Analysis of the performance of the operating room department of Scheper hospital

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Management summary

Theme and motive

The Operating Room (OR) department of Scheper hospital has to deal with arrivals of unplanned surgeries. These unplanned surgeries are either urgent surgeries or emergency surgeries. Urgent surgeries have to start before 8 to 48 hours after arrival, depending on the urgency level. Emergency surgeries have to start within 30 minutes of arrival. To deal with the arrival of unplanned surgeries, Scheper hospital reserves one afternoon operating session for these surgeries. This means that the hospital does not schedule elective surgeries in this session. We call this session the emergency session. The session results in a decrease in the number of disruptions in the elective program due to unplanned surgeries and less overtime for urgent surgeries. However, this comes at a price because the session is empty much of the time. To deal with this, the OR department sometimes allows elective surgeries to be performed in the emergency session in case the elective program is running late. However, this policy does not lead to the desired increase in the utilization of the session time. We investigate alternative ways to deal with unplanned surgeries to increase the utilization of available session time. Furthermore, we investigate the successfulness of additional interventions in increasing the performance of the OR department.

Method

To analyze the effectiveness of different possible interventions, we simulate the OR department using discrete event simulation. The input of the simulation model consists of the general characteristics of the OR department, e.g. the room opening plan (ROP) and historical surgery durations. In the period of our research, the ROP changed a number of times. In our simulations, we use the most recent ROP. Additionally, we develop a number of new ROPs as part of possible interventions. We gathered the data concerning surgery durations with the help of the IT department and this data needed little work. The main reason for this is the introduction of a standardized electronic form in which surgeons have to register, among other details, the surgery durations. The OR planner verifies this data, as a result we obtain a reliable data set.

We recommend

- the OR department to work without an afternoon emergency session. Instead, the OR department can deal with unplanned surgeries by reserving capacity in all sessions. We call this reserved capacity emergency slack [Section 4.2];

- the OR department to keep ORs open during the lunch break and to hire additional OR personnel to make sure the OR personnel can still have their lunch breaks ;

- to incorporate planned slack when scheduling surgeries. Management of the OR department, together with the board of Scheper hospital, have to decide on the allowed overtime probability. To help make this decision, Section 6.2 presents an overview of the expected consequences of varying overtime probabilities.

Motivation

We show that these recommendations together result in an increase in utilization of 7.8%, a decrease in elective overtime of 39.1 minutes per day, and an increase in overtime due to urgent surgeries by 12.1 minutes per day. This results in 27 minutes less overtime per day while working with 7.25 OR hours less per week and without an afternoon emergency session. Furthermore, working without a lunch break requires 0.4 full time equivalents (FTEs) OR personnel less to make sure that surgery assistants are relieved timely by colleagues. Planning slack makes it possible to set targets for the utilization of available OR time for the individual specialties. These targets keep into account characteristics of the surgeries performed by these specialties [Section 6.2].

Consequences

- Working without afternoon emergency sessions results in additional online rescheduling for the OR planner due to the arrival of urgent and emergency patients. However, the OR department has some experience in working without an afternoon emergency session, which should ease the implementation. We show that working without an afternoon emergency session results in on average 10 more disturbances per year in the elective program due to the arrival of an emergency surgery. Urgent surgeries start after the completion of the elective program and therefore do not cause disturbances in the elective program.

- Working without a lunch break requires 0.4 FTEs less personnel to relief OR personnel. However, not everybody can take their lunch break at the same time. We refer to Section 4.5 for a detailed description of the consequences of working without a lunch break.

- Using planned slack has minor consequences for the way the Intake office schedules surgeries since the OR department already schedules surgeries based on historical surgery times, without which it is not possible to incorporate planned slack. However, before this can be done, the board of Scheper hospital, together with the management of the OR department, will have to decide on an allowed overtime probability.

