, therefore it was not possible to take into account the end time of the last surgery of ophthalmology when planning the first surgery of dermatology. Hence, we assumed that dermatology could directly start at 11:45. There are two situations that are ignored in our model:

- there is a possibility that ophthalmology is still using the OR at that time;
- there is a possibility that the last surgery of ophthalmology finished before 11:45 (including the extra cleaning time), in this case dermatology could have started earlier.

From Figure 8.9, we get that both of the above mentioned situations occur. In reality, when dermatology starts directly after the OR is cleaned after the last surgery of ophthalmology, there is a chance that the last surgery on the OR day is finished earlier than predicted by the model. This occurs, when dermatology can start earlier than the actual start time of the OR shift of dermatology. Next to that, there is also a chance that the OR day is finished later than the model predicted. In this case, the last surgery of ophthalmology finished after the end time of the OR shift of ophthalmology, i.e. after the start time of the OR shift of dermatology. Therefore, the surgeries of dermatology have to start later than expected by the model.

Although both of these situations occur, and the predicted end time of the last surgery is different from what the model expected, the new end time still meets our constraints. At the closing time, the probability that the OR is still occupied is lower than 0.25 and the probability that the surgery (including cleaning time) is finished before the closing time plus 45 minutes is lower than 0.10. For the results that follow, we use the probability distribution of how these surgeries are planned in reality.

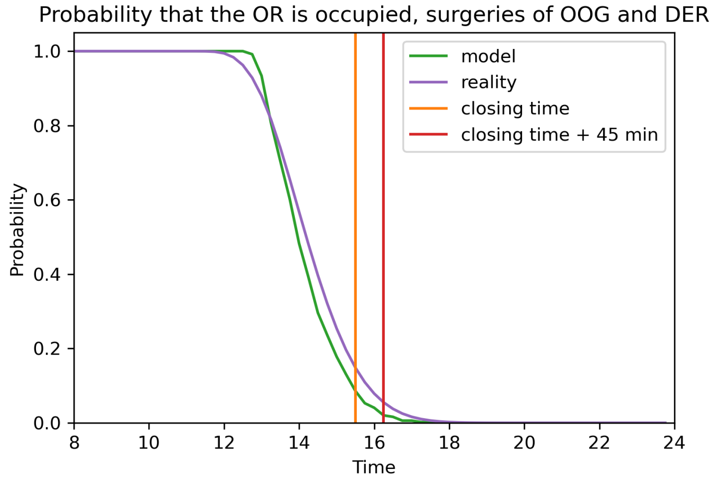

Figure 8.9: Probability that the OR is occupied at a certain time, for two scenarios.

Next, we compare the same kind of results as we looked at in Section 8.3. The schedules resulting from the different models are given in Appendix C.

Firstly, the OR utilisation given in Figure 8.10. As expected, models A and B use a higher percentage of the total OR time than models C and D. Next to that, there is a small difference between both models A and B and models C and D.

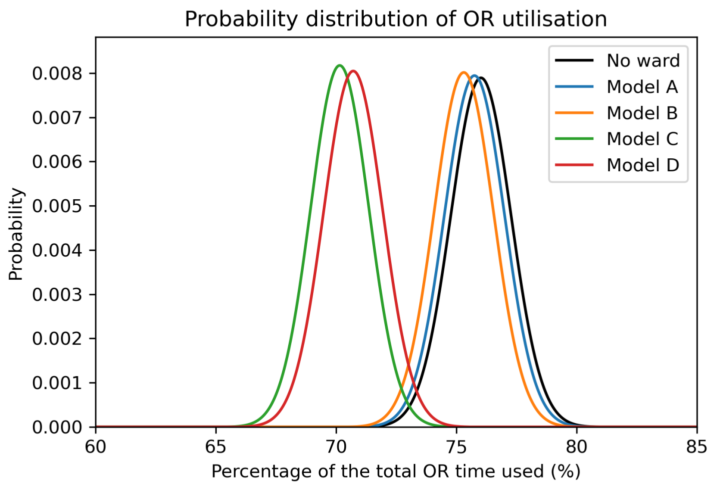

Figure 8.10: Comparison of the OR utilisation for different versions of the model.

Table 8.4: Variables α_s for all specialties $s \in S$, of different versions of the model.

Specialty (s)	Data	No ward	Model A	Model B	Model C	Model D
KIC	56.63	62.24	61.89	62.24	53.35	53.35
KNO	56.55	51.75	51.75	51.75	50.82	51.32
RON	48.39	55.76	55.76	55.76	55.76	55.76
URO	44.0	46.99	47.63	46.85	46.85	46.85
ORTO	37.57	28.30	28.30	28.30	28.30	28.30
PLCO	31.61	17.62	17.62	17.62	17.62	17.62
GYN	21.02	18.87	18.87	18.87	17.85	17.85
GAS	11.92	9.48	9.48	9.48	9.48	9.48
CAS	12.55	19.43	19.43	19.43	17.49	17.49
NEC	13.02	10.46	10.35	10.35	10.35	10.35
KAA	11.53	7.30	7.30	7.30	7.30	7.30
OOG	6.43	8.63	8.63	8.63	8.63	8.63
LOS	5.88	8.00	8.00	8.00	8.00	8.00
ORTR	6.51	8.00	8.00	8.00	8.00	8.00
PLCH	3.76	12.00	12.00	12.0	12.00	12.0
TAN	2.43	2.00	2.00	2.00	2.00	2.00
NEU	1.25	3.00	3.00	3.00	3.00	3.00
DER	3.76	4.00	4.00	4.00	4.00	4.00

Secondly, we compare the values assigned to α_s for all $s \in S$ by the different models, this information is provided in Table 8.4. In comparison with Table 8.1, it stands out that there are no longer specialties for which the model does not plan any surgeries. Hence, the scaling of the variable θ_w corresponding to the daycare unit gave the desired results.

Lastly, we compare the values assigned to θ_w for all $w \in W$ by the different models, which are given in Table 8.5 and Table 8.6. As mentioned before, it is not possible to compare the values from the data with the values generated by our model because we schedule a different number of surgeries. However, we are able to compare the values from the model, which does not take into account the levelling of the bed occupancy with model A and B. Because, from Table 8.4, we get that we planned similar surgeries. For almost all of the wards $w \in W$, the expectation of the maximum fraction of the beds available for elective OR patients that is used at each ward $w \in W$ during a time block $t \in T$ is increased when comparing the model that does not take into account the levelling of the bed occupancy with model A and B in Table 8.5. This is also the case when we compare the 90 percentile of the bed occupancy in Table 8.6.

In Appendix E, a selection of figures shows the bed occupancy for both the model which does not take into account the levelling of the bed occupancy and Model A, to provide insight on the bed occupancy over time for both models.

Table 8.5: Variables θ_w for all wards $w \in W$, of different versions of the model.

Ward (w)	Data	No ward	Model A	Model B	Model C	Model D
ICK1	0.91	0.94	0.91	0.89	0.82	0.81
ICK2	0.91	1.14	1.12	1.11	0.99	1.01
ICK3	0.81	1.00	0.91	0.96	0.81	0.81
ICK4	0.95	1.15	1.13	1.14	1.01	1.0
ICKT	0.91	0.98	0.99	0.99	0.87	0.87
ICN1	0.78	0.86	0.79	0.8	0.72	0.71
ICN2	0.77	0.86	0.83	0.82	0.74	0.74
ICN3	0.75	0.73	0.71	0.73	0.62	0.64
ICN4	1.04	1.09	1.00	1.02	0.89	0.90
SB2	38.46	196.84	131.68	142.18	98.98	112.52
KCN	1.13	1.40	1.12	1.14	1.04	1.07
KCZ	0.83	1.51	1.48	1.40	1.25	1.22
KTC	0.99	1.48	1.40	1.42	1.33	1.34
MCKG	0.96	1.27	1.20	1.21	1.12	1.13
SK4	1.14	1.21	1.10	1.19	1.11	1.06
SP4	1.09	1.08	1.05	1.00	0.94	0.96

Table 8.6: Variables θ_w for all wards $w \in W$ 90th percentile, of different versions of the model.

Ward (w)	Data	No ward	Model A	Model B	Model C	Model D
ICK1	2.70	1.77	1.78	1.74	1.76	1.67
ICK2	2.09	2.31	2.29	2.27	2.09	2.13
ICK3	1.6	1.78	1.67	1.72	1.56	1.55
ICK4	1.79	2.11	2.09	2.11	1.92	1.90
ICKT	1.74	2.12	2.14	2.14	2.01	2.02
ICN1	2.31	1.93	1.85	1.88	1.79	1.75
ICN2	2.13	1.94	1.89	1.89	1.87	1.87
ICN3	2.35	1.82	1.79	1.85	1.71	1.74
ICN4	3.80	2.90	2.67	2.78	2.54	2.44
SB2	135.0	344.33	261.29	267.28	192.44	228.6
KCN	1.97	1.94	1.66	1.65	1.54	1.55
KCZ	1.64	1.98	1.93	1.87	1.70	1.66
KTC	1.88	2.32	2.21	2.23	2.09	2.14
MCKG	1.94	2.14	2.03	2.05	1.96	1.97
SK4	2.14	1.66	1.57	1.60	1.53	1.44
SP4	3.78	2.51	2.45	2.38	2.28	2.32

9 | Conclusion and recommendations

The goal of this thesis was to create a model which maximises the utilisation of the OR and levels the bed occupancy at the different wards. Section 9.1 provides conclusions based on the results we gathered during this research. In Section 9.2, we provide some recommendations to improve the model, which could lead to better and more realistic results.

9.1 Conclusion

In this section, we draw conclusions from the results presented in Chapter 8.

As mentioned in Chapter 6, it is not possible to create the model at once, due to the high number of variables. Therefore, we used column generation, which makes it possible to optimise the model, because the model is optimised using pricing subproblems. However, it takes a lot of time to solve the pricing subproblems, in combination with the high number of iterations we were not able to perform the entire column generation algorithm. Therefore, time restrictions were set, both on the runtime of the pricing subproblems and the runtime of the entire algorithm. Since the algorithm is terminated before the algorithm is finished, it is unknown if the optimal solution of the RLPM is reached.

Next to that, because the column generation algorithm is used to optimise the RLPM, it could be the case that the columns added to the set of available columns do not improve the objective function value of our MILP. From Figure 8.8, we get that this is not the case, the objective value of the MILP improves over time.

This indicates that column generation can be used to optimise our model.

Although the aim is to schedule patient groups $g \in G$ according to the fractions n_g, it is shown in Section 8.2 that it is needed to plan extra surgeries if we want to optimise the utilisation of the OR.

In the same section, we showed that for some patient groups it holds that even if we plan only one surgery, there is a high probability that the surgery ends after the closing time of the OR. On the other hand, there are specialties for which it is not possible to schedule surgeries in such a way that they use a high percentage of their OR time. For example, for dental surgery, using Subsection 7.4.4, it is explained that it is not possible to split dental surgery in different patient groups. This results in a more than 80% chance that the last one-and-a-half-hour of the OR shift of dental surgery is not used.

From Section 8.4, we can also draw multiple conclusions. Firstly, scaling θ_w related to the daycare unit enforced the model to focus on all of the wards more evenly. Secondly, from Figure 8.9, we conclude that it does not cause any problems in our model if multiple specialties have OR time on the same OR day. However, at this moment, we can only conclude this for the MSS we used during this thesis. Thirdly, it is possible to define the values of r_{tw} per hour instead of per fifteen minutes. This change does not speed up the model, and does not significantly change the OR utilisation and. However, it does result in different schedules.

It is possible to focus the model either on levelling the bed occupancy or on the utilisation of the OR. But, there are also some differences between the reality and the model. There is a big difference between the number of surgeries that is scheduled by the model and the number of surgeries that is planned at the moment in the SCH. For some specialties the number of planned surgeries increased, for other specialties the number of planned surgeries decreased.

Concluding, we reached our goal, we created a model which maximises the utilisation of the OR and levels the bed occupancy at the different wards. It is important that our model also improves the levelling of the bed occupancy at the 90th percentile, because this indicates that the model is able to minimise the number of high peaks in the needed number of beds, which ensures that less surgeries have to be cancelled because there is no bed available. Next to that, this model can help to show the impact of changes the SCH might want to make in the MSS.

9.2 Recommendations

In this section, we provide recommendations for both the SCH and future research on this topic. In Subsection 9.2.1, we focus on the data registration of the SCH, the quality of the input influences since the quality of the results we gather from the model. In Subsection 9.2.2, different suggestions are given to improve the model and make the model more realistic.

9.2.1 Data registration

As mentioned in Chapter 7, some inconsistencies occurred in the provided data. During a surgery, a lot of information has to be registered in HiX, a program the hospital uses to log all the information regarding the patients. Sometimes, someone forgets to fill in all the fields or makes a mistake. It is recommended to integrate some automatic checks in the system such that the information is more accurate. One of those checks could be if the times of the different steps are in chronological order. For example, a surgeon cannot start before the patient is in the OR, or a patient cannot go to the recovery ward before the surgery had finished.

The staff of the SCH manually inserts the information regarding the patients. Therefore, the same information can be written down slightly different. For example, *"lokaal injecteren narcose"* and *"lokaal injecteren met narcose"* are the same procedure. The given example is relatively easy to spot without medical education. However, there are various names for the same procedures, which are more difficult to link to each other. Consequently, the last recommendation regarding the data registration would be to change the box which describes the procedure.This should be changed to a limited list of options the staff has to choose from. If they want to add extra notes about this specific procedure, they can type this in a second box. This contributes to making more accurate patient groups, with a better prediction of the duration of the surgery and time spend in the hospital.

Another recommendation regarding the data registration in the SCH, is to unify the different systems. For example, there are different abbreviations for the same specialty in the MSS and the export from HiX. Also, when someone enters data in HiX, this data is labelled differently in the export sheet. This could lead to confusion when someone analyses the data.

9.2.2 Research recommendations

In this section, multiple recommendations are provided to improve both the quality of the output of the model and the usability of the model.

Overtime

Constraints (5.9) do not apply to the first surgery of an OR day, such that the model also schedules surgeries that have a high chance of finishing after the OR should already be closed. However, some OR shifts are longer than other OR shifts. It might be more realistic to only allow the first surgery to have (a lot of) overtime if it is assigned to one of the longest OR shifts of the corresponding schedule.

Patient groups

Some decisions were made while creating the different patient groups in Section 7.4. For example, it did not matter on which ward a patient stayed when the patient groups were created. It could lead to more homogeneous patient groups if this is taken into account. Next to that, the ASA-score, a factor which reflects the overall health of a patient, is a factor that could influence both the LoS, and the surgery duration. Using this score as an indicator could also lead to more representative patient groups. Both of these suggestions could lead to a more accurate expectation of the surgery duration, and LoS of the patients on the different wards.

Lastly, the specialty plastic surgery is divided in PLCH and PLCO. At the moment, the model schedules too many PLCH surgeries and not enough PLCO surgeries, in comparison with the data. Therefore, it would be an option to assign some of the OR shifts of PLCH to PLCO.

Daycare unit

As mentioned in Chapter 8, there are some difficulties regarding the occupancy of the daycare unit, because this ward is only open during certain hours. In Section 8.4, we decided to divide the maximum expectation of the daycare unit by a hundred, such that the focus of the model is less on the daycare model. However, the problem is specifically related to the time blocks during which the ward is closed. At the moment, the maximum expectation of the daycare unit is outside of the opening hours of the ward. Therefore, during the day, the model is not forced to level the bed occupancy. Hence, it could be interesting to introduce two separate variables; one to minimise the maximum expectation of the bed occupancy of the daycare unit when the daycare unit is closed, and one to minimise the maximum expectation of the bed occupancy of the daycare unit when the daycare unit is opened. Both aspects are important. The goal is to minimise the number of beds that is used at the ward. And, if patients are still at the daycare unit after opening hours they have to be transferred to the MCU, which should be avoided as much as possible.

Fine-tuning of the model

Some minor adjustments could help to suit the needs of the SCH better. It is recommended to look specifically at three parts of the model. Firstly, the non-negative parameter ω, which is used to focus more on either the OR utilisation or the levelling of the ward occupancy. In Chapter 8, different values of ω were used to generate the corresponding schedules. However, due to a lack of time, we were not able to run the model with a lot of different values of ω. Hence, a different value of ω could result in a schedule that better suits the hospital's needs. Secondly, the probability that a surgery is not finished at the end of the OR day is described by Constraints (5.9). It might be interesting to reduce or increase this percentage. Thirdly, if it is more important to level the bed occupancy of certain wards in comparison with other wards, it is recommended to scale the corresponding values of θ_w in a similar way as the value of θ_w corresponding to the daycare unit is scaled.

Runtime

As mentioned before, it takes a lot of time to run the column generation algorithm. From the results, we get that the model converges within five days, if the pricing subproblems have a maximum runtime of two hours. It is recommend to investigate whether the schedule changes if there are no time restrictions.

It is recommended to calculate the maximum number of surgeries of a specific specialty that could be planned during one OR shift. This maximum number can be different per specialty. Instead of using the set $V = \{0, \ldots, 15\}$, it is possible to create different sets $V_s = \{0, \ldots, v_s^{\max}\}$ for each specialty $s \in S$, where $v_s^{\max}$ is the maximum number of surgeries that can be scheduled during one OR shift of specialty $s \in S$. This could decrease the time to run the algorithm. Due to a lack of time we were not able to implement this.

Column generation

During column generation, a column is added to the set of available columns if the corresponding objective function value of the pricing subproblem is negative. In this thesis, a column is only added if the objective function value rounded to three decimal places is negative. It is recommended to investigate if the outcome of the model changes if the objective function value is rounded to two decimal places. This could decrease the runtime of the model, but it is only an option if it does not result in a worse schedule.

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A | Ward capacity

This appendix contains the approximated capacity of the different wards at the SCH.

Table A.1: Ward capacity

	Weekday			Weekend		
Ward	07:00 - 16:00	16:00 - 23:00	23:00 - 07:00	07:00 - 16:00	16:00 - 23:00	23:00 - 07:00
ICK 1	1.5	1.5	1.5	1	1	1
ICK 2	2	2	2	2	2	2
ICK 3	2	2	2	2	2	2
ICK 4	3	3	3	2.5	2.5	2.5
ICK T	2	2	2	2	2	2
ICN 1	1.5	1.5	1.5	1.5	1.5	1.5
ICN 2	1	1	1	1	1	1
ICN 3	1	1	1	1	1	1
ICN 4	0.5	0.5	0.5	0.5	0.5	0.5
KCZ	10	9.5	9	8.5	8	8
KTC	4.5	4.5	4	3	3	3
MCKG	3.5	3.5	3	2.5	2.5	2.5
SK4	3.5	3	3	3	2	2
SP4	0.5	0.4	0.4	0.3	0.2	0.2

Table A.2: Ward capacity KCN

	Mon, Wed, Thu			Tue, Fri			Weekend		
Ward	07:00 - 16:00	16:00 - 23:00	23:00 - 07:00	07:00 - 16:00	16:00 - 23:00	23:00 - 07:00	07:00 - 16:00	16:00 - 23:00	23:00 - 07:00
KCN	8.5	8	7.5	10.5	8	7.5	5	4.5	4.5

Table A.3: Ward capacity daycare unit

	Weekdays		
Ward	07:00-10:00	10:00-14:00	14:00-18:00
Daycare unit	8.5	9	5.5

B | Patient groups

This appendix contains the different patient groups and information regarding the different procedures, both the mean surgery duration and the median LoS are given in minutes.