Samenvatting

Thema en aanleiding

Het operatiecomplex van het Scheper ziekenhuis moet elk jaar ongeplande operaties verwerken. De ongeplande operaties kunnen spoedopereaties zijn of urgente operaties. Spoedoperaties moeten binnen 30 minuten na aankomst starten, urgente gevallen moeten binnen 8 tot 48 uur na aankomst starten, afhankelijk van het urgentieniveau. Om met deze ongeplande operaties om te gaan heeft het Scheper ziekenhuis een spoedsessie in de middag ingesteld waar urgente en spoedoperaties worden uitgevoerd. In deze sessie worden geen electieve operaties gepland. Het gevolg van deze sessie is dat er minder verstoringen zijn in het electieve programma, door de aankomst van een spoedoperatie. Tevens worden er minder urgente operaties uitgevoerd buiten reguliere werktijd. Er kleven echter ook nadelen aan deze spoedsessie. De sessie staat namelijk voor een groot gedeelte van de tijd leeg. Om dit nadelige effect te bestrijden worden er soms electieve operaties uitgevoerd in de spoedsessie, wanneer het electieve programma uitloopt. Dit heeft helaas niet geleid tot de gewenste toename in bezetting van de spoedsessie. Wij onderzoeken alternatieve manieren om ongeplande operaties te verwerken, om zo de bezetting van de beschikbare operatiekamer (OK) tijd te verhogen. Verder onderzoeken we de effectiviteit van aanvullende interventies die de bezetting van de beschikbare OK tijd kunnen verhogen.

Aanpak

Om de effectiviteit van verschillende mogelijke interventies te analyseren voeren we simulaties uit met simulatie software ontwikkeld door E.W. Hans. Als input voor het model gebruiken we de algemene eigenschappen van het operatiecomplex, bijvoorbeeld het kamer openstellingsplan, en historische operatietijden. Het kamer openstellingsplan is gedurende ons onderzoek verschillende keren gewijzigd. In onze simulaties gebuiken we het meest recente kamer openstellingsplan. Verder onwikkelen we aanvullende kamer openstellingsplannen als onderdeel van mogelijke interventies. De data gebruikt in ons onderzoek is verzameld met hulp van de IT afdeling en behoefde weinig bewerking dankzij de gestandardiseerde manier waarop de data verzameld is. De data wordt namelijk door de chirurgen ingevuld in een electronisch registratiesysteem. Doordat de OK planner deze controleert is de kwaliteit van de resulterende data hoog.

Aanbevolen wordt

- om zonder spoedsessie te werken. In plaats daarvan kunnen ongeplande operaties opgevangen worden in het electieve programma [paragraaf 4.2];
- om door te werken gedurende de middagpauze. Hiervoor is het nodig om extra personeel aan te nemen zodat het OK personeel nog steeds pauze kan nemen;
- om tijdens het plannen van operaties gebruik te maken van *planned slack*. Het management van de OK afdeling moet gezamenlijk met het bestuur van Scheper ziekenhuis een toegelaten kans op overwerk vaststellen. Voor het maken van deze

keuze beschrijft paragraaf 6.2 de verwachte gevolgen van verschillende “kansen op overwerk” op de gemiddelde bezetting en de gemiddelde hoeveelheid overwerk.

Motivatie

We tonen aan dat deze aanbevelingen samen resulteren in een toename in de bezetting van de beschikbare OK tijd met 7,8%. Verder verminderen we overwerk veroorzaakt door electieve operaties met 39,1 minuten per dag. Overwerk veroorzaakt door urgente operaties neemt toe met 12,1 minuten per dag waardoor het totale overwerk afneemt met 27 minuten per dag. Verder werken we met 7 uur en een kwartier minder OK tijd per week en zonder spoedsessie. Verder is er 0.4 full time equivalents (FTE) minder OK personeel nodig. Het gebruiken van *planned slack* tijdens het plannen van operaties maakt het mogelijk om doelen te stellen voor de bezetting van OK tijd voor de individuele specialismes. Deze doelen nemen de variabiliteit in de operatieduur mee, waardoor een eerlijkere vergelijking mogelijk is tussen de verschillende specialismes.

Consequenties

- Als gevolg van het werken zonder spoedsessie zal de OK planner vaker moeten schuiven in het OK programma door de aankomst van een ongeplande operatie. Echter heeft het Scheper ziekenhuis enige ervaring met het werken zonder spoedsessie wat de implementatie van deze aanbeveling vergemakkelijkt. Verder tonen we aan dat het afschaffen van de spoedsessie resulteert in gemiddeld 10 extra verstoringen in het electieve programma door de aankomst van een spoed operatie. Urgente operaties starten na het electieve programma en deze zorgen dus niet voor verstoringen in het electieve programma.

- Het doorwerken tijdens de lunchpauze vereist 0.4 FTE OK personeel minder. Verder is het niet meer mogelijk om iedereen tegelijk een lunchpauze te laten hebben. Voor een gedetailleerde uitleg van de gevolgen van het werken zonder lunchpauze verwijzen we naar paragraaf 4.5

- Het invoeren van het plannen van operaties met *planned slack* is weinig ingrijpend, omdat er momenteel al gepland wordt met behulp van historische operatietijden. Het werken met historiche operatietijden is namelijk een verreiste voor het invoeren van *planned slack*. Het bestuur van het Scheper ziekenhuis zal samen met de manager van de OK afdeling nog wel een toegelaten kans op overwerk moeten vaststellen, voordat er gewerkt kan worden met *planned slack*.

Preface

After studying for six and a half years the end is finally there. By finishing this master's thesis, I also finish my study Industrial Engineering and Management, a study with many faces and many possibilities, something I discovered after starting with my Bachelor's assignment and even more so during my master. I have always had an interest for health care. In fact, after college, I first applied for medicine in Groningen. During my master, the courses given by Erwin Hans focused on optimization of health care processes. These courses were my favourites so when it came to selecting a subject for my master's thesis, the choice was easy. Thanks to Erwin Hans, I found a very interesting research project at the OR department of Scheper hospital in Emmen. This thesis describes the results of this project.

Without the help and support of Kars Tolsma I would not have been able to perform this research. First of all he made it possible for me to do my research and was willing to be my supervisor. He always helped me with information or pointed me into the direction of people who could help me with my questions. One of these people was Maarten Verzijl, the OR planner who helped me understand the scheduling process. Also, I thank Frits Groen for giving me the time to finish my thesis.

The help of my supervisors Marco Schutten and Erwin Hans was essential for the completion of this thesis. They helped me to structure my work and clearly describe my work. They taught me to be more critical of my own work, an important lesson that will hopefully stick with me throughout my life.

I could not have written this thesis without the help of my friends and family. Thank you all for your valuable advice! Thanks also for making my days as a student a time to remember for the rest of my life.

Finally the successful completion of my study would not have been possible without the support of my parents. I am grateful they let me study in my own way and at my own speed and helped me when necessary.

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Ate M. Jansma

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1. Introduction

Each year Scheper hospital has to deal with unplanned surgeries. These unplanned surgeries disturb the elective Operating Room (OR) schedule. In an attempt to limit this disturbing influence, the management of the OR department, in cooperation with the specialists using the OR department, chose to open an emergency session. Due to the limited number of unscheduled surgeries, this emergency session is an afternoon session and not a full day session. The emergency session is now in place for five years and has led to fewer disruptions in the elective program. However, this has come at a price because the emergency session is empty a significant fraction of the time it is scheduled. We will research whether it is possible to work without an emergency session and if so, under which constraints.

1.1 Background

In recent years, the health care managers and professionals have an increasing attention for more efficiency. This attention is instigated by an increase in health care demand due to an aging population [Hans et al., 2006], a demand from the government and society to increase the quality of care while lowering the cost of care, and tighter financing from the government in the form of general cutbacks [Leveste, 2007].

1.1.1 Scheper hospital

Scheper hospital is part of the Leveste foundation, a care group in Emmen, the Netherlands. Leveste has 3,600 employees, including 100 medical specialists. The foundation comprises two divisions: Care and Cure. The division Cure, Scheper hospital, is a regional hospital with 8 operating rooms, where 11 different specialties perform around 8,000 elective surgeries each year. The specialties are autonomous entities managed by the surgeons. The operating room department facilitates the day to day running of the operating rooms by providing the resources that make it possible for the surgeons to do their work. Examples of these resources are the operating room, equipment such as an X-ray machine, and the surgery assistants.

1.1.2 The emergency session

Since 2004, the operating room department has a reserved session in the afternoon for unplanned surgeries. This session is also used as a buffer for the elective program. When an unplanned surgery arrives in the morning and there is no free operating room, the patient will have to wait until the emergency session starts. However, if the patient needs immediate attention, the surgery is performed in the first available OR. These are the emergency surgeries. In practice, these make up only a limited portion of the total number of unplanned surgeries. The remaining unplanned surgeries are urgent surgeries. These surgeries have to be performed within 8 hours, 24 hours, or 48 hours, depending on the severity of the condition of the patient. Due to the limited number of unplanned surgeries, the management of the OR chose to allow the planner to plan elective surgeries in the emergency session, in case there are no unplanned surgeries. This is done in case the elective morning program is running late. Unplanned surgeries arriving in the afternoon or at night are dealt with by the afternoon and night shift, if they cannot wait until the next day.