B.1 Dental surgery (TAN)

Table B.1: Dental surgery

Procedure (in Dutch)	**Mean surgery duration**	**Median LoS**	**freq.**
Maag - gastrostomie - vervanging peg-sonde	79	338	1
Gebit - vrijprepareren geimpacteerd element	107	401	1
Pharynx - adenotonsillect.mbv dissectom. - tm 10 jaar	133	572	1
Bronchus - bronchoscopie met lavage	136	1491	1
Patient stichting de bijter	145	464	101
Bot - verwijderen osteosynthesemateriaal	147	807	1

B.2 Dermatology (DER)

Table B.2: Dermatology

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Huid - verwijderen naevus	20	148	1
Huid - oper.verwijdering kleine gezwellen	25	192	2
Penis - preputiumplastiek bij hypospadie	28	315	1
Huid - biopsie	31	246	4
Huid - stansbiopsie	49	322	1
Huid - oper.verwijderen gezwel.dmv moh-s chirurgie	62	533	1
Stralingsth.- laserbehandeling 0.5-1 procent lich. opp.	65	339	4
Huid - deroofing vlgs bos-vw.sinusdak dmv diatherm	77	1844	1
Stralingsth.- laserbehandeling meer dan 1 procent lich.op	80	559	5
Huid - kl.weinig gecompl.exc.ben.tumoren - n.funct	105	1431	1
Romp-schoud.- ruime excisie huid-tumor- met oml. weefsel	159	5967	1

B.3 Gastroenterology (GAS)

Table B.3: Gastroenterology group 1 (surgery duration ≤ 48)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Rectum - zuigbiopsie van rectaal slijmvlies	30	193	1
Lever - percutane -naald- biopsie	35	538	23
Dikke darm - coloscopie van het totale colon	37	290	1
Sigmoid - rectosigmoidoscopie met biopsie	42	285	7
Oesophagus - dilatatie	43	345	17
Dunne darm - oesofagogastroduodenoscopie met biopsie	43	337	227
Maag - gastrostomie - vervanging peg-sonde	45	316	166
Oes.scopie +Leverbiopt om 10.00 uur door radioloog	46	455	1

Table B.4: Gastroenterology group 2 (48 < surgery duration ≤ 58)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Maag - gastrostomie –peg-sonde– dmv scopie	49	2231	143
PEG plaatsing	51	3369	1

Table B.5: Gastroenterology group 3 (surgery duration > 58)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Duodenum - inbrengen voedingssonde incl. duodenoscop.	60	289	28
Oesophagus - verwijderen corpus alienum	62	740	3
Dikke darm - colonoscopie met biopsie	66	450	122
Maag - gastroscopie -fiber- diagn. -incl.proefexc.	74	396	2
Colonoscopie	75	462	1
Dikke darm - coloscopie met poliepectomie	109	368	1

B.4 Gynaecology (GYN)

Table B.6: Gynaecology group 1 (surgery duration ≤ 68)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Vagina - scopie incl.evt.vulvabiops.niet met hyst.sc	39	190	1
Abortus - vacuumcurettage - abortus prov.na 12 weken	43	645	5
Uterus - curettage - aspiratie- of vabra	46	443	1
Cervix - cerclage vlg shirodkar verwijderen	46	4182	5
Abortus - nacurettage	47	826	2
Partus - nacurettage	48	853	3
Abortus - curettage - missed abortion	52	366	2
Cervix - isthmuscerclage - shirodkarbandje	53	656	52
Maag - diagnostische gastroscopie	54	1156	2
Partus - cervixruptuur hechten - postpartum	55	454	1
Vaginale lage cervix cerclage –mcdonald–	56	672	24
Abortus - vacuumcurettage - abortus arte provocatus	56	493	1
Partus - natasten placenta	62	645	8
Vrw.gesl.org- plastische operatie van vulva of perineum	65	218	1
Partus - perineumruptuur hechten - 3de graad	66	747	4
Partus - placenta verwijderen - manueel - curettage	68	5607	1

Table B.7: Gynaecology group 2 (68 < surgery duration ≤ 95)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Sect.caesar.- primair - geen voorbehandeling wel kraambed	71	3195	25
Sect.caesar.- laag cervicaal zonder voorbehandeling	78	3872	32
Sect.caesar.- met voorbehandeling en kraambed	81	4609	43
Sect.caesar.- sectio caesarea	82	3225	655
Sect.caesar.- laag cervicaal met voorbehandeling	84	3769	140
Sectio caesarea	84	3493	1
Sect.caesar.- laag cervicaal	95	3130	6

Table B.8: Gynaecology group 3 (surgery duration > 95)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Uterus - ther. hysterosc. kl verr. poliepect. iud	100	1039	2
Sectio caesarea + sterilisatie	109	3136	1
Sterilisatie vrouw op verz.pat. tijdens sect.caes.	109	3208	28
Ovarium - adnex-extirpatie dmv laparoscopie	125	1852	1
Cervix - herstel scheuren	132	1169	2
Buik - relaparotomie - second-look-operatie	137	5829	1
Vulva - excisie of inkorten labia majora-minora	137	538	1
Uterus - hysteroscopie	138	1481	1
Cervix - cerclage - abdominaal - laparoscopisch	138	1727	5
Cervix - cervix cerclage - transabdominaal	146	1258	2
Cerclage abdominaal	155	1621	1
Buik - verwijd.intraperiton.endometriose-laparosco	157	1786	1
Uterus - extirpatie - abdominaal met adnexa	195	6249	3
Onderzoek - gynaecologisch onderzoek onder narcose	217	1556	1
Uterus - ext.rad. znd lymf. znd adnexext. - open	262	7457	1

B.5 Maxillofacial surgery (KAA)

Table B.9: Maxillofacial group 1 (surgery duration ≤ 84)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Tong - extirpatie frenulum labii en linguae	28	237	5
Mond - extirpatie tumor - weke delen	41	410	2
Speeks.klier- verwijderen steen per klier en-of ductus	49	383	1
Mond - kleine verr.- bijv.uitgebr.oper.wondtoil.-proefexc	62	336	12
Kaak - artroscopie - diagnostiek en lavage	65	494	4
Gebit - oper.verw.1-meer wort.rst.-corp.al.-k.helft	72	375	251
Gebit - vrijprepareren geimpacteerd element	72	379	11
Kaak - oper.verw.osteosynth.mat.-distrac-kaakhelft	74	524	16
Elementen - beh.1-meer gelux.el.-repl.-transpl.-fract.	82	390	16

Table B.10: Maxillofacial surgery group 2 (84 < surgery duration ≤ 128)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Ongecompliceerde extractie 1 of meer elem.in 1 kaakhelft	86	482	2
Gebit - vrijprepareren aanbr.ligatuur of extensie	92	367	72
Neusbijholte- oper.verw.kaakcyste kwartvol.- sinus maxil.	94	894	4
Maxilla - plaatsen bone-anchors-niet osteotom-fract-recon	95	364	1
Kaak - oper.verw.grote ben.tumoren-cyste-w.delen	104	406	8
Kaak - verkr.autotransplant.incl.transpl.bot of kraakbeen	117	1580	1
Maxilla - osteotom-distr.os zygomat.-maxil.-le fort i	121	1110	4
Mond - vestib-m.bodemplast-corr.p.alv.allopl-front-kaakh	126	380	1
Bov.luchtw. - laryngotracheoscopie - diagnostisch	127	2981	1

Table B.11: Maxillofacial surgery group 3 (surgery duration > 128))

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Mandibula - corr.benige kin-corticotom.tbv.rapidexpans.	136	429	1
Kaak - osteotom-distr.proc.alveol.frontged.-kaakh.	146	452	2
Tong - gedeeltelijke extirpatie	147	10264	1
Kaakgewricht- overbr.gnathosch.bottranspl.kaakrec.transpl	154	1526	145
Kaak - op.beh.meerv.mandibula-maxilla-zygoma-fract	163	1595	1
Assistentie bij een kaakchirurgische verrichting	167	2899	1
Mandibula - osteotomie-distractie enkelz. of frontged.	170	2955	12
Kaakgewricht- resectie tub.art.-ext.disc.art.-condylotom.	280	3126	3
BIG duplex, crista, combi PLC liprevisie	282	1535	1
Thorax - zuigdrainage behandeling - pneumothorax	328	3272	1

B.6 Neurological surgery (NEC)

Table B.12: Neurological surgery group 1 (LoS ≤ 7392 and surgery duration ≤ 117)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Ruggenmerg - diagnostische lumbaalpunctie	46	437	1
Halo - vest	60	1618	1
Schedel - inbrengen drukmeter	64	1729	16
Hersenen - diagnostische punctie - intracraniaal	66	5514	2
Ventrikelreservoir of anti-syphon device -asd-	86	1638	2
Hersenen - diagn.stereotact.biopt hersentumor lok.nno	93	724	1
Hersenen - vervangen –deel van– liquorshunt	95	1848	22
Schedel - excisie tumor schedelconvexiteit	101	597	14
Hersenen - evacuatie epiduraal hematoom - craniotomie	102	5383	2
Schedel - verw.distractiemateriaal na craniosynostosebeh.	103	618	119
Schedel - reexpl.wgs.directe postop.compl.-craniotom.	106	1947	1
Laminectomie - 1 niveau bij hnp of stenose	107	1598	1
Wervelkolom - uitw.fixatie halswerv.incl.evt.tractie-halo	108	4064	3
Wervelkolom - recidiefoperatie hernia nuclei pulposi	112	1781	1
Liquorshunt - klepsysteem	113	1862	1
Hersenzenuw - verwijd. of revisie nervus vagus stimulator	115	424	1

Table B.13: Neurological surgery group 2 (LoS ≤ 7392 and 117 < surgery duration ≤ 154)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Hersenen - endoscop.fenestr.binnen of buiten liquorsyst.	119	3577	6
Ruggenmerg - liquordrain.dmv interne liquordrain spinaal	120	3092	6
Perif.zenuw - exploratie tumor - behalve neuroom	123	730	1
Hersenen - revisie cq verwijderen shunt - ventrikel	124	1744	28
Hersenen - ventriculocisternostomie - 3e ventrikel	133	4320	20
Schedel - distractie schedelbeenderen bij craniosynostose	135	2936	113
Lumboperitoneale shunt	136	2333	2
Perif.zenuw - op.beh.neuroom-zenuwtumor - exc.of transpos	137	568	5
Spreidveren tbv craniosynostosebehandeling	138	3608	2
Wervelkolom - discectomie lumbosacraal - 1 segment - open	140	1997	3
Hersenzenuw - vervangen nervus vagus stimulator	140	664	2
Hersenen - stereotactische biopsie	147	3450	8
Hersenzenuw - implanteren nervus vagus stimulator	152	2646	8

Table B.14: Neurological surgery group 3 (LoS ≤ 7392 and surgery duration > 154)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Schedel - zaagsnedes-herposit.schedelbeend.craniosynost.	163	2692	1
Schedel - sekwestrectomie - verwijderen botlap-plast.	166	3989	1
Hersenen - herstel encefalokele	172	1630	6
Hersenen - evac.intracerebr.hemat.infratent.craniotom.	182	6315	1
Hersenen - ventriculostomie - overige	192	4590	1
Mond - vervaard.res.proth.-obt.klos-bestr.moul.etc	211	5438	1
Schedel - plast.van defect met bottranspl.znd.duratranspl	212	4896	18
Schedel - plast.van defect met alloplast.met duratranspl.	221	7324	1
Discusvervangende cage	226	4189	1
Schedel - reconstructie schedeldak	226	3762	2
Hersenen - fenestratie cyste - extracraniele shunt	245	3102	1
Intracr.vat-vw.a-v-malf.-opp.cerebr.-cerebell.-sm-gr.1-2	255	4618	1
Hersenen - navigatiegel.of stereotact.plaatsing devices	273	4484	5
Hersenen - biopsie mbv incisie	274	3414	3
Schedel - atlanto-occipitale decomp.incl.duraplastiek	305	5991	12
Schedel - autoloog bot - terugplaatsen botlap-plast.	417	5810	1
Hersenen - excisie tumor middelste schedelgroeve	499	5297	1
Hersenzenuw - nervus vagus stimulator	635	4142	1
Hersenen - op.beh.extr.ax.aand.supratent.znd falx of sin.	692	6961	3

Table B.15: Neurological surgery group 4 (LoS > 7392)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Hersenen - liquordrain.dmv interne liquordrain cranieel	151	7450	42
Hersenen - fenestratie cyste zonder shunt - ventrikel	169	8286	3
-re-spondylodese 5 of meer segmenten	619	8424	3
Ruggenmerg - operatie tethered spinal cord syndroom	365	8703	41
Schedel - plast.van defect met bottranspl.met duratranspl	198	8738	3
Ruggenmerg - verwijderen aandoening intramedullair	403	9218	2
Hersenen - excisie tumor achterste schedelgroeve	564	9279	2
Laminectomie - 1 niveau –uitgez.hnp of sten.zie 030327–	415	9829	1
Hersenen - op.beh.intraparenchymale aand.supratent.diep	508	10548	13
Schedel - op.beh.tum.schedelbas.front.sphen.hypof.orbita	600	10981	4
Schedel - plast.van defect met alloplast.znd.duratranspl.	149	11200	1
Hersenen - op.beh.intraparenchymale aand.infratent.diep	573	11654	20
Hersenen - inbrengen liquorreservoir cranieel	104	12422	8
Hersenen - endoscop.op.beh.aand.intra- en paraventricul.	184	13435	1
Hersenen - op.beh.intraparenchym.aand.supratent.oppervl.	381	13687	3
Ruggenmerg - biopsie mbv incisie	156	14055	1
-re-spondylodese 5-meer segm.incl. fix. occiput of bekken	485	14142	3
Liquorshunt - distale drain	104	14418	4
Hersenen - op.beh.extra-axiale tumor infratent.-brughoek-	506	15648	6
Laminectomie - 2-meer niveaus bij hnp of stenose	415	15905	1
Ruggenmerg - herstel meningokele niet gespecificeerd	151	16885	3
Ruggenmerg - verwijderen aandoening extramedullair	626	17631	1
Wervelkolom - biopsie bot incl. percutane botboring	335	20915	1
Ruggenmerg - spina bifida - plastiek n.n.o.	181	22369	4
Ruggenmerg - lumbale externe drainage	40	23435	2
Liquorshunt - externe - ventrikeldrain of lumbale drain	107	31794	1
Hersenen - navigatie- of echogeleide punctie hersenabces	100	32197	2
Hersenen - aanleggen extern ventrikel drainage systeem	171	32884	4
Schedel - boorgat –oa voor drain.epid.en of subd.ruimte-	150	33502	2
Vaten - inbrengen centrale veneuze lijn	182	39614	1
Orbita - exploratie dmv craniotomie	296	42444	1
atlanto-occipitale decompr., incl. duraplastiek	478	116324	1

B.7 Neurology (NEU)

Table B.16: Neurology

Procedure (in Dutch)	**Mean surgery duration**	**Median LoS**	**freq.**
Spier-pees - biopsie spier-pees-fascie	26	236	14
Injectie - botulinetoxine	34	284	14
Huid - biopsie	36	290	10
Ruggenmerg - diagnostische lumbaalpunctie	42	384	26
Perif.vaten - verwijderen port-a-cath	64	349	1
Oor - paracentese mbv buisjes oa.fowler - links	89	448	1
Larynx - direct diagn.laryngoscopie - incl.proefexc.	104	309	1
Laminectomie - 1 niveau bij hnp of stenose	168	330	1

B.8 Ophthalmology (OOG)

Table B.17: Ophthalmology group 1 (surgery duration ≤ 71)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Glas.lichaam- intravitreale injectie van medicatie	25	349	1
Traanapp. - herstel traanpunt	27	270	1
Corp.ciliare- diodelaser	33	384	3
Traanapp. - traanwegsondage - enkelzijdig	34	292	44
Oogkamer - punctie v.o.k. - n.n.o.	34	240	1
Cornea - verwijderen corpus alienum	34	302	2
Oogspieren - m.obliquus superior - tenotom.post. - enkz.	37	259	1
Ooglid - verwijderen aandoening ooglid znd reconstr.	38	191	1
Ooglid - extirpatie granuloom	40	432	2
Echografie - van het oog	41	157	1
Orbita - orbitotomie drainage abces	43	266	1
Traanapp. - traanklier verwijderen geheel of gedeeltel.	44	311	1
Oor - paracentese mbv buisjes oa.fowler - rechts	45	331	1
Ooglid - excisie-destructie van afwijk.oa.cryocoag.	47	376	4
Conjunctiva - tumoren verwijderen zonder plastiek	50	336	7
Conjunctiva - excisie-destructie afwijking	50	437	1
Oogbol - cryocoag. intraoculaire aandoening	50	526	1
Ooglid - verwijd. een of meer chalazia per zitting	51	278	6
Oogspieren - injectie met botuline	56	396	5
Ooglens - cataractextract.mbv faco-emuls.met vouwlens	57	351	3
Traanapp. - dacryocystorinostomie - intranasaal	58	527	1
Ooglens - nastaardiscissie - afschuiven - operatief	60	358	2
Cornea - kweek afnemen	60	501	1
Ooglid - excisie tumor	62	290	10
Orbita - orbitotomie - anterieur	66	459	3
Oogkamer - goniotomie	67	432	1
Iris - iridoplastiek of coreoplastiek - open	69	290	1
Strabismus 3	69	244	1

Table B.18: Ophthalmology group 2 (surgery duration > 71)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Cornea - edta spoeling met abrasie	73	419	1
Conjunctiva - extirpatie pterygium spec.conjunctivaplast.	77	488	1
Strabismus 2	78	492	4
Ooglid - blefaroplastiek - boven	79	1566	1
Ooglens - cataractop.extracaps.inbr.kunstlens-n.stand	80	348	20
Iris - iridotomie of iridectomie	81	1465	1
Ooglid - excisie biopsie	82	357	1
Ooglid - lidspleetverkleining - tarsorafie	82	345	3
Oogspieren - scheelzienoperatie schuine oogspieren	86	473	20
Glas.lichaam- voorsegment vitrect.voor strengen-nastaar	89	430	1
Reguliere operatie van scheelzien	89	460	28
Strabismus 1	92	556	2
Glas.lichaam- vitrectomie anterior	94	413	7
Oogbol - glaucoomoperaties	95	565	1
Oogspieren - scheelzienoperatie paralytisch	96	442	56
Oogspieren - vierspierenoperatie	100	439	60
Glas.lichaam- verwijderen siliconenolie	100	360	5
Cataract (Wolfs)	100	468	4
Ooglens - implanteren kunststoflens bij afaak oog	102	513	1
Ooglens - gesl.lensspoel.uitknip.acht.kapsel-cv membr	105	373	3
Ooglens - cataractoper. - implant.lens - vitrect.aok	106	1504	6
Oog - biometrie oogbol	109	356	1
Oogkamer - filtrerende oper.met drainage-implant v.o.k	112	438	2
Glas.lichaam- voorsegment vitrectomie	113	1057	4
Ooglens - extracapsulaire lensextractie - alle vormen	119	436	2
Ooglens - cataractoper.mbv faco-emuls.znd kunstlens	124	530	6
Glas.lichaam- pars plana vitrectomie bij ablatio retinae	126	507	1
Vitrectomie uitgebreid met eventueel cerclageband	137	501	1
Glas.lichaam- pars plana vitrect.-inbr.gas-endocoag.	157	541	1

B.9 Orthopaedic surgery - spinal (ORT)

Table B.19: Orthopaedic surgery - spinal

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Wervelkolom - verwijd.osteosynthesemateriaal - thoracaal	98	1539	1
Wervelkolom - verwijd.osteosynthesemateriaal -wervels nno	164	3879	5
Revisie spondylodese bij MMC & sluiten defect rug (PLC)	327	12380	1
-re-spondylodese 5 of meer segmenten	449	9539	241
-re-spondylodese 5-meer segm.incl. fix. occiput of bekken	478	11000	39
Wervelkolom - spondylodese thor.circumferent 2-3 segment	594	14575	1
Wervelkolom - spondylodese lumbaal anterior 2-3 segment	743	9684	1

B.10 Orthopaedic surgery - others (ORT)

Table B.20: Orthopaedic surgery - Others group 1 (LoS ≤ 2636 and surgery duration ≤ 108)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Gewricht - injectie intra-articulair - bov.extremiteit	14	414	1
Heup - injectie intra-articulair	19	261	3
Gewricht - injectie intra-articulair - ond.extremiteit	24	267	11
Knie - injectie intra-articulair	26	235	5
Pols - injectie intra-articulair	29	235	7
Gewricht - injectie intra-articulair	29	275	7
Huid - nagelextractie bij vinger of teen	35	167	1
Spier-pees - operatieve a1-pulley release	36	224	3
Radius - onbloed.repositie-aanleggen gips-proximaal	38	169	1
Voet - nagelbed-exc.grote teen -part.-met phenol	38	471	1
Femur dist. - onbloedige repositie-aanleggen gips	41	480	1
Heup - verwijderen heuppen	43	360	1
Tibia - verwijderen centrale mergpen	43	303	1
Enkel-voet - biopsie bot incl. percutane botboring	43	366	1
Elleboog - gesloten mobilisatie onder anesthesie	43	273	1
Onderbeen - fasciotomie	45	477	1
Ond.extr.-wondrandexc.of beh.wond gr.5cm znd wondrandexc.	45	2498	4

Enkel-voet - incisie-doorsnijd.spier-pees-fascie-bursa	46	360	2
Echo heup - m-z bovenbeen	48	822	2
Knie-o.been - overige incisie-doorsn. spier-pees-fasc.bur	48	297	1
Humerus - verwijderen osteosynthesemateriaal schacht	49	219	1
Bot - verwijd.osteosynthesemateriaal - overige	50	340	5
Voet - partiele excisie nagelbed - iedere volgende	52	411	1
Bot - verwijderen k-draden	52	344	12
Heup-b.been - biopsie bot incl. percutane botboring	53	373	1
Enkel-voet - tenotomie	54	335	4
Enkel-voet - verwijderen prothese	56	362	1
Pols - tenol. bij tendovagin.stenosans polsspier	56	262	2
Onderarm - verwijderen platen en schroeven radius-ulna	56	414	2
Humerus - verwijderen platen en schroeven	56	500	1
Voet - resectie artroplastiek dip-gewr.niet gesp.	57	400	1
Bovenbeen - verwijd. platen en schroeven femur - patella	57	350	1
Gesloten repositie DDH luxatie met adductorentenotomie	59	343	1
Femur - verwijderen centrale mergpen	60	367	5
Onderbeen - aanleggen circulair gips - voll.behandeling	60	216	2
Voet - verwijderen exostose voeten en tenen	60	382	4
Femur dist. - verw.osteosynthesemateriaal - rechts	61	535	1
Bot - verwijd.exostosen kleine beend.- voor de 1e	62	400	2
Schouder-arm- incisie-doorsn.spier-pees-fascie-bursa	63	420	2
Voet - resectie artroplastiek pipgewr.niet gesp.	64	458	1
Bot - verwijd.exostosen kleine beend.- elke volg.	64	449	1
Radius - k-draadfix.dist.na gesloten repositie	65	487	1
Radius - k - draadfix. wegens radiuskopfractuur	66	447	1
Voet - oper.hamerteen elke volgende onafh.1 of 2 v	66	362	1
Voet - oper.hamerteen - incl.dig.superduct.-dig.v	66	416	7
Voet - artrodese interfalangeaal gewricht voet	67	457	1
Bot - verwijd.centr.mergpen-cerclage uit een bot	68	348	2
Heup - oper.beh. verouderde congen.luxatie -enkelz	68	525	2
Hand-pols - excisie ganglion	68	505	2
Hand-pols - transpositie extensorpees	68	327	1
Hoofd-hals - torticollis operatie	68	381	5
Bot - verwijderen cerclage	69	292	1
Femur prox. - oper.beh.osteochondritis dissecans kop	69	379	2