1.2 Problem description

The management of the OR department perceives the performance of the emergency session to be low. The emergency session is empty for a substantial amount of time. Consequently an OR team of assistants and a surgeon stand by idle, resulting in high costs with a low return in the form of surgeries. At the same time, the specialists using the emergency session as well as the OR personnel, value the lower number of disturbances in the elective program due to the emergency session.

In the absence of an emergency session, unplanned surgeries have to be dealt with in the elective program. Before the existence of the emergency session this was done by either cancelling or postponing elective surgeries, or by postponing the unplanned surgery until the elective program was finished. Obviously, postponing is not an option for emergency surgeries. This policy leads to overtime, an undesired consequence for all parties involved. The management of the OR department dislikes overtime because it is more expensive in terms of OR personnel salaries. The OR personnel, as well as the specialists, do not like to work in overtime, especially if this overtime is not anticipated. It is therefore clear that going back to the old situation, working without an emergency session, is no option unless the risk of running into overtime can be limited. The main problem of our research is then:

The emergency session, including its dedicated personnel and specialist, is idle a substantial proportion of the time, resulting in high costs and low returns

This problem has many facets and it is not possible for us to examine them all. We choose to examine the problem from a scheduling perspective, specifically scheduling the ORs. Therefore the objective of our research is:

To compare different planning and scheduling methods of dealing with unplanned surgeries, in terms of OR utilization and other relevant performance indicators, and to give recommendations on how to improve the performance of the OR department

To reach this objective we propose the following research questions:

1. What is the context of our research?

Chapter 2 gives a description of the OR department. We summarize the surgeries performed, describe how the planning is organized, and analyze the current performance of the OR department.

2. Which methods for dealing with unplanned surgeries are available?

We search the existing literature for methods for dealing with unplanned surgeries. From this, we develop methods to increase the performance of the OR department.

3. What are suitable performance indicators to compare the different possible interventions?

By reviewing performance indicators from the literature as well as performance indicators used by the OR department of Scheper hospital, we develop a number of performance indicators which we can use to compare different interventions.

4. Which interventions will potentially increase the performance of the OR department of Scheper hospital?

Using the literature [Chapter 3], combined with the description of the OR department [Chapter 2], we suggest possible interventions that might increase the performance of the OR department [Chapter 4]. We analyze the expected performance of the OR department after implementing the interventions and analyze the consequences using computer simulation.

5. Which interventions are most suitable for the OR department of Scheper hospital?

Chapter 5 presents a simulation model. Using this simulation model we compare the different interventions we found in Chapter 4. We use the selected performance indicators from the literature and from Scheper hospital to evaluate the effectiveness of the different interventions [Chapter 6].

6. How can the management of the OR department perform the suggested interventions

Chapter 7 gives suggestions on how to implement the selected interventions. Furthermore we perform a stakeholder analysis.

2. Context

In this chapter we describe the OR department, the planning of the OR department, and the characteristics of the surgeries. In Section 2.1 we begin with the process, describing the surgeries and the recourses of the OR department. We continue in Section 2.2 with a description of the planning and control processes, using the planning and control framework introduced in Section 2.2.1 [Houdenhoven et al., 2007a]. In Section 2.3 we give an overview of the current performance using performance indicators also used by the OR department.

2.1 Process description

We describe the surgical procedures, both elective and unplanned, at Scheper hospital. We give durations, arrival patterns during the day and during the year, and frequencies. Section 2.1.2 continues with a description of the resources available at the OR department.

2.1.1 Surgical procedures

Scheper hospital has 11 specialties that perform surgery. The largest specialty is General Surgery, performing 1892 surgeries in the period January to November 2008. Each specialty has a number of sessions per week in which it can use an OR. There are morning, afternoon, and full day sessions. A specialty can have more than one session per (part of the) day. Each day, one afternoon session is reserved for unplanned surgeries.