Onderbeen - operatieve behandeling pseudo-artrose	70	360	1
Voet - excisie ganglion	71	360	2
Femur - oper.beh. epifysiolyse prox.-dist.femureind	72	1158	2
Spier-pees - biopsie spier-pees-fascie	73	527	1
Enkel-voet - transpositie van spier en pees	73	478	1
Bot - verwijd.plaat-schroeven elk volg.bot-1 zitt	75	544	1
Heup - gesloten repositie luxatie	76	448	8
Bot - verwijderen centrale mergpen	76	446	16
Bot - biopsie	77	455	3
Femur dist. - verwijd.osteosynthesemateriaal	77	366	1
Huid - verwijderen lipoom	77	334	1
Hand - exploratie extensorpezen duim	78	765	1
Knie - verwijderen corpus liberum gewricht- enkelz	78	317	1
Voet - artrodese talonaviculair	78	532	1
Heup-b.been - excisie afwijkingen weke delen overige	78	604	1
Bot - verwijderen 1 of meer schroeven uit een bot	79	447	22
Onderarm - epifysiodese distaal	79	427	1
Femur prox. - schroefosteosynthese - hals	79	264	1
Enkel-voet - partiele synoviectomie	80	359	1
Onderbeen - splittranspositie m.tibialis anterior	81	773	1
Bot - verwijderen osteosynthesemateriaal	82	438	36
Heup - repos.in anesth-heupgips cong.ontwricht.ez	82	433	75
Bovenbeen - revisie amputatiestomp	82	353	1
Enkel-voet - krappe excisie tumor weke delen	82	305	1
Knie - artroscopie - therapeutisch	82	555	1
Bot - verwijderen externe fixateur	83	566	12
Voet - excisie extra teen	83	1124	2
Femurschacht- verwijderen osteosynthesemateriaal	83	517	5
Bot - verwijderen krammen na epifysiodectomie	83	517	1
Bot - verwijderen cerclage of k-draad uit een bot	84	360	3
Heup-b.been - splijten overige spieren-pezen-fasc.	84	401	1
Hand-pols - krappe excisie tumor weke delen	84	441	1
Enkel-voet - ruime excisie tumor weke delen	85	341	1
Huidplastiek- correctie syndactylie	85	405	1
Hand-pols - excisie benigne tumor bot	86	359	4
Onderarm - epifysiodese wegnemen groeischijf	87	293	3

Radius - operatieve behandeling schachtfractuur	87	746	1
Tibia - open repositie-fixatie epifysiolysis-prox.	87	268	1
Voet - extirpatie os tibiale externum of sesambeen	88	484	8
Voet - excisie straal voet	88	392	3
Hand - operatie wegens mallet-finger	90	316	1
Femur - epifysiodese wegnemen groeischijf	90	471	69
Knie - artrosc.comb.met heelk.ingreep zelfde zitt.	90	634	1
Hand-pols - krappe excisie tumor bot	90	299	1
Bot - verwijderen plaat en schroeven uit 1 bot	90	448	62
Enkel - artroscopie	90	1805	1
Knie-o.been - excisie overige afwijkingen bot	91	534	1
Bot - verwijderen platen en schroeven	91	441	92
Knie - extirpatie laterale meniscus - totaal-part	91	548	2
Knie - synoviectomie via artroscopie	92	494	6
Bot - verwijd.exostosen middelgrote beenderen	92	429	6
Knie - exc.ov.pathol.afwijkingen via artroscopie	92	338	6
Voet - osteotomie van metatarsale of decapitatie	93	621	3
Voet - operatieve behandeling fractuur grote teen	93	422	1
Onderbeen - verbeteren amputatiestomp	93	416	5
Onderbeen - epifysiodese wegnemen groeischijf	95	432	41
Onderarm - oper.beh.geisol.breuk radius -schacht-ulna	95	389	1
Knie-o.been - krappe excisie tumor bot	95	824	1
Elleboog - artrolyse	96	584	2
Perif.zenuw - transpositie - nervus ulnaris	97	731	1
Wervelkolom - extirpatie van het os coccygis	97	527	2
Enkel-voet - excisie botstuk - partieel	98	390	2
Rectum - rectum - anus dilatatie	99	1814	1
Femur prox. - verwijderen osteosynthesemateriaal	99	486	89
Knie - extirpatie mediale meniscus - totaal-part.	100	1609	1
Onderbeen - verlenging achillespees-losmaken soleus	100	490	18
Bot - verwijderen exostosen grote beenderen	101	434	34
Knie - part.lat.meniscectomie via artroscopie	102	414	15
Hand - osteotomie vinger	102	379	1
Tibia - roterende osteotomie - distaal	105	531	1
Knie -artroscopie knie	106	2448	4
Anesthesie - bij onderzoek	107	334	10

Knie - part.med.meniscectomie via artroscopie	108	423	6
Knie - verwijderen corpus liberum artroscopisch	108	454	3
Enkel - nettoyage via artroscopie	108	412	1

Table B.21: Orthopaedic surgery - Others group 2 (LoS ≤ 2636 and 108 < surgery duration ≤ 154)

Procedure (in Dutch)	**Mean surgery duration**	**Median LoS**	**freq.**
nderarm - operatieve behandeling fractura monteggia	109	1499	1
Knie - excisie gewrichtskraakbeen	110	690	1
Onderbeen - percutane tenotomie achillespees	110	505	26
Enkel-voet - plastiek bot met metalen fixatie	110	1503	1
Enkel-voet - splijten banden-kapsel-ligament-tomie	111	1510	1
Tibia - correct.malunion-osteot.-osteosynth- rechts	112	1116	2
Knie - oper.behandeling osteochondritis dissecans	113	1582	2
Knie - op.beh.osteochondr.dissec.via artroscopie	114	549	3
Bovenbeen - verlenging hamstrings - mediaal	114	628	3
Radius - osteotomie radius distaal	115	509	1
Onderbeen - myotenotomie m.tibialis posterior	115	342	1
Heup - artrografie	116	429	27
Elleboog - repositie oude radiuskop lux. en peesplast.	117	703	1
Tibia - epifysiod.met op.mod.groeisch.dmv impl.	117	513	21
Knie-o.been - krappe excisie afwijkingen bot	117	1610	1
Enkel-voet - transplantatie-transpositie spier-pees	118	514	13
Knie - oper.beh. patellaluxatie	119	1455	1
Voet - operatieve behandeling naviculare fractuur	119	470	1
Femur prox. - op.beh.epifysiolysis caput femoris	120	1034	2
Femur - epifysiodese dmv krammen	120	610	11
Humerus - oper.behand.schachtfractuur - osteosynthese	121	1811	1
Schroeffixatie triplane fractuur (distale tibia) rechts	121	583	1
Injectie - botulinetoxine	122	145	3
Elleboog - operatieve behand. verse luxatie	122	392	2
Voet - continuiteitsresectie met autotransplantaat	122	439	1
Knie - patella stabilisatie - links	123	1809	4
Onderarm - gesl.repos.ulna-radiusschacht - mergpenfix.	124	1132	2
Voet - osteotomie calcaneus	124	490	8

Voet - excisie voetwortel bar voeten en tenen	124	341	1
Enkel-voet - dwyer calcaneus osteotomie	125	1762	2
Voet - correctie osteotomie metatars.1-proximaal	125	1617	1
Femur prox. - open repos.epifysiolyse met interne fixatie	126	422	1
Voet - oper.behandeling platvoet beperkt	127	453	3
Voet - continuit.resec.voetwortelbeen.-znd impl.	127	484	12
Femur - epifysiod.met op.mod.groeisch.dmv impl.	127	672	38
Onderbeen - opheffen epifysiodese - oa langenskiold	127	535	2
Knie - hechten mediale meniscus dmv artroscopie	128	971	2
Humerus - open repositie epifysiolysis distaal	129	499	1
Bot - excochl.en-of sekwestrotom.-middelgr.beend.	130	802	1
Knie - hechten meniscus dmv artroscopie	131	1094	6
Knie - nettoyage via artroscopie	131	646	7
Onderbeen - intramedull.fix.na gesl.repos.crurisfract.	132	540	1
Perif.zenuw - neurolyse - meer gecompliceerd	132	1094	2
Voet - oper.behandeling platvoet	132	1150	6
Clavicula - plaatosteosynthese	134	1044	2
Schouder - capsuloplastiek sternoclaviculair	134	710	2
Voet - plantaire release teen steindler	135	633	3
Humerus - oper.behand.pseudo-artrose met beentranspl.	136	459	1
Tibia - roterende-deroterende osteotomie	137	1713	5
Knie-o.been - transpositie m.tibialis posterior	137	1917	1
Onderbeen - gastrocnemiusplastiek	138	1652	4
Spier-pees - transpositie van 1 pees -verzetten insertie	138	1496	2
Enkel - plastiek ligament-chron.luxatie-artrotomie	138	390	1
Voet - oper.behandeling weke delen ivm klompvoet	138	1212	2
Voet - artrodese tarsometatarsaal 1–tmt1–	138	940	2
Voet - hallux valgus correctie osteotomie	138	482	8
Enkel - schroefosteosynth.bimalleol.na open repos.	140	636	2
Bot - contin.res.met autotranspl.- middelgr.beend	141	439	1
Onderarm - repos.radiuskopje met osteotomie ulna	141	1349	3
Voet - osteotomie os tarsale	142	507	2
Humerus - osteotomie met osteosynthese	142	447	2
Tibia - eminentia-fractuur proximaal	142	454	1
Bot - epifysiod.met op.mod.groeisch.dmv impl.	142	560	9
Enkel-voet - metatarsale osteotomie - links	143	639	1

Onderarm - ruime excisie afwijking bot radius-ulna	144	2272	2
Onderarm - excisie-excochleatie patholog.afwijking bot	144	692	1
Knie - verlengingsplastiek kniebuigers	145	1439	1
Pols - plastiek triangular fibrocartilage complex	145	450	1
Knie-o.been - transpositie m.tibialis anterior	146	1084	10
Knie-b.been - plastiek m.quadriceps	148	1696	2
Onderbeen - peestranspositie	149	542	21
Onderarm - extirpatie capitulum radii	149	525	1
Voet - correctie osteotomie voetbeenderen	150	1706	1
Voet - continuiteitresec. middenvoetsbeen-znd impl	151	448	1
arthroscopie knie	154	460	1
Voet - amputatie of exarticulatie teen	154	2468	2
Huid - littekencorrectie	154	471	3

Table B.22: Orthopaedic surgery - Others group 3 (LoS ≤ 2636 and surgery duration > 154)

Procedure (in Dutch)	**Mean surgery duration**	**Median LoS**	**freq.**
Onderbeen - oper.beh.verb.stand-osteotom.met osteosynth	155	1631	5
Onderbeen - open z-vormige verlenging achillespees	155	635	6
Onderbeen - schroefosteosynthese na open repos. cruris	156	1720	1
Enkel - oper.beh. malleolusfractuur - mediaal	160	974	2
Onderarm - krappe excisie tumor bot onderarm-elleboog	160	463	2
Voet - oper.beh.weke dln en osteotom.ivm klompvoet	160	1712	1
Knie-o.been - transplantatie van spier en pees	161	1238	2
Enkel-voet - transpositie pees voet	162	1084	4
Elleboog - artrosc.comb.met heelk.ingreep zelfde zitt.	162	466	2
Tibia - oper.behandeling eminentia-fractuur	164	1653	5
Bovenbeen - variserende osteotomie	165	2362	2
Onderbeen - overige osteotomieen tibia-fibula	165	1525	1
Onderarm - osteotomie radius en-of ulna	165	1584	18
Clavicula - oper.behandeling pseudo-artrose	166	473	1
Heup-b.been - adductoren-tenotomie - open	169	1508	36
Humerus - osteosynthese	169	637	1
Onderarm - ruime exc.tum.bot-radius-ulna	175	483	1
Voet - artrodese mtp-gewricht	176	1064	2

Blaas - botuline injectie	179	638	1
Knie - herstel mediale en collaterale banden	180	1612	2
Elleboog - artroscopie	180	428	1
Elleboog - plastiek ligamenten	185	1661	1
Knie - plast.voorste kruisband-scopie- autotranspl	188	1206	2
Voet - artrodese hallux	188	588	1
Tibia - correct.malunion-osteot.-osteosynth- links	190	1682	1
Voet - oper.behandeling platvoet uitgebreid	194	1780	28
Tibia - variserende osteotomie met osteosynthese	194	1086	2
Voet - oper.behandeling klompvoet	197	1555	12
Knie - plast.achterste kruisband-scopie-autotransp	197	1723	2
Enkel-voet - subtalaire artrorisis	198	1465	2
Knie - voor eo achter kruisbandplast.met transpl.	203	1615	13
Voet - minder samengest.oper.wgs holvoet-platvoet	208	688	1
Knie - artrotomie	213	2083	1
Heup-b.been - krappe excisie tumor weke delen	215	1354	1
Voet - artrodese subtalair	217	1644	1
Onderarm - osteosynthese ulna en radius	237	1533	1
Knie-o.been - radicale excisie afwijkingen bot	238	1771	1
Fibula - osteotomie	241	1542	1
Bovenbeen - operatieve verkorting	244	2520	2
Schouder-arm- ruime excisie tumor acrom.clav.humerus	247	1632	1
Knie - re-insertie voorste kruisband	262	1302	1
Huid - biopsie	267	1678	1

Table B.23: Orthopaedic surgery - Others group 4 (LoS > 2636)

Procedure (in Dutch)	**Mean surgery duration**	**Median LoS**	**freq.**
Femurschacht- intramedullaire fix.na open repositie	144	2681	1
Perif.zenuw - neurolyse - eenvoudig	124	2819	1
Humerus - oper.behandeling pseudo-artrose	249	2970	1
Voet - triple artrodese	244	2990	13
Knie - patellapees transpositie	190	3060	2
Femur - correctie malunion -osteotomie-osteosynth.-	245	3114	5
Bovenbeen - valgiserende osteotomie	216	3124	6

Osteosynthesemateriaal wervelkolom	143	3126	1
Knie - oper.behandeling habituele patellaluxatie	166	3159	3
Heup - gipsbroek	198	3215	43
Heup-b.been - osteotomie chiari - salter	192	3217	53
Bekken - variserende pandakosteotomie vlgs pemberton	179	3218	40
Heup-b.been - release hamstrings	290	3226	2
Heup - bloedige repositie cong.heupluxatie enkelz.	224	3282	30
Tibia - valgiserende osteotomie - distaal	220	3347	1
Knie - transpositie tuberositas tibiae	252	3383	4
Bovenbeen - valgis.c.q.variserende en-of derot.osteotom	218	3435	45
Voet - oper.behandeling holvoet uitgebreid	259	3444	1
Bot - transplantatie kraakbeen	146	3453	1
Heup - open repositie luxatie	241	3467	5
Femur - osteotomie subtrochantair volgens schanz	206	3540	5
Femurschacht- supracond.osteotom.met osteosynth.	218	3941	2
Femur - multiple osteotomieen	276	4065	2
Tibia - valgiserende osteotomie met osteosynthese	224	4112	2
Huid - klinische wondexcisie en wondtoilet	96	4414	1
Patella - operatieve behandeling fractuur	197	4503	1
Heup - verwijdering total hip vlgs girdlestone	156	4577	1
Knie-o.been - splijten spier-pees-fascie-bursa	201	4578	1
Heup-b.been - oper.beh.verbetering stand heup dmv osteot.	340	4609	1
Bovenbeen - operatieve verlenging of verkorting-bovenb.	225	4612	4
Voet - resect.metatars.capitula - inkort.metatars.	249	4659	1
Heup - pandakplastiek	218	4675	1
Onderbeen - verlengen bot mbv externe fixateur	212	4676	4
Voet - artroplastiek voor hallux rigidus znd proth	240	4728	2
Tibia - continuit.resectie plus autotransplantaat	420	4728	1
Bovenbeen - variserende deroterende osteotomie	245	4758	8
Femur - operatieve behandeling pseudo-artrose	187	4764	1
Huid - oper.verw.gezwell.uitg.diepere structuren	295	4770	1
Open repositie en Salter bekkenosteotomie links, evt femur	314	4792	1
Bovenbeen - valgiserende deroterende osteotomie	293	4930	2
Bot - uitname autoloog bottransplantaat	238	4980	1
Heup - bloedige repositie congenitale heupluxatie	301	5158	5
Femur - overige osteotomie	255	5366	8

Humerus - verlengen	186	5800	1
Femur prox. - operatie pseudo-artrose fractuur collum	225	5990	1
Voet - exarticulatie van de voet	206	5992	2
Onderbeen - amputatie	244	6060	3
Onderbeen - exarticulatie knie	199	6122	3
Heup-b.been - adductoren-tenotomie open met neurectomie	360	6292	1
Buik - hernia inguinalis - enkelzijdig - open	320	6320	1
Bovenbeen - operatieve verlenging	256	6351	1
Bovenbeen - intertroch.versch.osteotomie m.osteosynth.	222	6905	2
Bovenbeen - onbloedige repositie-aanleggen gips- links	57	7099	1
Wondrandexc.of behand.wond groter 5cm zonder wondrandexc.	28	7265	1
Femurschacht- operatieve beh. fractuur	112	7332	1
Tibia - osteosynthese proximale plateaufractuur	126	7425	1
Tibia - corr.osteotomie-spongiosaplastiek-plaat	295	7584	1
Bekken - winnen bot uit crista voor autotransplant.	522	9042	9
Huid - wondexcisie en wondtoilet	73	11367	1
Bekken - artrodese sacro-iliacaal gewricht	552	11400	1
Bekken - behandeling osteomyelitis	180	12016	1
Onderbeen - behandeling osteomyelitis - gentakralen	218	12050	1
Bovenbeen - onbloedige repositie-aanleggen gips- rechts	39	12176	1
Heup-b.been - behandeling osteomyelitis - links	97	12913	1
Femur - continuiteitresectie.-znd implant	255	13025	1
Rug -wondrandexc.of beh.wond gr.dan 5cm znd wondrandexc.	178	14907	1
Bovenbeen - oper.behandeling fractuur subtrochantair	50	15083	1
Voet - osteosynthese calcaneus	319	20979	1
Femurschacht- supracond.verlenging met externe fixateur	362	24898	1
Bekken - osteosynthese	340	26943	1
Bronchus - flexibele bronchoscopie nno	520	53333	1

B.11 Otorhinolaryngology (KNO)

Table B.24: Otorhinolaryngology group 1 (LoS ≤ 1516 and surgery duration ≤ 54)

Procedure (in Dutch)	**Mean surgery duration**	**Median LoS**	**freq.**
Oor - paracentese - rechts	16	236	1
Trommelvliesbuisjes SKZ	19	217	1
Tong - klieven frenulum linguae	25	195	10
Oor - verwijderen corpus alienum oor uitwendig	27	235	13
Neus - antroscopie dmv optiek-evt.proefexc.-evt.nasendosc	28	341	2
Neus - scleroseren bloedvaten	28	308	9
Luchtwegscopie - diagnostisch SKZ	28	351	1
Speeks.klier- sialoendoscopie gl.parotis	29	289	1
Oor - paracentese - links	34	258	8
Oor - paracentese mbv buisjes oa.fowler - rechts	35	260	468
Oor - paracentese mbv buisjes oa.fowler - links	36	258	271
Neus - repositie en-of fixatie fractuur	38	268	6
Oor - microscopisch oortoilet - enkelzijdig	39	225	33
Injectie - botulinetoxine	40	309	10
Speeks.klier- exc.speekselsteen - sialoendoscopie-parotis	41	270	20
Neus - nasendoscopie dmv optiek evt. met proefexc.	43	299	3
Pharynx - adenotomie - zelfstandige ingreep	46	367	140
Bronchus - scopie by kind.jonger dan 1 jr - fiberscoop	48	276	1
Huid - wondexcisie en wondtoilet	50	374	2
(adeno) tonsillectomie met coblatie en scopie	51	1267	1
Speeks.klier- exc.speekselsteen - sialoendoscopie-submand	54	254	6
Palatum - excisie benigne tumor	42	252	1