To simulate the OR planning we need historical surgery times. For this purpose we have collected data on surgery procedures performed between January and November 2008. Since the hospital switched to a new IT system at the end of 2007, no data from before January 2008 is available. Furthermore, because we collected the data in December 2008 we do not have data for December 2008. For each surgery we know the surgeon who performed the surgery, the specialty of the surgeon, the OR in which the surgery was performed, the time the patient entered and left the OR, whether the patient was an adult or a child, and whether the surgery was elective or urgent. The OR department makes a distinction between 4 levels of urgency. The highest level of urgency is reserved for emergency patients, who need surgery within 30 minutes. Section 2.2.3 gives an overview of the urgency levels.

From the historical data we have established the number of surgeries performed and the mean and standard deviations of the different surgeries performed. Since we are interested in the performance of the OR department during regular working hours, we remove surgeries performed in weekends when we determine the number of surgeries. Furthermore we remove emergency surgeries performed outside regular working hours. Emergency surgeries have to be performed within 30 minutes of arrival and can therefore not be postponed until regular working hours (08:00 - 16:00). Ideally we would like to remove only the emergency surgeries arriving outside regular working hours. Unfortunately we do not know the arrival times of unplanned surgeries. For the remaining surgeries, we assume that they could have been performed in regular working hours but were postponed until after 16:00 because of capacity limitations during regular working hours. However, we include the surgeries performed in the weekends when we calculate the average duration and standard deviation of the surgery types to get a more accurate estimate. Furthermore, we have removed the surgeries performed by 6 specialties. These specialties perform only 11 or less surgeries per year and have no dedicated ORs [Section 2.2.3]. For a detailed description of the surgeries we have removed from the data, we refer to Appendix A.

Elective surgeries

In our surgery analysis we categorize surgeries based on their medical specialty. Table 1 shows the mean and standard deviations of the durations of the surgeries performed by the different specialties. These durations are measured from the time the patient enters the OR to the time the patient leaves the OR. We see that Anesthesiology is also performing surgeries. These surgeries are minor, have an average duration of 11.1 minutes, and make up 2.7% of the total number of elective surgeries during working hours and only 0.45% of the total surgery duration. Ophthalmology and Oral Surgery only perform a relatively small number of surgeries. In light of this, the decision has been made to cancel the Ophthalmology session in 2009. Furthermore the specialties Oral Surgery and Dentist share a session in 2009. For a more detailed overview of the tactical changes in the available sessions we refer to Section 2.2.3. For a more detailed overview of the surgeries performed during 2008 we refer to Appendix B.

Table 1: Elective Surgeries (Jan-Nov 2008, X-care)

	Average surgery duration (min)	Standard deviation (min)	# of surgeries	Part of total # of elective surgeries
General Surgery	81.6	51.4	2274	36.47%
Orthopedics	64.5	42.9	1897	24.05%
Gynecology	54.4	32.2	1097	11.73%
Plastic Surgery	77.7	42.5	580	8.86%
ENT	39.9	17.7	593	4.65%
Urology	89.7	81.9	476	8.39%
Neurosurgery	73.5	17.1	217	3.13%
Anesthesiology	11.1	8.8	206	0.45%
Dentist	67.3	26.2	111	1.47%
Ophthalmology	43.2	21.0	54	0.46%
Oral Surgery	47.3	25.5	37	0.34%
Total	67.3	47.4	7542	100.0%

Table 2 gives the 10 most performed surgeries during the period of January to November 2008. The Orthopedic surgery “Arthroscopy of the knee” is the most frequently performed surgery (N=579), accounting for 30.7% of the total number of Orthopedic surgeries. This top 10 comprises almost 24% (1805) of the total number of 7542 elective surgeries and almost 21% of the total elective surgery time.