Table B.25: Otorhinolaryngology group 2 (LoS ≤ 1516 and 54 < surgery duration ≤ 100)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Oor - plaats.koppelst.op impl.tbv hoortoest.-baha	57	404	10
Neus - nasendoscopie	58	585	11
Pharynx - tonsillect.mbv dissectie - vanaf 16 jaar	59	519	3
Pharynx - tonsillect.mbv dissectietechniek-tm 10 jaar	59	458	106
Pharynx - adenotonsillect.mbv dissectom. - tm 10 jaar	63	1354	268
Speeks.klier- biopsie glandula parotis - links	63	301	1
Bov.luchtw. - laryngotracheoscopie - diagnostisch	64	692	133
Larynx - directe therapeutische laryngoscopie	66	1335	15
Speeks.klier- totale excisie gl.sublingualis	67	314	7
Pharynx - tonsillect.mbv dissectietechn.-11 tm 15 jr	68	544	10
Neus - biopsie of uitstrijk mbv nasendoscopie	69	544	21
Pharynx - adenotonsillect.mbv dissectie-vanaf 16 jaar	69	443	1
Oor - plaats.implant.petrosum tbv hoortoest.-baha	71	380	26
Larynx - dir.diagn. scopie -op.microsc.- met biopsie	74	240	1
Larynx - indir.diagn. laryngoscopie - incl.proefexc.	76	1319	36
Verwijderen drain rechts	79	424	1
Larynx - directe ther. laryngoscopie - microscopisch	79	546	284
Lymf.syst. - excisie lymfeklier	79	402	1
ATE	82	591	1
Pharynx - adenotonsillect.mbv dissect.- 11 tm 15 jaar	84	981	8
Hoofd-hals - wondexcisie-wondtoilet	86	503	7
Oor - excisie preauriculaire cyste of fistel	88	424	28
Lymf.syst. - ther.verw.lymfekl.-o.kaak-cliv-m.stern-v.ju	91	387	1
Oor - attico-antrotomie middenoor	95	555	1
Speeks.klier- extirpatie gl.submandibularis	95	638	5

Table B.26: Otorhinolaryngology group 3 (LoS ≤ 1516 and 100 < surgery duration ≤ 148)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
BERA kind met narcose – Audiologisch centrum	102	362	10
Trachea - canule verwisselen	104	361	2
Speeks.klier- part.extirpatie opperv.deel gland.parotis	105	621	5
Oor - excisie aandoen. uitwend. gehoorgang excl.exostose	105	465	11
Oor - meatusplastiek concha	109	481	31
Neusbijholte - operatie sinus sphenoidalis - endonasaal	114	516	2
Lip - excisie - wigexcisie	118	308	1
Trachea - sluiten tracheostoma	122	1489	28
Huidplastiek- precisie van transpositielap hoofd en hals	124	313	1
Oor - myringoplastiek nno	127	474	38
Neusbijholte- infundibulotomie - enkelzijdig	127	588	15
Oor - exploratie cavum tympani en trommelvlies	128	487	87
Oor - geh.verb.oper.bij otoscler.dmv stapedolyse	131	1313	1
Hoofd-hals - ruime excisie huid-tumor-met oml.weefsel	138	1506	1
Neus - extirpatie mediane neuscyste - tumor	144	674	10
Oor - ketenreconstructie	144	492	61

Table B.27: Otorhinolaryngology group 4 (LoS ≤ 1516 and surgery duration > 148)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Bot - transplantatie kraakbeen oorschelp	149	571	1
Neusbijholte- endonasale ethmoidalis operatie	178	1040	12
Oor - verw.exostosen met lospreparen gehoorgang	198	677	3
Oor - exc.tumor middenoor eo binnenoor excl.brughoektumor	223	499	1
Oor - –pre–cochleaire implantaten - kinderen	265	1506	81
Oor - rotsbeen en mid.oor ingr.-tympanoplast. nno	298	1477	171

Table B.28: Otorhinolaryngology group 5 (LoS > 1516)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Patient stichting de bijter	136	1534	1
Oor - mastoidoper.met inbegrip alle complicaties	265	1536	32
Larynx - ther.laryngoscopie mbv microscoop en laser	117	1542	42
Tong - gedeeltelijke extirpatie	70	1544	2
Nasopharynx - opheffen choanaalatresie - bij kinderen	105	1563	13
Pharynx - extirpatie laterale halsfistel-cyste	154	1572	11
Hals - verwijd. mediane halscyste of halsfistel	108	1650	23
Oor - conservatief radicaal middenoor	296	1705	2
MOND - EXCISIE RANULA MONDBODEM	97	1725	3
Schildklier - excisie mediale halscyste	130	1908	1
Trachea - diagnostische tracheoscopie	32	2559	2
Mandibula - osteotomie-distractie enkelz. of frontged.	235	2779	1
Larynx - direct diagn.laryngoscopie - incl.proefexc.	95	3045	41
Kaak - oper.verw.osteosynth.mat.-distrac-kaakhelft	359	5690	1
Pharynx - drainage tonsil - peritonsillair abces	19	6928	1
Pharynx - herexploratie hoofd-hals - abces	232	7342	1
Schedel - reconstructie dak met craniaal deel orbita	264	8748	1
Pharynx - laryngofissuur met operatie vlg rethi	297	8892	16
Bronchus - bronchoscopie met lavage	92	8894	2
Mond - kleine verr.- bijv.uitgebr.oper.wondtoil.-proefexc	69	8900	1
Trachea - resectie - cervicaal	315	9610	6
Neus - behand.neusbloeding met bellocq-tamponade	31	11492	1
Mandibula distracte & Luchtwegscopie - diagn SKZ	161	14218	1
Schedel - subtotale petrosectomie	343	16603	2
Schedel - excisie tumor schedelbasis	241	20153	1
Trachea - tracheostomie - tijdelijk	126	64727	9

B.12 Paediatric cardiac surgery (CAS)

Table B.29: Paediatric cardiac surgery group 1 (surgery duration ≤ 96)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
EFO/ablatie op magneetkamer	4	1648	1
Hart - echocardiografie	30	407	1
Thorax - verwijderen reveal monitor loop rec. -subc.	35	383	12
Hart - behandeling met de cardioverter	40	1684	2
Hart - inwendinge hartritme monitor-ilr-reveal	46	1590	3
Thorax - implant. reveal monitor loop rec.-subcutaan	54	497	15
Thorax - re-fixatie van het sternum - n.n.o.	55	115303	1
Hoofd-hals - verwijd.ecmo-shunt a.car.comm.-v.jug.int.	60	48233	1
Hart - verwijderen van corpus alienum - myocard	60	30230	1
Pleura - zuigdrainage behandeling - pleuravocht	67	397	1
Hart - myocardbiopsie met re katheterisatie	78	569	10
Hart - biopsie myocard	82	663	139
Hart - vervangen pacemaker met 1 elektrode	95	1781	1

Table B.30: Paediatric cardiac surgery group 2 (96 < surgery duration ≤ 134)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Hart - kather.rechts - swan-ganz-kath.hartmin.vol.	104	1731	1
Hart - a.pulmonalis ballon valvulotomie	105	1920	5
Hart - duct.botalli sluiting mbv paraplu-katheter	110	1650	11
Hart - sluiten asd dmv paraplu-katheter	110	1674	19
Hart - inbrengen pacemaker met 1 elektrode	110	56064	2
Hart - echografie transoesofagaal	111	1572	25
Hart - plastiek van aortaklep mbv ballonkatheter	113	2858	1
Hart - kath.sluit.dilatat.cong.of verworv.hartvit.	114	1619	46
Hart - echocardiografie 3-dimensionaal	119	593	10
Hart - inbrengen aicd met 2 elektrodes	125	2978	5
Hart - duct.botalli sluiting mbv coils dmv endosc	126	1653	17
Aorta - katheterisatie aortaboog incl. zijtakken	130	3042	1

Table B.31: Paediatric cardiac surgery group 3 (surgery duration > 134)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Larynx - direct diagn.laryngoscopie - incl.proefexc.	135	1546	1
Hart - inbrengen pacemaker met 2 elektrodes	140	2303	2
Hart - katheterisatie rechts met angiocardiografie	149	1688	235
Hart - katheterisatie links met angiocardiografie	150	1692	90
A.pulmonalis- dotter-procedure pta-behandeling	151	6438	8
Hart - elektrofysiologisch onderzoek voll.behand.	154	1144	2
Hart - rashkind-procedure -septa	158	16533	1
Aorta - pta thoracale aorta met plaatsen stent	164	1616	8
Pta niet-coronaire centrale arterien excl.nierarterie	171	1559	1
Thorac.vaten- embolisatie fistels pulmonale vaten	175	1641	1
percutane interventie (sluiten venoveneuze en evt aorto-pulm	249	97845	1
Cardiovasculaire stent	368	1690	1

B.13 Paediatric pulmonary disease (LOS)

Table B.32: Paediatric pulmonary disease

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
infuus inbrengen onder narcose en bloedafname	21	212	1
Hemat.syst. - punctie beenmerg - o.a. sternum	57	329	1
Bronchus - bronchoscopie met lavage	60	404	260
Bronchus - flexibele bronchoscopie nno	62	1054	4
Arterie - centrale lijn inbrengen	70	9189	1
Bronchoscopie(flex.) diagnostisch met lavage & MDL	76	570	1
Bronchus - therapeutische bronchoscopie - nno	109	2752	28
Larynx - direct diagn.laryngoscopie - incl.proefexc.	391	280918	1

B.14 Paediatric surgery (KIC)

Table B.33: Paediatric surgery group 1 (LoS ≤ 9006 and surgery duration ≤ 59)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
dilatatie anus	11	436	1
Maag - maagsonde inbrengen mbv endoscopie	21	261	1
Huid - biopsie	29	210	1
Vulva - verwijderen condylomata acuminata	29	221	1
Huid - verwisselen verband onder anesthesie	30	3182	6
Injectie - botulinetoxine	30	262	27
Oor - excisie ooraanhangsel	31	300	1
excisie lymfeklier hals+diagnostische punctie schildklier IR	32	360	1
Scopie met oprekken Savary (Dr de Ridder kMDL)	33	346	1
exploratie navel	33	223	1
Voet - partiele nagelbedexcisie van de grote teen	34	360	4
Anus - excisie skintags	34	269	1
Huid - incisie abces	36	387	2
Spier-pees - biopsie spier-pees-fascie	37	431	1
Pijnbestrijd- diagnostische epidurale blokkade-cervicaal	37	226	1
Beandeling VVM b.been re met bleomycine onder narcose	38	309	1
Dikke darm - coloscopie tm halverwege colon transversum	38	565	1
Anus - incisie perianaal abces	40	321	7
Buik - verwijderen corpus alienum van buikwand	40	307	2
Lymf.syst. - biopsie lymfeklier hals	40	589	2
Rectum - rectum - anus dilatatie	41	254	40
Lymf.syst. - excisie lymfangioom - abdomen	41	170	1
Sigmoid - rectosigmoidoscopie met biopsie	43	254	14
Femur dist. - k-draadfixatie na gesloten repositie	43	527	1
Oesophagus - ph-meting	44	354	2
Huid - partiele nagelbedexcisie	44	480	2
Rectum - biopsie mbv incisie	45	165	1
Huid - nagelextractie vinger of teen onder anesth	45	357	13
Rectum - biopsie	46	251	3
Bov.luchtw. - laryngotracheoscopie - diagnostisch	46	328	1
Huid - wondexcisie en wondtoilet	46	5183	2

Rectum - biopsie - full thickness	47	314	45
Huid - matig gr. en-of gecompl.exc.maligne tumor	48	277	1
Oor - paracentese mbv buisjes oa.fowler - links	48	354	1
Huid - totale excisie van een nagelbed	49	469	2
Buik - littekenbreuk - electief met c.a.	49	329	1
Huid - excisie atheroomcyste	49	270	16
Perif.vaten - verwijderen port-a-cath	49	340	132
Spier-pees - biopsie	49	292	2
Anus - incisie fistula ani	50	347	24
Romp - littekenexcisie	50	322	4
Dikke darm - toucher onder anesthesie	50	325	59
Maag - gastrostomie - vervanging peg-sonde	50	278	17
Pharynx - adenotomie - zelfstandige ingreep	50	345	1
Lymf.syst. - biopsie lymfeklier	50	346	4
Huid - verwijderen naevus	51	274	13
beklemde liesbreuk	51	2224	1
Huid - verwijderen dermoid cyste	51	298	37
revisie litteken, draadfistel	52	363	1
Huid - diepte biopsie - true cut	52	363	3
Buik - hernia inguin.beklemd znd darmresect.-tomie	52	1433	1
Buik - spoelen buikholte	52	283	1
Maag - gastrotomie - verwijderen corpus alienum	52	228	3
Injectie - corticosteroiden	54	382	25
Huid - excisie kleine path.afw. - overige	54	280	32
Buik - navelbreuk - mayo-plastiek - 12 jr en ouder	54	284	1
Bot - verwijd.centr.mergpen-cerclage uit een bot	55	406	5
Rectum - rectoscopie	55	408	1
Anus - operatie recidief fistula ani	55	358	12
Verwijderen port-a-cath + Gyn	55	401	1
Penis - circumcisie	56	317	7
Rectum - rectoscopie therapeutisch	56	3598	4
Maag - perforatie overhechten	56	436	1
Huid - oper. verwijderen gezwel dmv slow MOHS chirurgie	57	329	1
Hand - partiele excisie 1 nagelbed	58	348	2
Huid - verwijderen fibroom	58	391	11
Buik - hernia epigastrica - acuut	58	379	12

Huid - biopsie van huid en subcutis mbv incisie	58	391	18
Perif.zenuw - neurolyse - eenvoudig	59	233	1
Buik - herstel hernia parumbilicalis zond.plast.	59	340	2
Hand - excisie extra vinger	59	298	1

Table B.34: Paediatric surgery group 2 (LoS ≤ 9006 and 59 < surgery duration ≤ 84)

Procedure (in Dutch)	**Mean surgery duration**	**Median LoS**	**freq.**
Mond - excisie overige afwijkingen	60	2530	2
Blaas - suprapubische katheter inbrengen	61	404	2
Lymf.syst. - excisie lymfeklier lies	61	568	1
Hoofd-hals - torticollis operatie	62	243	3
Mnl.gesl.org- hydrokele of spermatokele operatie	62	352	2
Oesophagus - biopsie mbv overige oesofagoscopie	62	388	14
Huid - littekencorrectie	62	366	17
Penis - phimosis-operatie - dorsal slit	62	352	2
Huid - excisie angiomata	63	1388	1
Spier-pees - blootleggen en doorsnijden pezen en spieren	63	333	1
Testis - orchidopexie via scrotale incisie - enkelz.	64	457	1
Pharynx - excisie laterale halscyste	65	328	25
Oesophagus - pneumodilatatie	65	406	111
Buik - navelbreuk - herstel zonder plastiek	65	399	3
Buik - hernia inguinalis electief dmv laparotomie	65	550	8
Huid - proefexc.al of niet coag.hyfrec.excl.pa-ond	66	477	1
Oesophagus - scopie mbv fiberscoop diagn.incl.proefexc.	66	416	24
Huid - klinische wondexcisie en wondtoilet	66	3741	18
Buik - hernia inguinalis - enkelzijdig - open	66	440	673
Anus - correctie slijmvlies ectropion	66	379	19
Buik - navelbreuk - mayo-plastiek - tot 12 jaar	67	388	36
Blaas - excisie urachusfistel	67	390	22
Buik - operatie recidief hernia inguinalis	68	381	19
Maag - gastroscopie -fiber- diagn. -incl.proefexc.	68	430	7
Maag - sluiten voedingsfistel van de maag	69	466	17
BUIK - HERNIA INGUINALIS HERNIORAFIE - DUBBELZ.	69	330	1
Vagina - excisie van septum longitudinaal	70	546	1
Oesophagus - dilatatie	70	532	10

Huid - extirpatie fistel	70	361	1
Huid - verwijderen lipoom	70	363	13
Anus - v-y-plastiek	71	425	1
Dunne darm - oesofagogastroduodenoscopie met biopsie	71	406	2
Huid - oper.grote en gecompl.gezwel.intra-subcut.	71	409	1
Huid - kl.en-of weinig gecompl.exc.maligne tumor	72	454	1
Oor - paracentese mbv buisjes oa.fowler - rechts	73	3074	1
Oor - excisie preauriculaire cyste of fistel	73	294	3
Huidplastiek- primaire oper.beh.ernstige verwondingen	73	243	1
Huid - operatie sinus pilonidalis -sacraal dermoid	73	440	16
Bronchus - bronchoscopie met lavage	74	412	2
Mnl.gesl.org- excisie hydrokele en hematokele	74	394	1
Lymf.syst. - excisie lymfeklier	74	396	32
Lymf.syst. - excisie lymfokele	74	273	1
Perif.vaten - inbr.centr.veneuze katheter -voed-drukmet.g	75	1841	1
Huidtranspl.- klein en of weinig gecompliceerd	76	547	1
Schildklier - excisie mediale halsfistel	76	319	1
Huid - oper.verwijderen gezwel.dmv moh-s chirurgie	77	221	1
Buik - oper.grote en gecompl.gezwel.intra-abdomin.	77	634	1
Huid - hechten wond primair	77	420	6
excisie dfsp linker onderbeen volgens breuninger	77	204	1
Mnl.gesl.org- hydrokele oper. met verzorging liesbreuk	79	431	13
Maag - gastrostomie –peg-sonde– dmv scopie	81	3068	6
Huid - oper.verw.gezwell.uitg.diepere structuren	81	398	11
Buik - hernia inguin. met plastiek - laparotom. enkelz	81	406	2
excisie weke delen zwelling sternum	83	475	1
Buik - exploratie lies	83	322	3
inspectie perineum onder narcose	83	301	1
Toegangschir- hickman-katheter - inbrengen	83	536	7

Table B.35: Paediatric surgery group 3 (LoS ≤ 9006 and 84 < surgery duration ≤ 163)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Lymf.syst. - sentinel node procedure oksel	86	395	1
Huid - oper.verwijdering kleine gezwellen	87	394	3
Vagina - colpotomie - incisie en drainage	88	426	1
Testis - orchidopexie via inguinale incisie - enkelz	88	413	65
Oesophagus - verwijderen corpus alienum	89	360	7
Bot - verwijderen platen en schroeven	91	422	1
Buik - herstel littekenbreuk dmv laparotomie	92	588	34
Thorax - inbrengen thoraxdrain	92	5804	1
Perif.vaten - inbrengen port-a-cath systeem	93	593	23
Schildklier - excisie mediale halscyste	94	458	37
Bot - verwijderen plaat en schroeven uit 1 bot	94	507	8
Maag - gastro-enterostomie opheffen dmv endoscopie	96	1926	1
Tuba uterina - salpingectomie dmv laparoscopie	96	1719	1
Bot - verwijderen osteosynthesemateriaal	96	1680	1
Buik - femoraalbreuk mac vayplast.-laparotom.-enkz	96	428	2
Vaten - inbrengen centrale veneuze lijn	98	1953	3
Toegangschir- c.v.d.-katheter perifeer bloedvat inbrengen	98	1760	22
split skin graft door PLHK	99	735	1
Huid - oper. grote en gecompl.gezwellen - klinisch	99	393	11
Pleura - pleurodese niet gespecificeerd	99	8512	1
psarp	100	534	1
Buik - adhesiolyse en biopsie dmv laparoscopie	101	1887	1
Blaas - cystoscopie	102	369	6
Darm - opheffen strengileus via laparoscopie	103	1916	1
Duodenum - inbrengen voedingssonde incl. duodenoscop.	104	4024	2
Peritoneum - inbrengen kath. tbv capd dmv laparoscopie	106	6061	5
Testis - fowler-stephens fase 1 - via laparoscopie	106	419	4
Liesbreuk overig bdz	107	583	1
Blaas - uretrocystoscopie nno	108	878	8
Mamma -ablatio mammae	108	1903	1
Ovarium - adnex-extirpatie dmv laparoscopie	109	1564	4
Buik - laparoscopie- biopsie	112	1240	4
Dunne darm - operatie meckel-divertikel	112	1645	1

Toegangschir- revisie cimino-shunt	112	533	3
Maag - gastrostomie via laparoscopie	118	3562	20
Vrw.gesl.org - adnexoperatie - ovariumtumor - eenzijdig	120	1605	7
Dikke darm - appendectomie via laparoscopie	123	1824	10
Dunne darm - resectie meckel-divertikel via laparoscopie	124	2027	4
Uterus - verwijderen uterushoorn dmv laparoscopie	126	1967	1
Maag - percutane gastrostomie - pull techniek	127	3036	3
Huidplastiek- matig grote en of gecompl.transpositie	127	1505	1
Dikke darm - aanleggen appendicostomie via laparoscopie	128	8571	3
Maag - resectie subtotaal nno dmv laparoscopie	129	8812	1
Uterus - verwijderen uterushoorn dmv laparotomie	130	4730	1
Buik - laparoscopie - diagnostisch n.n.o.	130	749	21
Jejunum - aanleggen voedingsfistel via laparoscopie	131	5843	1
Toegangschir- port-a-cath als c.v.d.-katheter	132	1742	4
Vagina - vaginoscopie -kind-	133	286	3
Thorax - proefthoracoscopie	136	566	17
Maag - gastrostomie - open	140	7328	5
Hoofd-hals - ruime excisie huid-tumor-met oml.weefsel	141	6012	1
Longen - wigexcisie enkelzijdig mbv vats	141	7185	3
Testis - fowler-stephens fase 2 - dmv laparoscopie	142	938	2
Mamma - probe-geleide lumpectomie	143	3147	1
littekenbreuk buik	143	1836	1
Bot - verwijderen k-draden	145	438	1
Galblaas - cholecystectomie via laparoscopie	145	1727	31
Longen - wigexcisie	146	4882	1
Schildklier - hemithyreoidectomie zonder sternotomie	150	1770	4
Wervelkolom - resectie sacrococcygeaal teratoom	150	5936	5
Peritoneum - klieven bandjes van ladd dmv laparoscopie	151	4784	2
Dikke darm - hemicolectomie via laparoscopie - rechts	151	5925	1
Uterus - tot. laparoscopische hysterectomie –tlh–	152	1870	1
Diafragma - oper.hern.diaphragmat.recidief - thoracaal	153	3275	1
Dikke darm - opheffen stoma	153	7414	21
Hemat.syst. - punctie beenmerg - o.a. sternum	154	3994	2
Thorax - correctie trechterborst	155	6102	53
Diafragma - herstel hernia via laparoscopie	158	3974	2
Larynx - directe therapeutische laryngoscopie	160	1459	3
Duodenum - resectie web wgs atresie	163	5939	1

Table B.36: Paediatric surgery group 4 (LoS ≤ 9006 and surgery duration > 163)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Peritoneum - verwijderen mesenteriaalcyste	164	1736	1
Mediastinum - operatie van tumoren	170	3103	1
Galblaas cholecystostomie via laparoscopie	172	4560	4
Nasopharynx - opheffen choanaalatresie - bij kinderen	172	2129	1
Buik - proeflaparotomie	175	6521	8
Dikke darm - resectie ileocaecaal via laparoscopie	178	8921	15
Rectum - posterieure sagitt.anorect.plastiek–psarp-	179	7386	37
Milt - splenectomie dmv laparoscopie	180	5922	22
Thorax - correctie kippenborst	183	4568	5
Bijschildkl.- parathyreoidectomie - totaal	191	1735	1
Rectum - resectie rectosigmoid - open	195	5969	1
Maag - fundoplicatie dmv laparoscopie	195	7377	9
Milt - resectie cyste dmv laparoscopie	200	4664	1
banding ciminoshunt	201	1950	1
Maag - fundoplastiek volgens nissen	207	7419	23
Dunne darm - jejunotomie-ileotomie	217	4496	1
Rectum - abdom.-anter.resectie met prim. anastomose	225	4668	1
Diafragma - para-oesofageale hernia diaphragmatica	226	7676	4
Larynx - indir.diagn. laryngoscopie - incl.proefexc.	235	5789	1
Rectum - resectie vlgs duhamel dmv laparoscopie	235	6081	5
Milt - splenectomie electief dmv laparotomie	238	6114	3
Rectum - post.sagitt.anorect.plastiek via laparosc.	270	8320	2
Spier-pees - oper.grote en gecompl.gezwel.intramusculair	282	6171	1
Longen - lobectomie enkelzijdig dmv thoracoscopie	422	7371	3

Table B.37: Paediatric surgery group 5 (LoS > 9006)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Buik - correctie omfalokele primair	185	9206	1
Schildklier - totale strumectomie	152	9580	2
Maag - gastrotomie via laparoscopie	126	10045	4
Rectum - resectie rectosigmoid via laparoscopie	259	10066	22
Longen - bullectomie via thoracoscoop	169	10140	2
Nier - verwijderen niertransplantaat - rechts	178	10201	1
Dikke darm - resect.part.niet gespec.zonder prim.anastom	238	10211	1
Longen - lobectomie - segmentresectie	289	10362	10
Hart - inbr.broviac atrium centr.ven.toedien.syst.	108	10632	31
Huidtranspl.- split-skin graft naar lokalisatie nno	107	10904	1
Darm - ileo-anale anastomose met pouch via lap.sc.	357	10910	4
Thorax - borstwandcorrectie	125	10997	2
Dikke darm - subtotale colectomie zonder prim.anastomose	340	11148	2
Oesophagus - resectie partieel met end-to-end-anastomose	350	11359	1
Dikke darm - subtotale colectomie via laparoscopie	270	11532	5
Dikke darm - operatie van appendiculair abces dmv endosc	124	11650	1
Dikke darm - resectie ileocaecaal	180	11683	5
Ileum - aanleggen ileostomie dmv laparoscopie	187	11702	5
lap pullthrough hirschsprung	199	11769	1
Diafragma - operatie wegens cong. hernia diaphragmatica	186	11794	7
Buik - relaparotomie - postoperatieve complicaties	232	11905	3
Peritoneum - intraperitoneaal kath.capd spoel verwijd.	65	12098	4
Rectum - anteriorres.rectosigm evt met tyd ap lapara	350	12388	2
Dikke darm - hemicolectomie met prim.anastomose - links	292	12590	4
Oesophagus - oesofagotracheale fistel sluiten	377	12987	1
Darm - entero-enterostomie - ileum-rectum	229	13011	1
extripatie doorgehaald colon via buik/perineum	250	13074	1
Rectum - abdominoperineale extirpatie omring.struct.	410	13529	1
Rectum - anteriorresect.rectosigm.evt.met tijd.a.p.	309	14479	4
Dikke darm - hemicolect.met prim.anast.dmv laparosc. -li	251	14586	1
Dunne darm - ileusoperatie - opheffen volvulus - streng	121	14727	1
Ileum - opheffen ileostomie dmv laparoscopie	140	15477	2
Thorax - proefthoracotomie	333	15963	2

Pleura - pleurodese met bullectomie	160	16938	2
Huid - wisselen vacuum assisted closure syst.-pomp	43	17166	5
Urethra - reconstructie	538	17227	1
Ileum - opheffen stoma	184	17407	70
Darm - ileorectale anastomose dmv laparoscopie	166	18122	2
Peritoneum - adhesiolyse dmv laparotomie	202	18824	6
Perif.vaten - reconstructie arterie zonder transplantaat	79	19435	1
Thorax - empyema thoracis behandeling	300	19953	1
Dikke darm - eindstandig colostoma met slijmfistel	136	20385	1
Ureter - reconstructie bij niertransplantatie	254	21100	2
cystovaginaoscopie en vaginaplastiek	133	21673	1
Nier - transplantatie levende-donor-nier - links	258	21975	5
Nier - transplantatie levende-donor-nier - rechts	280	23968	18
Dikke darm - resectie sigmoid zonder primaire anastomose	297	26424	2
Huid - verwijderen corpus alienum	37	27275	1
Dunne darm - resectie	157	28663	5
Dunne darm - duodenoduodenostomie	148	30266	2
Dikke darm - proctocolect.-ileum-pouch-anale-anast.scopi	412	31985	2
Dikke darm - anus praeternat.opheffen dmv colonres.buikw	237	32112	1
Bov.luchtw. - spoedintubatie larynx-trachea	67	34563	1
Dunne darm - aanleggen voedingsfistel oa. vlgs.witzel	166	34876	2
Diafragma - hernia diaphragmatica - abdominaal	147	37879	5
Maag - gastrostomie als onderdeel van laparotomie	150	40460	3
Oesophagus - atresie	356	45058	4
Larynx - direct diagn.laryngoscopie - incl.proefexc.	117	52879	1
Diafragma - oper.hern.diaphragmat.recidief - abdominaal	252	54011	2
Dunne darm - entero-enterostomie jejunum-jejunum	177	54715	5
Peritoneum - intraperit.kath.capd spoel inbr.-laparotom.	110	55428	2
Lymf.syst. - lymfeklierdissect.-laparotom.-retroperit.li	294	57544	1
Buik - herstel gastroschisis met vreemd materiaal	164	63597	3
Oesophagus - correctie atresie via thoracoscopie	414	63716	1
opheffen stoma en stenose	151	67242	1
Bronchus - diagnostische bronchoscopie	331	69960	1
Ileum - ileostomie	163	74063	4
Dikke darm - resectie ileocaecaal met prim.anastomose	230	76327	2
Buik - herstel gastroschisis primair	82	80762	2

wissel vac	72	82146	1
Longen - longbiopsie dmv thoracoscopie	144	98564	2
Dikke darm - resectie sigmoid met primaire anastomose	186	98832	1
Ileum - resectie met primaire anastomose	324	101950	2
Buik - plastiek buikwand	68	103219	1
Diafragma - herstel hernia via thoracoscopie	234	103773	1
Dikke darm - tot.colectomie met ileorectale anastomose	424	165729	1
Hoofd-hals - aanleggen ecmo-shunt a.car.comm.-v.jug.int.	164	214309	1
Jejunum - aanleggen eindstandig stoma	168	249195	1

B.15 Plastic surgery - hand (PLC)

Table B.38: Plastic surgery - Hand

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Hand - gesloten repositie met k-draadfixatie	64	408	2
Hand - tenotomie	77	295	1
Hand - fractuurbeh.metacarp.k-dr of schroef percut	80	374	2
Hand-pols - excisie benigne tumor bot	82	425	1
Hand-pols - reconstructie ligament incl.peestransplant	87	307	2
Hand - tenolyse extensorpees vinger of handpalm	98	308	4
Hand - artrolyse gewrichten hand en vingers	102	402	4
Hand - osteotomie vinger	103	426	23
Hand-pols - transpositie spier	109	616	3
Hand - tenolyse flexorpees	112	372	2
Hand - artrodese interfalangeaal gewricht	112	486	7
Hand - amputatie of exarticulatie van een vinger	116	510	3
Hand - artrodese carpometac.of metacarpofal.gewr.	120	386	2
Hand - excisie extra vinger	121	414	90
Hand-pols - artropl.metacarpof.-interf.gewr.-autol.mat.	122	437	8
Hand - osteotomie phalanx-os metacarpale- distract	125	379	9
Hand - derotatie osteotomie os metacarpale	130	768	1
Hand-pols - tenosynoviectomie flexorpezen	139	554	1
Hand-pols - oper.beh.pseudo-artrose m. bottransplantaat	143	429	3
Hand - handversmalling met straaltranspositie	146	568	8
Hand - plastische operaties mbv peestransplantaat	180	584	1
Hand - derotatie osteotomie phalanx	190	515	2
Hand - pollicisatie	220	644	12
Hand - replant.of transpl. en revascul. vinger	237	1642	1

B.16 Plastic surgery - others (PLC)

Table B.39: Plastic surgery - Others group 1 (LoS ≤ 3489 and surgery duration ≤ 92)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Perif.zenuw - neurolyse - eenvoudig	39	148	1
Ooglid - implantatie goudgewichtje in bovenooglid	41	134	1
TELCODE - OK - TIJD	42	402	1
Oor - reconstructie znd transplantatie oorschelp	46	284	1
Huid - kl.weinig gecompl.exc.ben.tumoren - funct.g	51	298	12
Spier-pees - operatieve a1-pulley release	54	298	30
Voet - amputatie of exarticulatie teen	57	249	1
Huidtranspos- kleine-weinig gecompliceerd direct gesteeld	60	333	1
Behand.wond kleiner-gelijk aan 5cm zonder wondrandexcisie	65	363	1
Huidplastiek- dermolipectomie-borsten of buik–dogearcorr	67	415	1
Huid - transplantatie vet	67	267	2
Huid - kl.weinig gecompl.exc.ben.tumoren - n.funct	68	326	176
Perif.zenuw - primaire hechting hand	70	306	2
Huid - klinische wondexcisie en wondtoilet	72	203	1
Ooglid - vw.aand.incl.recon.met zwaail.of trans-impl	73	364	4
Hoofd-hals - torticollis operatie	73	315	3
Mamma - tatoeage tepelhof	74	452	1
HAN/SMITS+vNIE; Triggerf.dig 2,3,4 +evt fds slip verwijd.	75	216	1
Pols - artrolyse polsgewricht	76	346	1
Huidplastiek- hechten reven platysma –platysmaplastiek–	77	392	1
Huid - matig gr. en-of gecompl.exc.benigne tumor	77	496	8
Pols - secundaire hechting extensoren polsspier ed	78	413	1
Huid - kl.en-of weinig gecompl.exc.maligne tumor	78	337	31
Wondrandexc.of behand.wond groter 5cm zonder wondrandexc.	79	551	1
Huidplastiek- lip - klieven abbe-plastiek	79	505	1
Ooglid - reven levator bij ptosis	80	375	16
Huidtranspl.- klein en of weinig gecompliceerd	80	330	8
Ooglid - frontalissuspensie	81	352	16
Onderzoek - gynaecologisch onderzoek onder narcose	81	472	2
Oor - excisie ooraanhangsel	82	323	2
Oor - correctie lop ear oorschelp	83	1334	1

Huidplastiek - axiale lappen - extremiteiten	84	424	2
Huidtranspos- klein eo weinig gecompl.of opschuifplastiek	84	416	10
Huidtranspl.- split-skin graft - klein	84	1596	1
Huid - lipofilling hoofd en hals	84	366	2
Huidtranspl.- zeer groot e-o gecompliceerd-md 9 proc.opp.	85	446	1
Huid - oper.verw.gezwell.uitg.diepere structuren	85	335	57
Perif.zenuw - neurolyse - meer gecompliceerd	85	520	7
CRA; verwijderen frame (ca. 3 wk na 30/3)	87	431	1
Perif.zenuw - neurotomie	91	366	1

Table B.40: Plastic surgery - Others group 2 (LoS ≤ 3489 and 92 < surgery duration ≤ 135)

Procedure (in Dutch)	**Mean surgery duration**	**Median LoS**	**freq.**
Gebit - oper.verw.1-meer wort.rst.-corp.al.-k.helft	93	551	1
Oor - plast.corr.oorschelp deform.–cup-lop ear–	93	484	6
Huid - nagelextractie bij vinger of teen	93	362	8
Bot - verwijd.exostosen kleine beend.- voor de 1e	94	311	3
Huid - dermisvet graft hoofd en hals	95	379	16
Pols - carpaaltunnelrelease	95	438	3
Bot - verwijderen osteosynthesemateriaal	95	443	13
Huidtranspos- matig groot en of matig gecompliceerd	96	425	41
Bovenarm - amputatie	96	370	3
Perif.zenuw - decompressie	96	1095	2
Huid - implantatie skin-expander	100	1827	1
Perif.zenuw - neurolyse - onderarm-hand-pols	100	458	4
Huidplastiek - axiale lappen - bovenste deel romp	105	1810	1
Voet - excisie extra teen	106	378	69
Voet - osteotomie metatarsale	106	375	1
Bot - operatief verwijderen van schedeldistractor	108	668	62
Huidplastiek- doorsnijden - terugleggen gesteelde huidlap	108	338	1
Spier-pees - hechten derde en volg.flexorpezen- per pees	110	372	2
Huidplastiek- primaire oper.beh.ernstige verwondingen	110	1060	2
Huidtranspos- groot en of gecompliceerd naar lokalis.nno	111	292	9
Voet - osteot-decapitat. os metatars. met distract	111	540	3
Perif.vaten - inbrengen port-a-cath systeem	111	427	1
Onderarm - resectie spier-pees-fascie en overige bursa	112	493	6

Perif.zenuw - excisie van afwijkingen - oa. neuroom	112	384	2
Huidtranspl. - split-skin graft - groot	112	460	3
Huid - oper. grote en gecompl.gezwellen - klinisch	113	2588	1
Onderarm - osteotomie radius of ulna	113	403	23
Bot - verwijd.exostosen middelgrote beenderen	114	452	2
Huidplastiek - axiale lappen - onderste deel romp	115	498	1
Arm - decompr.–fasciotom.– compartimentsyndroom	115	349	5
Huid - transplantatie van derma en-of vet	119	510	1
CRA; Cranioplastiek inbrengen veren	120	2960	1
Huidplastiek- lokale transpositielap–rotatie–zeer groot	120	520	3
Huidtranspl.- wolfe graft op hand	120	330	2
Huidtranspl.- zeer groot e-o gecompliceerd md 3 proc.opp.	125	351	5
SCH; Lipsluiting	131	1354	1
Bot - verwijderen platen en schroeven	132	980	2
Pols - transpositie spier en pees	132	484	30
Huidplastiek- lipcorrectie secundair	133	562	17
Schouder-arm- secundair hechten pees	134	594	19
Huidplastiek- littekencorrectie dmv lokale transpositie	135	446	8

Table B.41: Plastic surgery - Others group 3 LoS ≤ 3489 and 135 < surgery duration ≤ 183)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
SCH/KNO; Palatoraphie/ intravelaire veloplastiek + oorinspec	141	1534	1
Hoofd-hals - gest.myocutane lap mondholte-far-larynx-oes	142	1036	2
Lip - operat. behand. schisis - incompleet - enkz	144	1516	18
Neus - reconstructie neusvleugel	145	431	1
Pols - artrodese van het polsgewricht	145	570	4
Ooglid - reconstructie - transpositielap	146	527	3
Lip - operat. behand. schisis - compleet - enkelz	147	1575	57
Huidtranspos- zeer groot en of gecompliceerd	148	1456	3
Perif.zenuw - excisie van overige afwijkingen	149	506	4
Huidtranspos - cutane transpositie op hoofd en hals	151	473	1
Pols - primaire hechting extensoren polsspier ed	151	455	18
Oor - reconstructie schelp met transpositie	151	872	3
Spier-pees - transpositie van 1 pees -verzetten insertie	152	351	1

Huidplastiek- sec.beh.congenitale lipspleet-enkelzijdig	154	650	9
Huid - inbrengen tissue expander - borst	155	3305	1
Spier-pees - hechten een of twee flexorpezen - per pees	158	437	11
SCH/KNO; Palatoraphie/ intravelaire veloplastiek+MOB	161	1527	1
Huidplastiek- matig grote en of gecompl.transpositie	162	625	2
Onderarm - osteotomie radius-of ulnaschacht distractie	162	616	4
Mamma - wis.tiss.expander met prothese ter reconstr	163	1607	1
SCH; Palatoraphie/ intravelaire veloplastiek	164	1582	1
Huidplastiek - axiale lappen - hoofd-hals	164	1121	2
Lip - operat. behand. schisis - compleet - dubb.z	165	1597	23
Injectie - corticosteroiden	170	875	1
Oor - plast.corr.standdev.oorschelp - corr.skelet	171	536	7
Huidplastiek- correctie syndactylie	174	456	116
Perif.zenuw - transplantatie nervus facialis	177	1576	4

Table B.42: Plastic surgery - Others group 4 (LoS ≤ 3489 and surgery duration > 183)

Procedure (in Dutch)	**Mean surgery duration**	**Median LoS**	**freq.**
Palatum - prim.beh.verhemeltespleten achterste deel	194	1542	86
Hoofd-hals - transpositie musculus temporalis	196	1455	1
Palatum - palatorrafia anterior bij palatoschisis	209	1585	95
Pharynx - faryngoplastiek	209	1534	28
Palatum - sluiten fistel - defect	212	1549	10
Spier-pees - hechten 3e en volg. extensorpezen- per pees	213	1246	2
Mandibula - verlengen mbv vrij bottransplantaat	215	1504	5
Onderarm - amputatie	223	1960	1
Inbrengen tissue expander algemeen	226	1505	1
Oor - paracentese mbv buisjes oa.fowler - links	231	1552	5
SCH; sluiten palatum en lipcorrectie	244	1917	1
SCH/KNO/VERS: sluit. palatum Langenbeck+corr neus+lip	255	1574	1
Spier-pees - herstel strekpees secundair - per pees	261	1725	1
Oor - paracentese mbv buisjes oa.fowler - rechts	268	1584	1
Mamma - plastiek ter verkleining - enkelzijdig	269	3075	1
Huidplastiek- prim.beh.congenitale lipspleet-enkelzijdig	305	1808	1
HAN/SCH; desynd. 3e web en verbinding 2e web+palatumsluiting	318	1565	1

Table B.43: Plastic surgery - Others group 5 (LoS > 3489)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
Hersenen - herstel encefalokele	252	3789	2
Schedel - plast.van defect met bottranspl.met duratranspl	130	4059	1
Spreidveren tbv craniosynostosebehandeling	137	4102	1
Oogbol - enucleatio bulbi met vast implantaat	392	4121	1
Huidtranspos- huidspierlap naar defect op extremiteiten	110	4432	2
Larynx - direct diagn.laryngoscopie - incl.proefexc.	239	4505	6
Huidplastiek- matig grote-gecompl.transpositie - gesteeld	292	4532	1
Inwendige schedeldistractor	191	4533	3
Kaak - op.beh.meerv.mandibula-maxilla-zygoma-fract	292	4549	1
Schedel - alloplastiek - cranioplastiek	215	4574	21
Tot.lichaam - zeer gecompl.vrij gevascul.weefseltranspl.	381	4652	1
Schedel - distractie schedelbeenderen bij craniosynostose	203	4664	5
Neus - corr.benig-kraakbenig skelet met transplant	210	4788	1
Huid - abrasie huidgebied groter dan 1 proc.lich.	322	5123	1
Spier-pees - vrij transplantaat - gevasculariseerd	407	5566	6
Schedel - reconstructie schedeldak	256	5743	105
CRA; occipitale distractie met grote veren	232	5825	1
CRA; Posterieure veerdistractie	212	5856	1
Schedel - craniectomie plastiek craniosynostose	189	5876	1
lase, curretage en excisie naevi	237	5923	1
Maxilla - osteotomie - le fort i	299	6564	1
Schedel - reconstructie dak met craniaal deel orbita	287	6969	76
Mandibula - corr.benige kin-corticotom.tbv.rapidexpans.	294	7066	1
CRA; facial bipartition	361	7180	1
Schedel - zaagsnedes-herposit.schedelbeend.craniosynost.	319	7199	17
Heup-b.been - adductoren-tenotomie - open	352	7214	1
Oor - reconstructie met transplantatie oorschelp	189	7341	1
Maxilla - osteotomie-distractie - le fort iii	368	10050	2
Aangezicht - frontofaciale advancement–monoblock osteot	387	11100	8
CRA/KAAK/NECH; mediane faciotomie	361	12984	1
Huid - necrotectomie	146	14385	1
Techniekkosten mondziekten en kaakchirurgie	457	28867	1
wondinspectie en verbandwissel	30	35599	1