Table 2: 10 most performed elective surgeries during working hours (Jan-Nov 2008, X-care)

Type	#	% Of total # of respective specialty	Average duration (min)	Specialty
Arthroscopy of the knee	579	30.7%	30.5	Orthopedics
Laparoscopic cholecystectomy	247	13.1%	75.2	General Surgery
Inguinal hernia, groin rupture	170	9.0%	54.8	General Surgery
Reduction mammaplasty /reconstruction	133	23.3%	106.6	Plastic Surgery
Total knee prosthesis	124	6.6%	98.2	Orthopedics
Gastric Sleeve.	121	6.4%	96.4	General Surgery
Tonsillectomy patient > 16 years	110	18.6%	41.1	ENT
Septum correction	110	18.6%	55.2	ENT
Therapeutic hysteroscopy, small	109	9.8%	37.0	Gynecology
Lumbar hernia	102	47.4%	75.7	Neurosurgery

Figure 1 shows the starting time of the 7542 elective surgeries performed in the period January - November 2008. We divided the day into periods of 30 minutes. The second bar indicates the number of surgeries starting between 7:30 and 8:00. We assume that the 101 elective surgeries starting between 16:00 and midnight should have been performed in the elective program but ran into overtime. The last bar in Figure 1 indicates these surgeries.

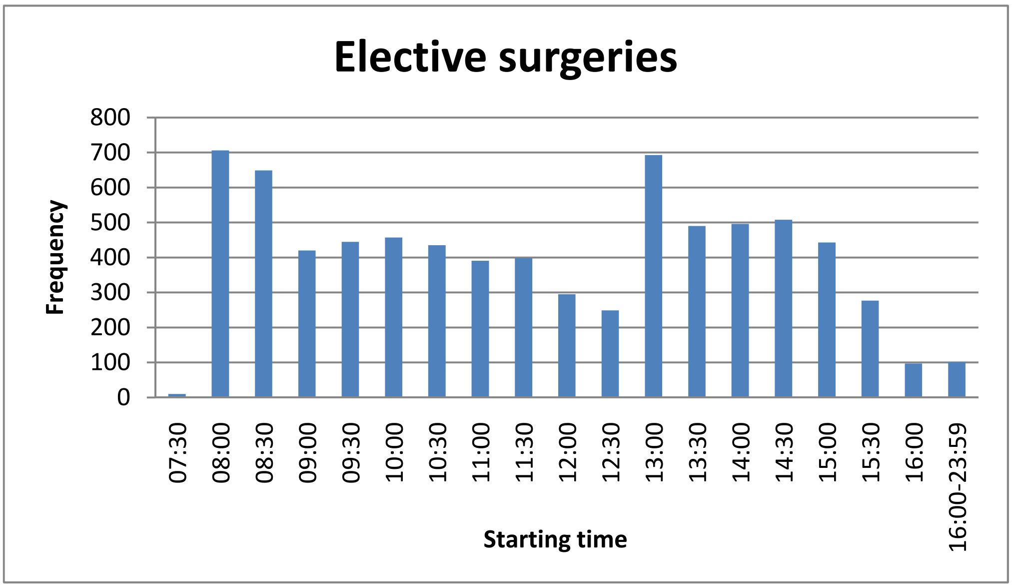

Figure 1: Starting times of elective surgeries during working hours (N= 7542, Jan-Nov 2008, X-care)

A relatively high number of surgeries start between 7:30 and 8:30 while the regular program starts at 8:00. This indicates that it is not uncommon for the regular program to start early. The high number of surgeries starting between 12:30 and 13:00 is due to the lunch break from 12:15 to 13:00. Figure 2 shows the effect of the lunch break in more detail. Here we see a relatively low number of surgeries starting just prior and during the lunch break, with a large increase in the interval 12:45 to 13:00.

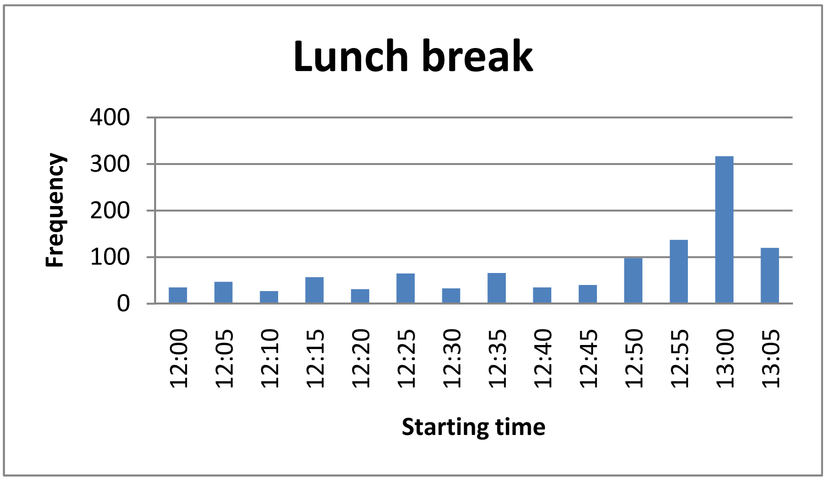

Figure 2: Influence of the lunch break on the elective program (N=1108, Jan-Nov 2008, X-care)