B.17 Radiology (RON)

Table B.44: Radiology group 1 (surgery duration ≤ 76)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
MRI hersenen onder narcose+ OK hlk 02/04	16	167	1
Infuus	19	76957	1
infuus onder narcose voor MP kuur aangezien dit meerdere mal	20	3015	1
Epiduraal met bloedpatch	20	1684	1
Huid - biopsie	23	369	1
Inbrengen perifeer infuus, venapunctie (39680)	23	42301	2
Ruggenmerg - punctie lumbaal - therapeutisch	25	3414	1
perifer infuus	26	117609	1
Bleomycine injectie kind narcose	26	1403	1
infuus onder narcose voor nierscan	27	503	1
Oor - microscopisch oortoilet - enkelzijdig	29	135	1
behnanelimg VVM knie met bleomycine onder narcose	29	321	1
Anesthesie - bij onderzoek	30	1571	1
infuus	30	2505	1
Schedel - inbrengen drukmeter	35	269	1
bleomycine behandeling vvm b.been li onder narcose R3	35	199	1
Spier-pees - biopsie spier-pees-fascie	36	196	1
Bleomycine behandeling Vvm schouder re onder narcose R3	36	306	1
MRI hersenen onder narcose, iom anesth dr. de Leeuw 29.05	36	15485	1
bleomycine injectie lip onder narcose	36	184	1
bleomycine injectie onder narcose in R3	37	266	1
sclerotherapie middels bleomycine vvm thoraxwand/flank re	37	340	1
Test - uitvoeren begel. en bewaken nefrol. diagn. tests.	40	1638	13
MRI herenen onder narcose	41	310	1
Echogeleide puncite knie rechts; Recidief cyste proximale ti	42	245	1
mri hersenen onder narcose	42	252	1
Hersenen - aanleggen extern ventrikel drainage systeem	43	1009	1
CT hoofd/hals + MRI hersenen onder narcose	43	260	1
Bleomicyne behandeling onder nacose in R3	43	248	1
botox injecties buikwand echogeleid dr Nanko de Graaf	43	302	1

bleomycine VVM onder narcose in R3	45	229	1
embolisatie onder narcose in R3.	45	396	1
Vaten - inbrengen centrale veneuze lijn	45	30110	1
Sclerotherapie VVM kuit re onder narcose in R3	45	252	1
Nier - fijne naald aspiratie biopsie -f.n.a.b.-	46	1808	11
behandeling vvm b.been re met bleomycine onder narcose	47	301	1
Sect.caesar.- primair - geen voorbehandeling wel kraambed	47	2624	1
bleomycine behandeling Vvm b.been re onder narcose	48	325	1
Partus - placenta verwijderen - manueel - curettage	48	4355	1
Bleo schouder onder narcose in R3	48	253	1
bleomycine behandeling VVM	49	228	1
MRI hersenen onder sedatie	49	354	2
Behandeling mdl, radiologie, psychiatrie etc. onder anesthesie	49	294	366
lokaal injecteren met narcose	50	279	1
MRI bekken onder narcose	50	400	1
MRI hersenen + dna afname onder narcose	50	238	1
Behandeling MDL, radiologie, psychiatrie etc. onder anesthesie	51	263	1641
MRI hersenen onder narcose, programma op GenR scanner.	51	283	1
sclerotherapie onder narcose in R3	51	266	1
behandeling bleomycine	52	321	1
Larynx - indir.diagn. laryngoscopie - incl.proefexc.	53	215	1
bleo onder narcose in R3	53	555	1
MRI hersenen onder narcose	53	240	27
MRi hersenen onder narcose	54	344	1
MRI hersenen + labafname onder narcose	55	1417	1
Lymf.syst. - excisie lymfeklier	56	400	1
lokaal injecteren narcose	57	334	1
Voedings-centr.ven.kath.inbrengen niet gerel.aan operat	57	12703	3
intubatie op ok	59	5226	1
Perif.vaten - inbr.centr.veneuze katheter -voed-drukmet.g	60	20079	1
VVM b.been li met bleomycine onder narcose	61	292	1
Sect.caesar.- laag cervicaal met voorbehandeling	62	5209	1
Ruggenmerg - diagnostische lumbaalpunctie	62	278	2
epifysiodese heup	64	2335	1
Oor - paracentese mbv buisjes oa.fowler - rechts	64	317	1
MRI vinger li. onder narcose	65	162	1

lokaal injecteren bleo onder narcose	66	326	1
Oog - biometrie oogbol	66	327	1
Bov.luchtw. - laryngotracheoscopie - diagnostisch	68	253	1
bahndeling vvm met bleomycine onder narcose in SKZ ,dagopnam	69	271	1
Partus - natasten placenta	69	1607	1
CT hoofd + MRI hersenen onder narcose	71	193	1
Diagnostische angiografie been links. KIND	72	433	1
MRI hersenen + cwk onder narcose	73	178	1
MRI onder narcose	74	462	1

Table B.45: Radiology group 2 (surgery duration > 76)

Procedure (in Dutch)	**Mean surgery duration**	**Median LoS**	**freq.**
Oor - paracentese mbv buisjes oa.fowler - links	78	404	1
MRI kind narcose SK1N - 1 onderzoek	86	3202	1
Bleomycinr injectie VVM rug onder narcose in R3 Sophia	87	246	1
MRI hoofd/hals onder narcose & lipbiopt (KAA)	87	265	1
Nier - fijne naald aspiratie biopsie -f.n.a.b.-	93	7648	1
Trachea - canule verwisselen	94	336	1
Dunne darm - oesofagogastroduodenoscopie met biopsie	95	390	1
Behandeling mdl, radiologie, psychiatrie etc. onder anesthesie	100	360	43
Oor - microscopisch oortoilet - enkelzijdig	101	430	1
Behandeling MDL, radiologie, psychiatrie etc. onder anesthesie	102	354	276
Peritoneum - intraperit.kath.capd spoel inbr.-laparotom.	105	22890	1
Functiebep. - fundosc.voorsegm.-onz.ond.narc.- evt.oogdr.	109	466	1
Ct onder narcose	113	1522	1
Pharynx - adenotonsillect.mbv dissectom. - tm 10 jaar	113	1679	1
Perif.vaten - inbr.centr.veneuze katheter -voed-drukmet.g	118	15135	1
MRI hersenen onder narcose	125	279	1
SPECT CT onder narcose	126	715	1
Vaten - inbrengen centrale veneuze lijn	133	14138	2
MRI hersenen + cwk onder narcose	146	453	1
Sect.caesar.- laag cervicaal zonder voorbehandeling	149	7308	1
CT geleide biopt enkel links onder narcose	153	442	1
Arterie - centrale lijn inbrengen	163	21939	1

MRI MSK li + neurofibroom onder narcose+ CVL wissel	171	25941	1
Larynx - direct diagn.laryngoscopie - incl.proefexc.	178	44683	1
Neus - nasendoscopie dmv optiek evt. met proefexc.	237	609	1
Larynx - indir.diagn. laryngoscopie - incl.proefexc.	250	62800	1
Bov.luchtw. - laryngotracheoscopie - diagnostisch	280	1686	1

B.18 Urology (URO)

Table B.46: Urology group 1 (LoS ≤ 3406 and surgery duration ≤ 73)

Procedure (in Dutch)	**Mean surgery duration**	**Median LoS**	**freq.**
Blaas - katheterisatie	15	283	1
Onderzoek - gynaecologisch onderzoek onder narcose	26	327	4
Onderzoek - neuro-urologisch - modulatietesting	28	192	2
Blaas - suprapubische katheter verwisselen	33	248	5
Vagina - losmaken van adhesies	34	358	3
Penis - plastiek preputium	36	358	1
Vagina - scopie incl.evt.vulvabiops.niet met hyst.sc	36	323	3
Ureter - subostiale inj.bulkvormer mbv cystosc.- ez	36	397	5
Ureter - double j-splint verwijderen	40	338	9
Blaas - biopsie	40	203	1
Ureter - splint verwijderen	40	321	60
Botox blaas 200 E	40	220	1
Urethra - kalibratie	40	335	1
Meatotomie	42	300	1
Penis - frenulum plastiek	43	246	3
Blaas - botuline injectie	44	296	68
Orchidopexie	48	409	1
Lies-exploratie; evt laparoscopie	50	435	1
Urinewegen - injectie met botuline - urethrale sfincter	50	343	13
Nier - marsupialisatie cyste dmv laparoscopie	51	457	1
Urinewegen - injectie met bulkvormer via urethrascopie	53	456	3
Urethra - dilatatie meatus	54	350	4
Urethra - excisie para-urethrale cyste	58	1776	2
Penis - frenulum- en preputiumplastiek	58	379	6

Urethra - meatotomie	58	394	33
Orchidopexie kind	58	392	6
cc met meatotomie	59	333	1
Huid - littekencorrectie	59	404	1
Urethra - dilatatie - overige	62	498	2
Mnl.gesl.org- palomo–ligatie v.spermatica bij varicokele	62	315	1
Testis - orchidectomie-enkelz. zonder epididymect.	62	378	2
Blaas - uretrocystoscopie nno	62	407	333
congenitaal megapreputium	63	405	1
Urinewegen - urethra opspuiten met bulkvormer	63	349	1
Urethra - plast.operatie - sluiten fistel	66	430	1
Urethra - urethrotomia interna a vue bv. vlgs. sachse	66	482	30
Penis - frenulotomie preputii	66	452	1
punctie niercyste door radioloog	68	554	1
Preputiumplastiek	70	270	1
Penis - preputiumplastiek bij hypospadie	71	390	3
Blaas - suprapubische katheter inbrengen	71	1679	24
Ureter - transuretrale resectie van ureterokele	72	2385	6
Mnl.gesl.org- excisie hydrokele en hematokele	72	366	1

Table B.47: Urology group 2 (LoS ≤ 3406 and 73 < surgery duration ≤ 107)

Procedure (in Dutch)	**Mean surgery duration**	**Median LoS**	**freq.**
ws enkel huidcorrectie dmv z-plastiek	74	324	1
Testis - orchidopexie via scrotale incisie - enkelz.	74	466	10
Buik - littekenbreuk - electief met c.a.	74	1810	1
Testis - orchidectomie enkelz. dmv inguinale incisie	74	388	46
Urethra - oper. beh. een of meer urethrafistels	76	966	2
Testis - orchidectomie-enkelz. met-zond epididymect.	76	350	12
Testis - implantatie prothese - enkelzijdig	79	477	5
correctie buried penis	81	427	1
Vas deferens- vasectomie - sterilisatie - enkelzijdig	82	262	2
Testis - biopsie	83	388	2
Mnl.gesl.org- hydrokele oper. met verzorging liesbreuk	85	382	66
Penis - circumcisie	85	406	42
Chordectomie + circumcisie	88	471	1

Blaas - cystoscopie	89	1665	35
Testis - excisie tumor	90	476	2
chordectomie met hemi-CC	91	427	1
Buik - herstel littekenbreuk dmv laparotomie	91	3249	1
Testis - orchidopexie - open procedure - enkelzijdig	91	427	31
Revisie AVS + scopie stoma en blaas + evt deflux BH	93	414	1
Penis - lokale excisie van afwijkingen	96	480	4
Penis - plastisch herstel	97	422	28
Cystoscopie+Excisie urachus	98	410	1
Testis - orchidopexie via inguinale incisie - enkelz	98	443	473
Ureter - double j-splint inbrengen	101	1236	4
Penis - chordectomie	103	454	31
Testis - reorchidopexie dmv laparotomie-enkelzijdig	103	510	19
Buik - hernia inguinalis - enkelzijdig - open	104	518	13
circumcisie met meatotomie	105	418	1
Testis - orchidopexie dmv laparotomie - rechts	106	546	10

Table B.48: Urology group 3 (LoS ≤ 3406 and 107 < surgery duration ≤ 127)

Procedure (in Dutch)	**Mean surgery duration**	**Median LoS**	**freq.**
Testis - orchidopexie dmv laparotomie - links	109	570	5
Penis - hypospadie - secundaire huidcorrectie	110	359	2
Testis - orchidofuniculolyse dmv laparotomie	112	524	3
Testis - exploratie wegens abdominale testis	112	485	3
Blaas - revisie plastiek	113	2348	4
Buik - exploratie lies	114	403	7
Testis - fowler-stephens fase 1 - via laparoscopie	115	1092	2
BURRIED PENIS	115	383	1
Huid - biopsie	116	1346	2
Penis - fistelsluiting bij hypospadie	117	2877	13
Nier - proeflumbotomie	118	2941	1
Hypospadie distaal	120	462	4
orchidopexie re	121	532	1
Penis - hypospadie prim.beh-exc.chorde-strekk.penis	124	457	87
Blaas - operatief aanleggen fistel - cystostomie	127	3114	2

Table B.49: Urology group 4 (LoS ≤ 3406 and surgery duration > 127)

Procedure (in Dutch)	Mean surgery duration	Median LoS	freq.
enis - hypospadie - correctie distaal - magpi	129	447	145
Testis - fowler-stephens fase 2 - dmv laparoscopie	132	1705	3
Ovarium - adnex-extirpatie dmv laparoscopie	134	1641	2
Nier - percutane litholapaxie	137	3199	1
Penis - hypospadie-prim.chir.beh.-reconstr.urethra	141	493	31
Urethra - open urethraplastiek-anterieure benadering	142	3271	1
Ureter - ureterorenoscopie met paxie-trypsie	145	3376	2
Blaas - revisie appendicovesicostomie	148	2244	2
Buik - laparoscopie - diagnostisch n.n.o.	148	686	12
Midschacht hypospadie	151	3051	1
Penis - herstel hypospadie - lysis corpora cavernos	157	473	12
Penis - reven bij peyronie-curved penis-nesbit corr	160	3007	4
Nier - nefrectomie partieel dmv laparoscopie	206	1747	1
Nier - nefrectomie via laparoscopie - rechts	211	3248	3
Penis - behandeling van epispadie nno	213	3174	1
Vagina - verwijdingsplastiek van introitus vaginae	214	2506	2
Nier - nefrectomie via laparoscopie - links	228	2624	12
Nier - nefrectomie radicaal dmv laparoscopie	245	2551	6
Pyelum - pyeloplastiek via laparoscopie	268	1815	83
Uterus - verwijderen uterushoorn dmv laparoscopie	290	3046	1

Table B.50: Urology group 5 (LoS > 3406)

Procedure (in Dutch)	**Mean surgery duration**	**Median LoS**	**freq.**
Urethra - urethraplastiek - perineaal	200	3891	2
Nier - nefrectomie partieel abdominaal	170	4261	9
Nier - nefrect.en tot.ureterect.dmv aparte incisie	139	4372	5
Nier - nefrect.mal.tumoren - thor.abdom. - links	164	4391	3
Blaas - oper.verwijderen stenen - corpora aliena	104	4544	6
Nier - nefrectomie na ingreep aan dezelfde nier	140	4564	2
Nier - nefrectomie - totaal	183	4586	11
Nier - retrograde pyelografie - dubbelzijdig	173	5965	2
Penis - hypospadie - correctie proximaal - duckett	178	6017	22
Ureter - ureterocutaneostomie - enkelzijdig	219	6051	3
Penis - hypospadie-reconstr.urethra mbv gest.huidtr	205	6198	3
Nefrectomie links + cystoscopie (klepresectie) + circumcisie	161	7205	1
Penis - plast.op.tunica albugin.van corp.cavernosum	204	7316	2
Hypospadie midschacht	136	7406	1
Nier - verwijderen steen endoscopie - litholapaxie	313	8731	1
Blaas - appendicovesicostomie vlgs mitrofanoff	224	8817	7
Pyelum - pyeloplastiek	175	8851	58
Blaas - blaasvergrotende operatie ileo-cystoplast.	263	9017	9
Ureter - operatieve behandeling van ureterokele	165	9190	3
cystoscopie met afsluiten blaashals	268	10249	1
Ureter - reanastomose - cohen	182	10298	8
Penis - hypospadie - correctie secundair	162	10309	25
Ureter - ureterimpl.in blaas zelfst.ingr.-enkelz.	188	10388	14
Nier - retrograde ureteropyelografie	303	11691	1
Urethra - operatie van urethradivertikel	230	11742	1
Ureter - rekalibratie ureteren - bv.volgens hendren	267	12661	2
Blaas - sluiten cystostomie - operatief	214	13204	2
Blaas - resectie partieel	198	14468	1
Vesicostoma aanleggen	151	14637	1
Blaas - diverticulectomie - zelfstandige ingreep	200	16269	2
Urethra - transuretrale resect.of coagulatie kleppen	64	18724	9
Ureter - reconstructie bij niertransplantatie	324	37530	2

C | Schedules

This appendix contains the schedules, which resulted from the different models. All four weeks of the MSS are shown in these schedules. If the abbreviation of a specialty is given, that specialty has an OR shift on the day given at the top of the column in the OR mentioned at the beginning of the row. The abbreviation of the specialty is either followed by numbers or by -. The numbers indicate the order the different patient groups that are scheduled. These numbers correspond with the numbers in Appendix B. If the abbreviation is followed by -, this indicates that this specialty has OR time, but the model did not schedule any patient groups.

	Week 1				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI		RON: 1, 1, 1, 1, 1, 1			RON: 1, 1, 1, 1, 1, 2
1	GYN: 1	GYN: 1	GYN: 2	GYN: 2	GYN: 2
2	LOS: 1	KNO: 1, 2, 1, 3		LOS: 1	
3	KIC: 5	GAS: 2, 1	KNO: 2, 4	KIC: 1	KNO: 4, 2
4			KNO: 1, 2, 5	ORTO: 2, 1	OOG: 2, 2 & DER: 1, 1
5	PLCH: 1, 1	KNO: 2, 5	URO: 2, 1, 4	URO: 1, 2, 3	URO: 2, 2, 5
6	PLCH: 1, 1			PLCO: 2, 3	KIC: 1
7	URO: 2, 2, 2, 1	KIC: 2, 2, 2, 1	KIC: 2, 3, 3	KIC: 3, 1	KIC: 2, 3, 1
8	ORTR: 1	ORTO: 3, 1	ORTO: 3, 1	ORTR: 1	ORTO: 3, 1
9	CAS: 1, 3, 2		CAS: 1, 2, 3		
10	NEC: 4	PLCO: 5	PLCO: 5	NEC: 3	ORTO: 4

	Week 2				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI	RON: 1, 1, 1, 1, 1, 2	RON: 1, 1, 1, 1, 1, 2			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 2	GYN: 2	GYN: 2	GYN: 2
2	LOS: 1	KNO: 4, 2		LOS: 1	
3	KIC: 5	GAS: 3, 1, 2		KIC: 5	KNO: 2, 1, 5
4			KNO: 4, 2	ORTO: 3, 1	TAN: 1, 1
5	URO: 5, 5	KNO: 1, 1, 1, 2, 3	URO: 1, 1, 4	URO: 2, 1, 4	URO: 2, 1, 4
6	PLCH: 1, 1		KAA: 2, 1, 1, 1	PLCO: 2, 2, 1	KIC: 4
7		KIC: 5, 1	KIC: 2, 2, 2, 2, 1	KIC: 3, 1	KIC: 5, 1
8	ORTR: 1	ORTO: 2, 1	ORTO: 3, 1	ORTR: 1	ORTO: 3, 1
9	CAS: 3, 3		CAS: 2, 1, 3		
10	NEC: 1, 2, 2	PLCO: 4, 1	PLCO: 2, 2, 1	NEC: 2, 1, 2	ORTO: 4

	Week 3				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI		RON: 1, 1, 1, 1, 1, 1			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 2	GYN: 2	GYN: 2	GYN: 3
2	LOS: 1	KNO: 5, 2		LOS: 1	
3	KIC: 5	GAS: 1, 1		KIC: 5	KNO: 2, 2, 1, 2
4			KNO: 2, 2, 1, 3	ORTO: 2, 1	OOG: 2, 2 & DER: 1, 1
5	PLCH: 1, 1	KNO: 1, 1, 1, 1, 3	URO: 3, 1, 5	URO: 2, 2, 3	URO: 2, 2, 2, 1
6	PLCH: 1, 1		KAA: 2, 3, 1	PLCO: 2, 3	KIC: 3
7	URO: 1, 2, 5	KIC: 2, 2, 2, 1	KIC: 2, 3, 3	KIC: 2, 2, 2, 1	KIC: 2, 3, 3
8	ORTR: 1	ORTO: 3, 1	ORTO: 2, 1	ORTR: 1	ORTO: 4
9	CAS: 3, 3		CAS: 3, 1, 2		
10	NEC: 2, 1, 1	PLCO: 2, 3	PLCO: 5	NEC: 4	ORTO: 4

	Week 4				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI	RON: 1, 1, 1, 1, 1, 2	RON: 1, 2			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 2	GYN: 2	GYN: 2	GYN: 3
2	LOS: 1	KNO: 1, 2, 5		LOS: 1	
3	KIC: 4	GAS: 3, 1, 1		KIC: 4	KNO: 2, 1, 2, 3
4		NEU: 1, 1, 1	KNO: 4, 2	ORTO: 4	OOG: 2, 2, 1, 1, 1
5	URO: 1, 2, 4	KNO: 1, 1, 1, 1, 1, 3	URO: 1, 2, 4	URO: 2, 1, 4	URO: 2, 1, 4
6	PLCH: 1, 1		KAA: 3, 3	PLCO: 4, 1	KIC: 4
7		KIC: 2, 2, 2, 2, 1	KIC: 2, 3, 1	KIC: 2, 3, 1	KIC: 2, 2, 2, 2, 1
8	ORTR: 1	ORTO: 3, 1	ORTO: 4	ORTR: 1	ORTO: 2, 1
9	CAS: 1, 3, 2		CAS: 2, 1, 3		
10	NEC: 4	PLCO: 4, 1	PLCO: 2, 3	NEC: 4	ORTO: 2, 1

Figure C.1: Resulting schedule of the model from Section 8.2.