Figure 3 shows the number of elective surgeries per month in the period January - November 2008. We see a drop in the number of surgeries in July and to a lesser degree in August. This is caused by the OR working at a reduced capacity due to the summer holidays during July and the first half of August. This effect is most noticeable for the specialty Orthopedics, with almost half of the average number of surgeries per month performed in July.

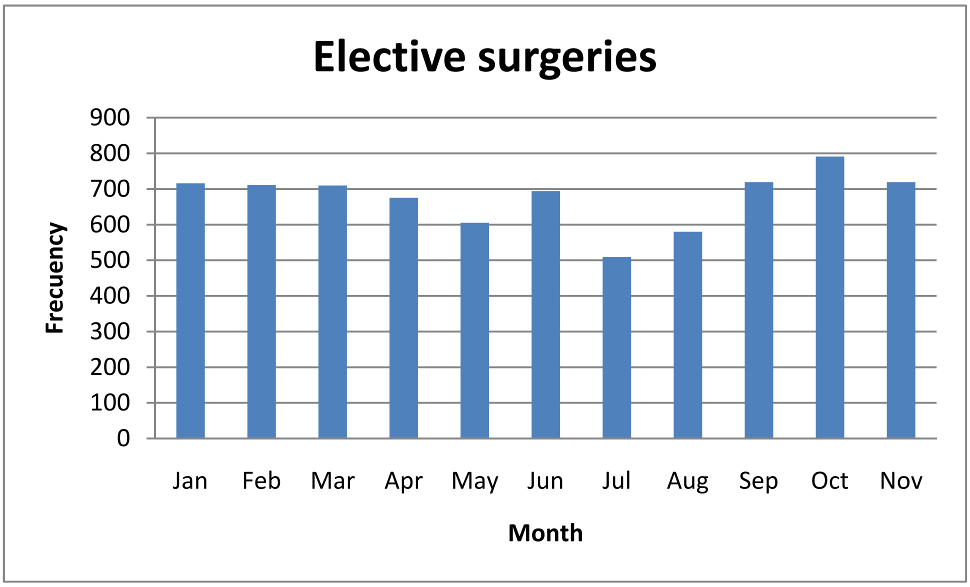

Figure 3: Number of elective surgeries during working hours per month (N=7542. Jan-Nov 2008, X-care)

Table 3 gives the average changeover times between surgeries. These are average changeover times per specialty. The average surgery times in Table 1 and Table 2 are measured from the time the patient enters the OR to the time the patient leaves the OR. Between the departure of one patient and the arrival of the next patient, the OR is empty for a short time. This is the changeover time. The changeover times in Table 3 are between surgeries in the same session.

Table 3: Average changeover times between surgeries (Jan-Nov 2007, X-care)

Specialty	Changeover time (min)
General Surgery	10
Orthopedics	9
Gynecology	8
Plastic Surgery	13
ENT	6
Urology	8
Neurosurgery	7
Anesthesiology	9
Dentist	9
Ophthalmology	8
Oral Surgery	7

Urgent and emergency surgeries

Besides elective surgeries, the OR department also performs urgent and emergency surgeries. In the period January - November 2008 the OR department performed 769 urgent surgeries during weekdays. Of these 769, 408 were performed during regular working hours, meaning that almost 47% of these surgeries started outside regular working hours. Of the 408 surgeries starting during regular working hours, 27% started in the morning, 10% during the lunch break, and 63% in the afternoon. Figure 4 shows the starting times of the urgent surgeries per quarter of an hour.