	Week 1				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI		RON: 1, 1, 1, 1, 1, 1			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 2	GYN: 2	GYN: 3	GYN: 2
2	LOS: 1	KNO: 2, 5		LOS: 1	
3	KIC: 5	GAS: 1, 3	KNO: 2, 2, 1, 2	KIC: 3	KNO: 2, 4
4			KNO: 2, 2, 1, 1	ORTO: 1	OOG: - & DER: 1, 1
5	PLCH: 1, 1	KNO: 2, 1, 1, 1	URO: 2, 1, 4	URO: 1, 1, 3	URO: 2, 1, 4
6	PLCH: 1, 1			PLCO: 2, 3	KIC: 5
7	URO: 2, 2, 2, 1	KIC: 2, 2, 1	KIC: 3, 2, 1	KIC: 2, 2, 2, 1	KIC: 3, 2, 1
8	ORTR: 1	ORTO: 2, 1	ORTO: 3, 1	ORTR: 1	ORTO: 3, 1
9	CAS: 3, 1, 2		CAS: 3, 1		
10	NEC: 4	PLCO: 2, 3	PLCO: 4, 1	NEC: 3	ORTO: 3, 1

	Week 2				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI	RON: 1, 1, 1, 1, 1, 2	RON: 1, 1, 1, 1, 1, 2			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 2	GYN: 2	GYN: 2	GYN: 3
2	LOS: 1	KNO: 2, 1, 5		LOS: 1	
3	KIC: 4	GAS: 2, 1, 3		KIC: 1	KNO: 2, 3, 3
4			KNO: 2, 4	ORTO: 1	TAN: 1, 1
5	URO: 5, 3	KNO: 2, 4	URO: 2, 1, 4	URO: 2, 1, 4	URO: 2, 1, 4
6	PLCH: 1, 1		KAA: 3, 1, 2	PLCO: 4, 1	KIC: 5
7		KIC: 3, 2, 1	KIC: 3, 2, 1	KIC: 2, 2, 2, 1	KIC: 5, 3
8	ORTR: 1	ORTO: 3, 1	ORTO: 3, 1	ORTR: 1	ORTO: 4
9	CAS: 3, 1, 2		CAS: 3, 3		
10	NEC: 2, 1, 2	PLCO: 4, 1	PLCO: 5	NEC: 4	ORTO: 4

	Week 3				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI		RON: 1, 1, 1, 1, 1, 1			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 2	GYN: 2	GYN: 1	GYN: 2
2	LOS: 1	KNO: 1, 1, 1, 1, 1		LOS: 1	
3	KIC: 5	GAS: 1, 1		KIC: 3	KNO: 2, 3, 3
4			KNO: 2, 1, 1, 1, 1	ORTO: 1	OOG: 2, 2 & DER: 1, 1
5	PLCH: 1, 1	KNO: 1, 1, 5	URO: 2, 1, 4	URO: 2, 1, 3	URO: 5, 5
6	PLCH: 1, 1		KAA: 3, 1, 2	PLCO: 2, 1	KIC: 5
7	URO: 2, 2, 2, 1	KIC: 2, 2, 1	KIC: 3, 2, 1	KIC: 2, 2, 1	KIC: 4, 3
8	ORTR: 1	ORTO: 2, 1	ORTO: 2, 1	ORTR: 1	ORTO: 4
9	CAS: 3, 3		CAS: 2, 1, 3		
10	NEC: 4	PLCO: 2, 3	PLCO: 5	NEC: 2, 1, 1	ORTO: 4

	Week 4				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI	RON: 1, 1, 1, 1, 1, 2	RON: 1, 2			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 2	GYN: 2	GYN: 1	GYN: 2
2	LOS: 1	KNO: 2, 3, 3		LOS: 1	
3	KIC: 5	GAS: 2, 1, 1		KIC: 3	KNO: 4, 2
4		NEU: 1, 1, 1	KNO: 2, 1, 5	ORTO: 2, 1	OOG: 2, 2, 1, 1
5	URO: 2, 2, 2, 1	KNO: 2, 4	URO: 2, 2, 1	URO: 2, 1, 4	URO: 5, 5
6	PLCH: 1, 1		KAA: 3, 1, 1	PLCO: 2, 3	KIC: 4
7		KIC: 2, 2, 2, 1	KIC: 2, 2, 2, 1	KIC: 2, 2, 2, 3	KIC: 4, 1
8	ORTR: 1	ORTO: 2, 1	ORTO: 2, 1	ORTR: 1	ORTO: 4
9	CAS: 3, 1, 2		CAS: 1, 2, 3		
10	NEC: 2, 1, 1	PLCO: 4, 1	PLCO: 5	NEC: 1, 2, 2	ORTO: 4

Figure C.2: Resulting schedule using $\omega = 1$ in Section 8.3.

	Week 1				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI		RON: 1, 1, 1, 1, 1, 1			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 2	GYN: 2	GYN: 1	GYN: 2
2	LOS: 1	KNO: 1, 2, 1, 3		LOS: 1	
3	KIC: 3	GAS: 1, 3	KNO: 2, 4	KIC: 1	KNO: 4, 2
4			KNO: 1, 2, 5	ORTO: 2, 1	OOG: 2, 2 & DER: 1, 1
5	PLCH: 1, 1	KNO: 2, 5	URO: 2, 1, 5	URO: 1, 1, 5	URO: 2, 1, 4
6	PLCH: 1, 1			PLCO: 2, 3	KIC: 5
7	URO: 2, 1, 4	KIC: 2, 2, 2, 1	KIC: 2, 2, 2, 2, 1	KIC: 3, 1	KIC: 3, 2, 1
8	ORTR: 1	ORTO: 3, 1	ORTO: 3, 1	ORTR: 1	ORTO: 4
9	CAS: 3, 1, 2		CAS: 1, 1, 3		
10	NEC: 3	PLCO: 5	PLCO: 4, 1	NEC: 4	ORTO: 4

	Week 2				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI	RON: 1, 1, 1, 1, 1, 2	RON: 1, 1, 1, 1, 1, 2			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 2	GYN: 2	GYN: 2	GYN: 3
2	LOS: 1	KNO: 4, 2		LOS: 1	
3	KIC: 4	GAS: 1, 3, 2		KIC: 5	KNO: 2, 1, 5
4			KNO: 4, 2	ORTO: 2, 1	TAN: 1, 1
5	URO: 1, 2, 4	KNO: 1, 1, 1, 2, 3	URO: 2, 2, 5	URO: 1, 2, 4	URO: 1, 3, 5
6	PLCH: 1, 1		KAA: 2, 3, 2	PLCO: 2, 2, 1	KIC: 4
7		KIC: 3, 2, 3	KIC: 5, 1	KIC: 2, 2, 2, 1	KIC: 3, 2, 1
8	ORTR: 1	ORTO: 3, 1	ORTO: 3, 1	ORTR: 1	ORTO: 3, 1
9	CAS: 3, 1, 2		CAS: 3, 3		
10	NEC: 4	PLCO: 4, 1	PLCO: 2, 2, 1	NEC: 2, 2, 1	ORTO: 3, 1

	Week 3				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI		RON: 1, 1, 1, 1, 2			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 2	GYN: 2	GYN: 1	GYN: 2
2	LOS: 1	KNO: 5, 2		LOS: 1	
3	KIC: 5	GAS: 1, 2		KIC: 3	KNO: 2, 2, 1, 2
4			KNO: 2, 2, 1, 3	ORTO: 2, 1	OOG: 2, 2 & DER: 1, 1
5	PLCH: 1, 1	KNO: 1, 1, 1, 1, 3	URO: 1, 2, 4	URO: 3, 1, 3	URO: 2, 1, 4
6	PLCH: 1, 1		KAA: 3, 3	PLCO: 2, 3	KIC: 3
7	URO: 2, 1, 4	KIC: 2, 2, 2, 1	KIC: 2, 2, 2, 2, 1	KIC: 2, 2, 2, 1	KIC: 3, 2, 1
8	ORTR: 1	ORTO: 4	ORTO: 3, 1	ORTR: 1	ORTO: 3, 1
9	CAS: 3, 1, 2		CAS: 3, 2		
10	NEC: 4	PLCO: 2, 3	PLCO: 4, 1	NEC: 1, 1, 1	ORTO: 4

	Week 4				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI	RON: 1, 1, 1, 1, 1, 2	RON: 1, 1, 1			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 2	GYN: 2	GYN: 2	GYN: 3
2	LOS: 1	KNO: 1, 2, 5		LOS: 1	
3	KIC: 5	GAS: 1, 1, 1		KIC: 4	KNO: 2, 1, 2, 3
4		NEU: 1, 1, 1	KNO: 4, 2	ORTO: 2, 1	OOG: 2, 2, 1, 1, 1
5	URO: 1, 2, 4	KNO: 1, 1, 1, 1, 1, 3	URO: 2, 2, 2, 1	URO: 2, 2, 2, 1	URO: 2, 2, 5
6	PLCH: 1, 1		KAA: 1, 1, 1, 1	PLCO: 2, 3	KIC: 4
7		KIC: 5, 3	KIC: 5, 1	KIC: 2, 3, 1	KIC: 3, 2, 1
8	ORTR: 1	ORTO: 2, 1	ORTO: 2, 1	ORTR: 1	ORTO: 4
9	CAS: 3, 3		CAS: 2, 1, 3		
10	NEC: 2, 2	PLCO: 5	PLCO: 5	NEC: 1, 1, 1	ORTO: 4

Figure C.3: Resulting schedule from model A in Section 8.4.

	Week 1				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI		RON: 1, 1, 1, 1, 1, 1			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 3	GYN: 2	GYN: 1	GYN: 2
2	LOS: 1	KNO: 1, 2, 1, 3		LOS: 1	
3	KIC: 4	GAS: 2, 1	KNO: 2, 4	KIC: 1	KNO: 4, 2
4			KNO: 1, 2, 5	ORTO: 2, 1	OOG: 2, 2 & DER: 1, 1
5	PLCH: 1, 1	KNO: 2, 5	URO: 2, 1, 4	URO: 3, 4	URO: 2, 2, 5
6	PLCH: 1, 1			PLCO: 2, 3	KIC: 5
7	URO: 1, 1, 5	KIC: 3, 1	KIC: 2, 3, 1	KIC: 2, 2, 2, 1	KIC: 2, 3, 1
8	ORTR: 1	ORTO: 3, 1	ORTO: 3, 1	ORTR: 1	ORTO: 2, 1
9	CAS: 1, 2, 3		CAS: 3, 3		
10	NEC: 3	PLCO: 2, 3	PLCO: 4, 1	NEC: 4	ORTO: 2, 1

	Week 2				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI	RON: 1, 1, 1, 1, 1, 2	RON: 1, 1, 1, 1, 1, 2			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 3	GYN: 2	GYN: 2	GYN: 2
2	LOS: 1	KNO: 4, 2		LOS: 1	
3	KIC: 4	GAS: 3, 1, 2		KIC: 5	KNO: 2, 1, 5
4			KNO: 4, 2	ORTO: 2, 1	TAN: 1, 1
5	URO: 1, 2, 4	KNO: 1, 1, 1, 2, 3	URO: 1, 3, 5	URO: 1, 2, 4	URO: 1, 2, 4
6	PLCH: 1, 1		KAA: 3, 2, 2	PLCO: 2, 2, 1	KIC: 5
7		KIC: 3, 5	KIC: 2, 3, 3	KIC: 2, 2, 2, 1	KIC: 2, 2, 2, 2, 1
8	ORTR: 1	ORTO: 3, 1	ORTO: 3, 1	ORTR: 1	ORTO: 2, 1
9	CAS: 3, 1		CAS: 3, 1, 2		
10	NEC: 4	PLCO: 4, 1	PLCO: 2, 2, 1	NEC: 4	ORTO: 4

	Week 3				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI		RON: 1, 1, 1, 1, 2			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 2	GYN: 2	GYN: 1	GYN: 2
2	LOS: 1	KNO: 5, 2		LOS: 1	
3	KIC: 5	GAS: 1, 1		KIC: 4	KNO: 2, 2, 1, 2
4			KNO: 2, 2, 1, 3	ORTO: 1	OOG: 2, 2 & DER: 1, 1
5	PLCH: 1, 1	KNO: 1, 1, 1, 1, 3	URO: 1, 2, 4	URO: 1, 2, 2	URO: 5, 3
6	PLCH: 1, 1		KAA: 3, 1, 1	PLCO: 2, 3	KIC: 1
7	URO: 2, 2, 5	KIC: 3, 3	KIC: 3, 2, 1	KIC: 2, 2, 2, 1	KIC: 3, 2, 1
8	ORTR: 1	ORTO: 3, 1	ORTO: 2, 1	ORTR: 1	ORTO: 3, 1
9	CAS: 3, 1, 2		CAS: 3, 1, 2		
10	NEC: 2, 1, 2	PLCO: 5	PLCO: 4, 1	NEC: 2, 1, 1	ORTO: 3, 1

	Week 4				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI	RON: 1, 1, 1, 1, 1, 2	RON: 1, 1, 1			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 2	GYN: 2	GYN: 2	GYN: 2
2	LOS: 1	KNO: 1, 2, 5		LOS: 1	
3	KIC: 4	GAS: 3, 1, 1		KIC: 1	KNO: 2, 1, 2, 3
4		NEU: 1, 1, 1	KNO: 4, 2	ORTO: 4	OOG: 2, 2, 1, 1, 1
5	URO: 1, 2, 4	KNO: 1, 1, 1, 1, 1, 3	URO: 2, 2, 2, 1	URO: 2, 2, 2, 1	URO: 1, 2, 1
6	PLCH: 1, 1		KAA: 3, 1, 1	PLCO: 2, 3	KIC: 5
7		KIC: 2, 2, 2, 2, 1	KIC: 3, 2, 1	KIC: 2, 2, 2, 2, 1	KIC: 3, 5
8	ORTR: 1	ORTO: 4	ORTO: 4	ORTR: 1	ORTO: 4
9	CAS: 3, 3		CAS: 2, 1, 3		
10	NEC: 2, 1, 1	PLCO: 5	PLCO: 5	NEC: 1, 1, 1	ORTO: 4

Figure C.4: Resulting schedule from model B in Section 8.4.

	Week 1				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI		RON: 1, 1, 1, 1, 1, 1			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 2		GYN: 2	GYN: 2
2	LOS: 1	KNO: 2, 2, 3		LOS: 1	
3	KIC: 3	GAS: 3, 1	KNO: 1, 2, 1, 2	KIC: 1	KNO: 2, 3, 2
4			KNO: 4, 2	ORTO: 2, 1	OOG: 2, 2 & DER: 1, 1
5	PLCH: 1, 1	KNO: 2, 1, 1, 2	URO: 2, 1, 4	URO: 2, 1, 3	URO: 2, 2, 5
6	PLCH: 1, 1			PLCO: 2, 3	KIC: 5
7	URO: 2, 2, 2, 1	KIC: 3, 3	KIC: 2, 2, 2, 3	KIC: 2, 2, 1	KIC: 5, 1
8	ORTR: 1	ORTO: 2, 1	ORTO: 1	ORTR: 1	ORTO: 4
9			CAS: 3, 3		
10	NEC: 2, 1, 2	PLCO: 5	PLCO: 5	NEC: 1, 1	ORTO: 4

	Week 2				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI	RON: 1, 1, 1, 1, 1, 2	RON: 1, 1, 1, 1, 1, 2			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 2	GYN: 2	GYN: 1	GYN: 2
2	LOS: 1	KNO: 4, 2		LOS: 1	
3	KIC: 4	GAS: 1, 1, 2		KIC: 3	KNO: 2, 1, 5
4			KNO: 2, 4	ORTO: 2, 1	TAN: 1, 1
5	URO: 2, 1, 4	KNO: 1, 1, 1, 5	URO: 2, 1, 4	URO: 1, 2, 4	URO: 5, 5
6	PLCH: 1, 1		KAA: 3, 2, 2	PLCO: 2, 3	
7		KIC: 3, 5	KIC: 2, 2, 2, 1	KIC: 2, 2, 2, 1	KIC: 3, 1
8	ORTR: 1	ORTO: 3, 1	ORTO: 2, 1	ORTR: 1	ORTO: 1
9	CAS: 3, 1, 2		CAS: 3, 1, 1		
10	NEC: 4	PLCO: 4, 1	PLCO: 5	NEC: 2	ORTO: 3, 1

	Week 3				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI		RON: 1, 1, 1, 1, 2			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 3	GYN: 2	GYN: 2	
2	LOS: 1	KNO: 2, 5		LOS: 1	
3	KIC: 5	GAS: 1, 3		KIC: 1	KNO: 4, 2
4			KNO: 1, 2, 1, 1, 2	ORTO: 2, 1	OOG: 2, 2 & DER: 1, 1
5	PLCH: 1, 1	KNO: 1, 1, 2, 3	URO: 1, 2, 4	URO: 1, 1, 1	URO: 3, 3, 2
6	PLCH: 1, 1		KAA: 3, 1, 1	PLCO: 2, 3	KIC: 5
7	URO: 2, 1, 4	KIC: 3, 1	KIC: 3, 2, 1	KIC: 2, 2, 1	KIC: 4, 1
8	ORTR: 1	ORTO: 2, 1	ORTO: 1	ORTR: 1	ORTO: 4
9	CAS: 3, 2		CAS: 3, 3		
10	NEC: 3	PLCO: 2, 1	PLCO: 4, 1	NEC: 4	ORTO: 4

	Week 4				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI	RON: 1, 1, 1, 1, 1, 2	RON: 1, 1, 1			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 2	GYN: 1	GYN: 2	GYN: 2
2	LOS: 1	KNO: 3, 1, 1, 3		LOS: 1	
3	KIC: 4	GAS: 2, 1, 1		KIC: 2	KNO: 4
4		NEU: 1, 1, 1	KNO: 2, 1, 1, 1, 1	ORTO: 1	OOG: 2, 2, 1, 1, 1
5	URO: 1, 2, 4	KNO: 3, 5	URO: 2, 2, 5	URO: 2, 2, 2, 1	URO: 5, 1
6	PLCH: 1, 1		KAA: 3, 1, 1	PLCO: 2, 3	
7		KIC: 3, 5	KIC: 2, 2, 2, 1	KIC: 2, 2, 2	KIC: 2, 2, 1
8	ORTR: 1	ORTO: 3, 1	ORTO: 1	ORTR: 1	ORTO: 4
9	CAS: 3, 1, 2		CAS: 1, 2, 3		
10	NEC: 4	PLCO: 1	PLCO: 4, 1	NEC: 1, 2	ORTO: 4

Figure C.5: Resulting schedule from model C in Section 8.4.

	Week 1				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI		RON: 1, 1, 1, 1, 1, 1			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 2	GYN: 2	GYN: 1	GYN: 2
2	LOS: 1	KNO: 1, 1, 2, 3		LOS: 1	
3	KIC: 3	GAS: 1, 1	KNO: 1, 2, 1, 1, 2	KIC: 1	KNO: 4, 1
4			KNO: 2, 1, 1, 3	ORTO: 1	OOG: 2, 2 & DER: 1, 1
5	PLCH: 1, 1	KNO: 1, 1, 5	URO: 3, 1, 5	URO: 3, 2, 2	URO: 2, 1, 4
6	PLCH: 1, 1			PLCO: 2, 3	KIC: 5
7	URO: 1, 2, 4	KIC: 3, 3	KIC: 2, 2, 2, 1	KIC: 2, 2, 2	KIC: 5, 1
8	ORTR: 1	ORTO: 2, 1	ORTO: 2, 1	ORTR: 1	ORTO: 4
9	CAS: 3, 1, 2		CAS: 3, 3		
10	NEC: 4	PLCO: 5	PLCO: 4, 1	NEC: 1, 1, 1	ORTO: 4

	Week 2				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI	RON: 1, 1, 1, 1, 1, 2	RON: 1, 1, 1, 1, 1, 2			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 2	GYN: 2	GYN: 1	GYN: 2
2	LOS: 1	KNO: 1, 1, 2, 1, 3		LOS: 1	
3	KIC: 4	GAS: 1, 3, 1		KIC: 1	KNO: 2, 5
4			KNO: 2, 2, 1, 2	ORTO: 2, 1	TAN: 1, 1
5	URO: 1, 2, 4	KNO: 4, 2	URO: 3, 1, 5	URO: 2, 2, 2	URO: 2, 2, 5
6	PLCH: 1, 1		KAA: 3, 1, 1	PLCO: 2, 3	
7		KIC: 3, 5	KIC: 2, 2, 2, 1	KIC: 2, 2, 1	KIC: 4, 1
8	ORTR: 1	ORTO: 3, 1	ORTO: 2, 1	ORTR: 1	ORTO: 1
9			CAS: 2, 3		
10	NEC: 2, 2	PLCO: 5	PLCO: 4, 1	NEC: 1, 2	ORTO: 1

	Week 3				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI		RON: 1, 1, 1, 1, 2			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 3	GYN: 2		GYN: 2
2	LOS: 1	KNO: 1, 1, 5		LOS: 1	
3	KIC: 3	GAS: 3, 2		KIC: 1	KNO: 4, 2
4			KNO: 2, 4	ORTO: 1	OOG: 2, 2 & DER: 1, 1
5	PLCH: 1, 1	KNO: 1, 1, 2, 2	URO: 1, 2, 4	URO: 1, 2, 1	URO: 2, 1, 4
6	PLCH: 1, 1		KAA: 3, 1, 1	PLCO: 2, 3	
7	URO: 1, 2, 5	KIC: 2, 5	KIC: 2, 2, 2, 1	KIC: 2, 2, 2, 1	KIC: 3, 5
8	ORTR: 1	ORTO: 2, 1	ORTO: 3, 1	ORTR: 1	ORTO: 4
9	CAS: 1, 3, 2		CAS: 3, 1, 2		
10	NEC: 4	PLCO: 2, 1	PLCO: 4, 1	NEC: 3	ORTO: 4

	Week 4				
	Monday	Tuesday	Wednesday	Thursday	Friday
MRI	RON: 1, 1, 1, 1, 1, 2	RON: 1, 1, 1			RON: 1, 1, 1, 1, 1, 2
1	GYN: 2	GYN: 2	GYN: 2	GYN: 2	
2	LOS: 1	KNO: 4, 2		LOS: 1	
3	KIC: 4	GAS: 1, 1, 2		KIC: 1	KNO: 2, 5
4		NEU: 1, 1, 1	KNO: 2, 2, 1, 3	ORTO: 1	OOG: 2, 2, 1, 1, 1
5	URO: 1, 2, 4	KNO: 2, 3, 3	URO: 1, 2, 4	URO: 2, 2, 2, 1	URO: 5, 1
6	PLCH: 1, 1		KAA: 2, 2, 3	PLCO: 2, 3	
7		KIC: 2, 3, 1	KIC: 2, 3, 3	KIC: 2, 2, 2, 1	KIC: 3, 5
8	ORTR: 1	ORTO: 3, 1	ORTO: 2, 1	ORTR: 1	ORTO: 4
9	CAS: 3, 3		CAS: 1, 3, 1		
10	NEC: 2	PLCO: 1	PLCO: 5	NEC: 4	ORTO: 4

Figure C.6: Resulting schedule from model D in Section 8.4.

D | Time comparison creating pricing subproblems

This appendix contains information regarding the the runtime of the different pricing subproblems.

Table D.1: Time in seconds it takes to create the different pricing subproblems.

Specialty (s)	r_{tw} **is defined for all** $t \in T$	r_{tw} **is defined for all** $t \in \{0,4,8,\ldots,t^*-3\}$
KIC	2569	808
KNO	1506	441
RON	322	92
URO	1416	421
ORTO	1398	417
PLCO	1029	320
GYN	1028	305
GAS	191	54
CAS	387	111
NEC	525	151
KAA	142	41
OOG	95	27
LOS	127	36
ORTR	127	36
PLCH	95	27
TAN	16	5
NEU	16	5
DER	32	9
Total	11020	3303.0

E | Bed occupancy

In this appendix, the bed occupancy of the model without taking bed occupancy into account and model A from Section 8.4 are presented.

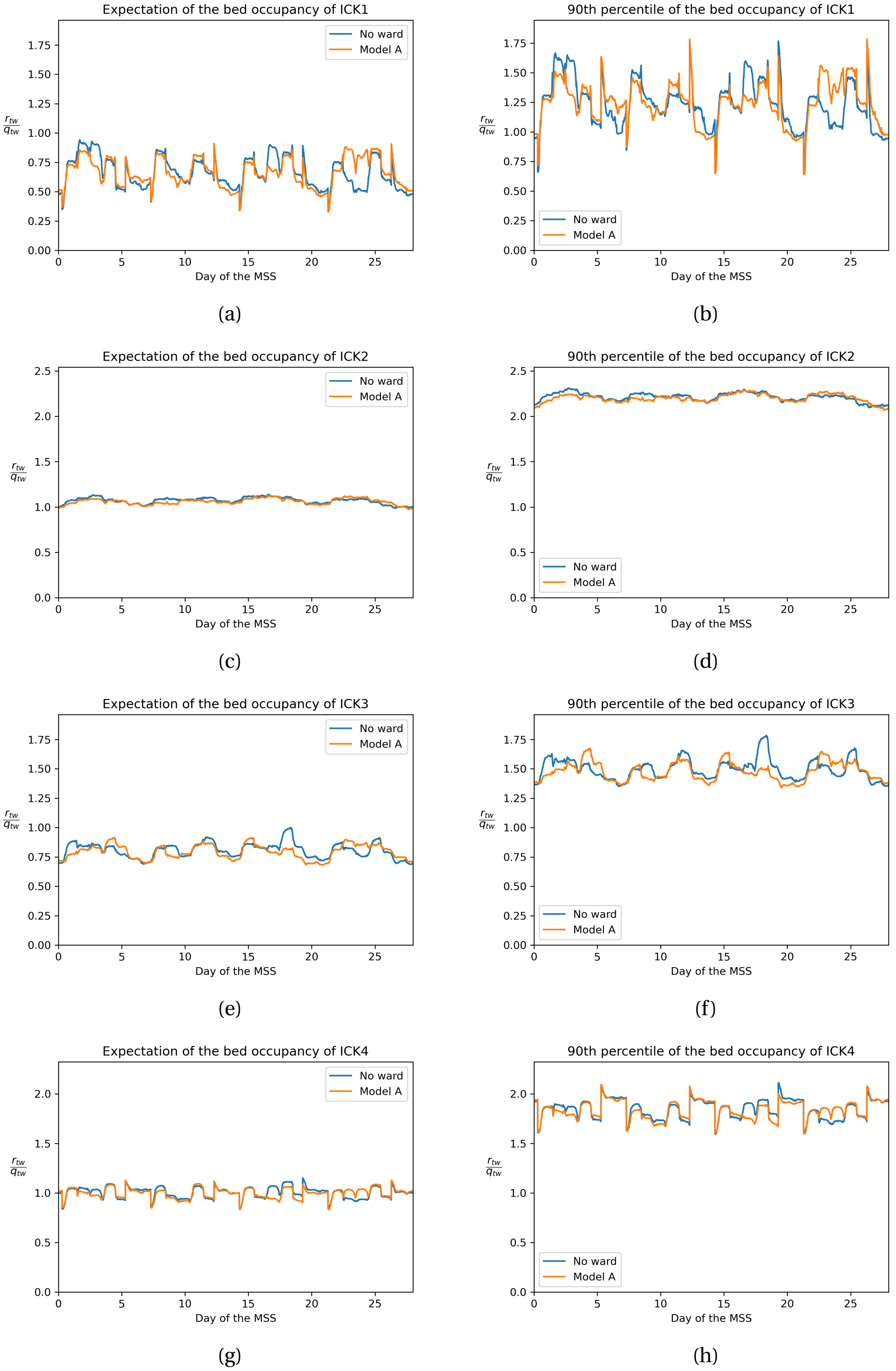
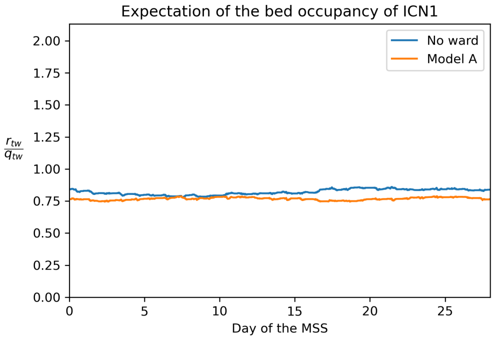
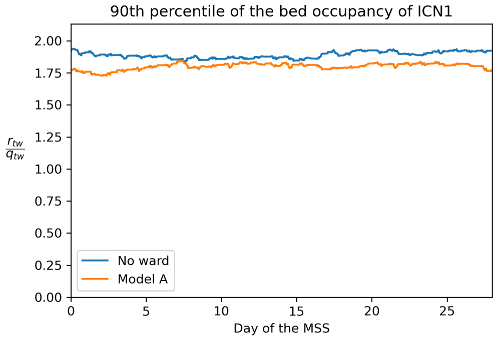


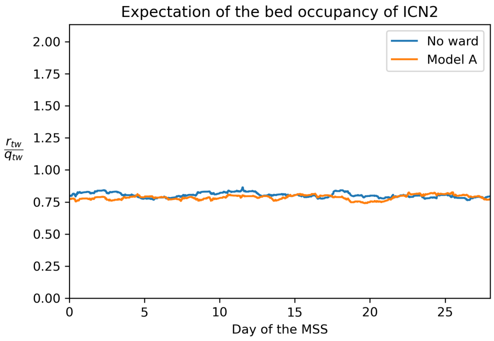
Figure E.1: Ward occupancy - 1



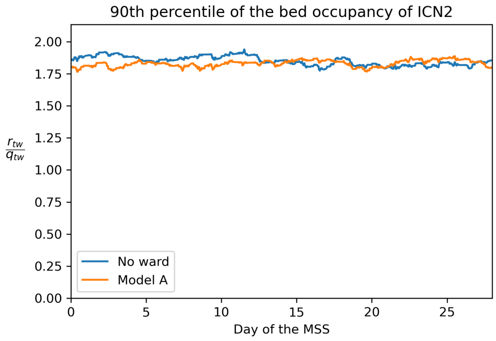
(a)



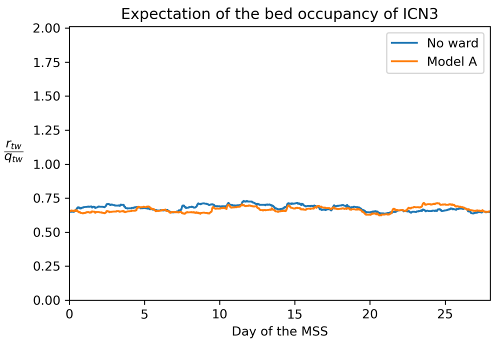
(b)



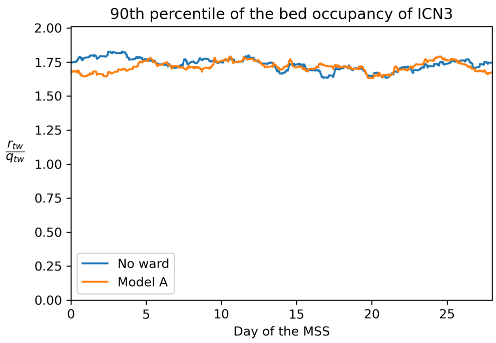
(c)



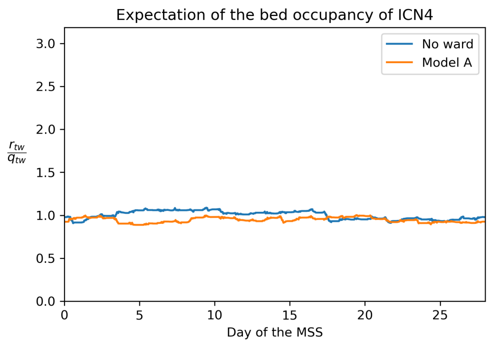
(d)



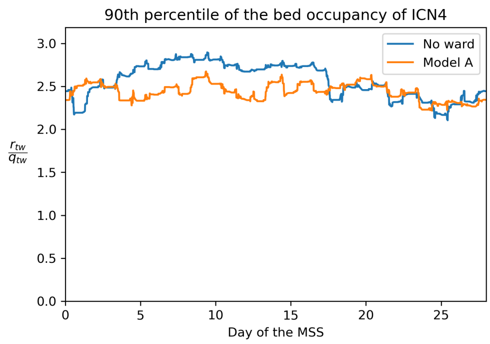
(e)



(f)

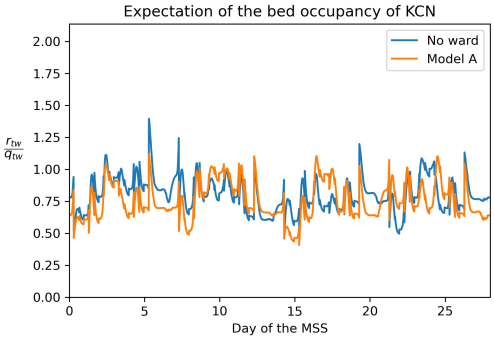


(g)

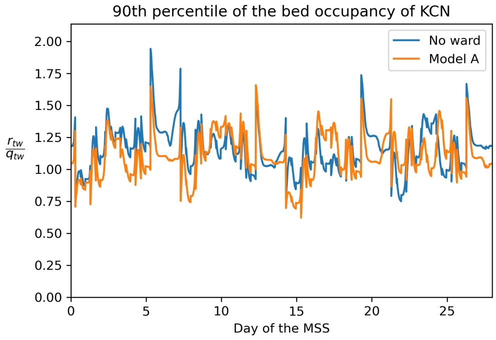


(h)

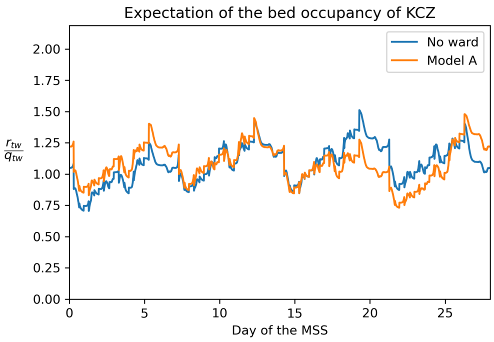
Figure E.2: Ward occupancy - 2



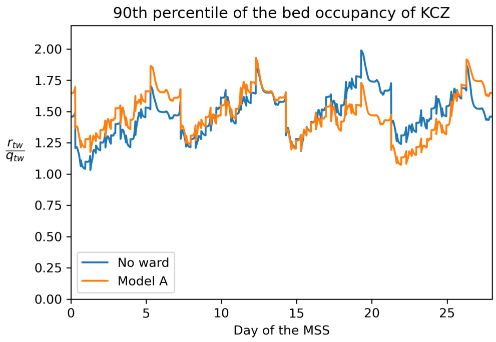
(a)



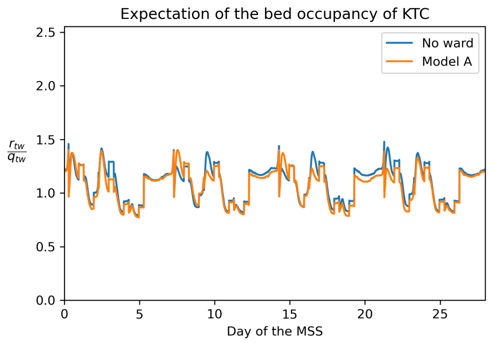
(b)



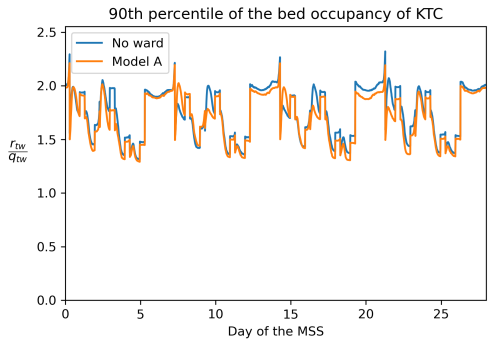
(c)



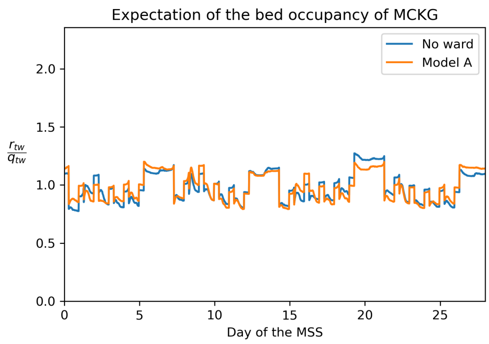
(d)



(e)



(f)



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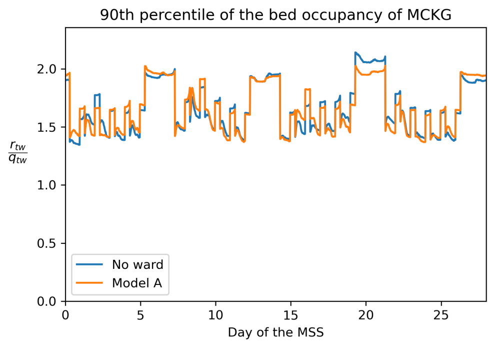
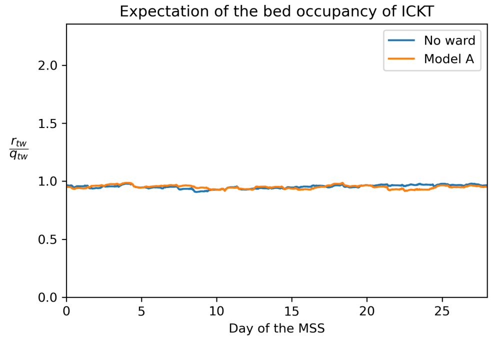
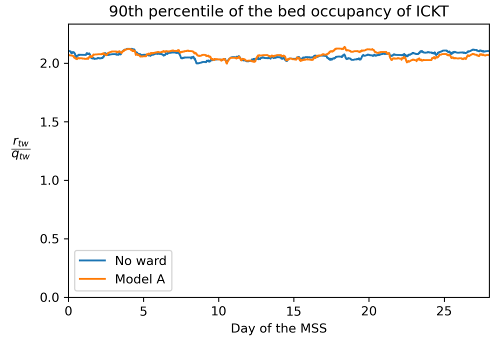


(h)

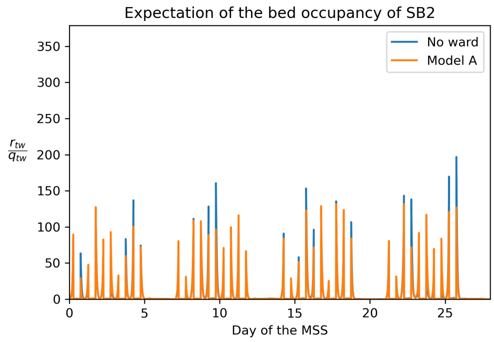
Figure E.3: Ward occupancy - 3



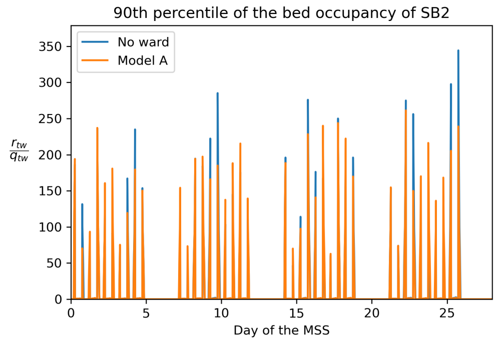
(a)



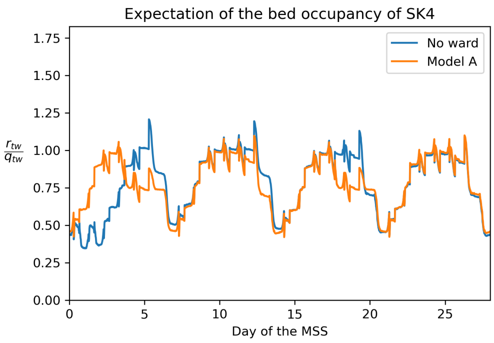
(b)



(c)



(d)



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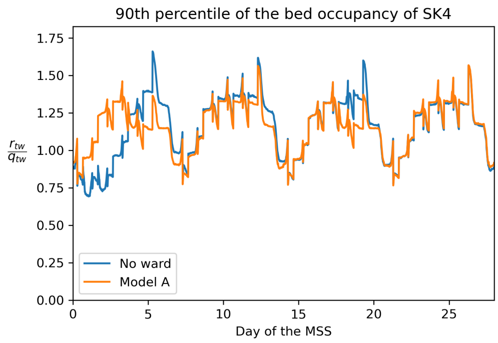

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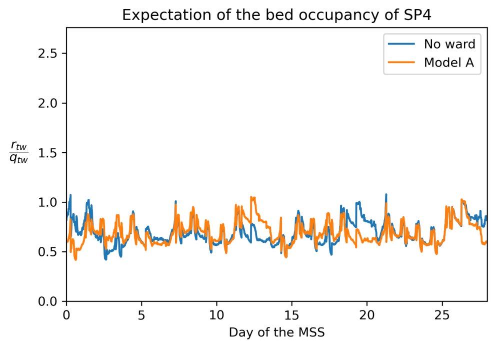
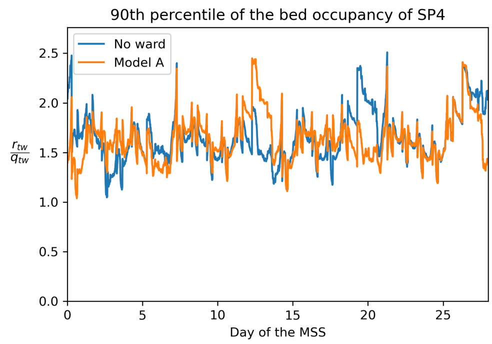


(g)



(h)

Figure E.4: Ward occupancy - 4