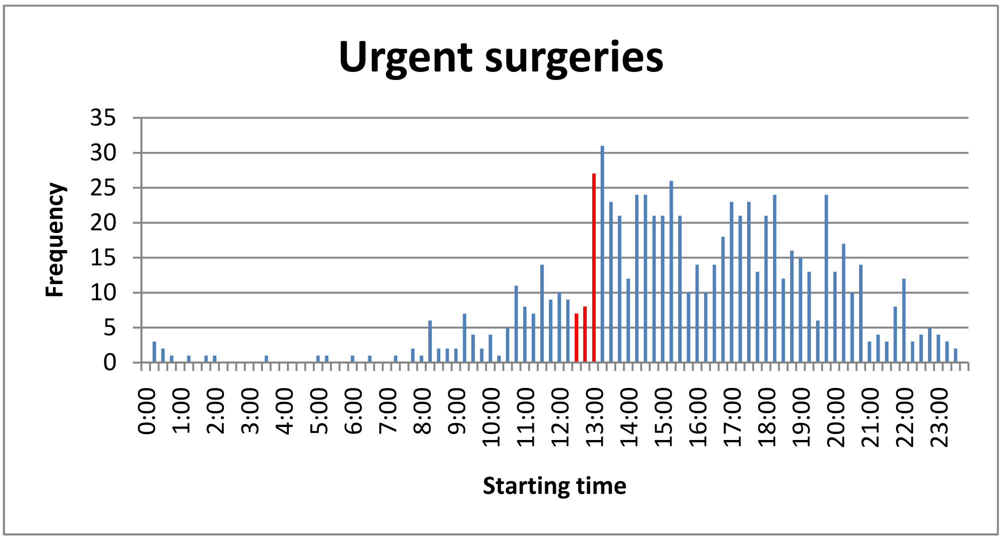

Figure 4: Starting times of urgent surgeries during working hours (N= 769, Jan-Nov 2008, X-care)

When we divide the number of surgeries in the morning and the afternoon by the available hours in the morning and afternoon, respectively 4.25 hours and 3 hours, we see that in total 23.5 urgent surgeries per hour started in the morning versus 85.3 per hour in the afternoon. So the number of surgeries per hour starting in the afternoon is more than 3 times as high as that in the morning.

In the period January - November 2008 the OR department performed 56 emergency sugeries during regular working hours. These surgeries started homogeneously during the day as Figure 5 shows. In fact 50% of the emergency surgeries started in the morning and 7% started during the lunch break. The remaining 43% started in the afternoon. This is reasonable since emergency surgeries have to start within 30 minutes of arrival and therefore cannot be postponed until the emergency session starts.

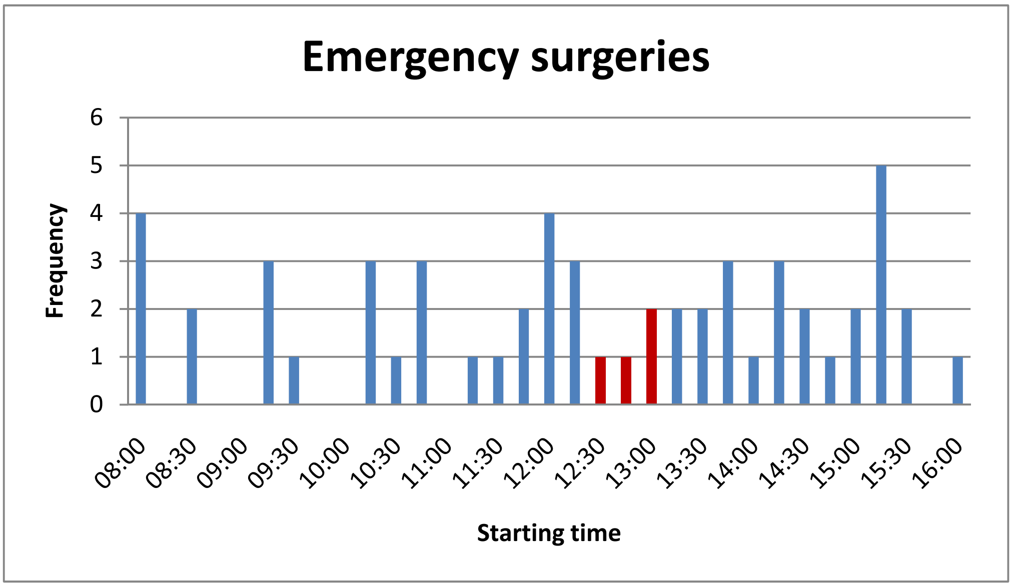

Figure 5: Starting times of emergency surgeries during working hours (N=56. Jan-Nov 2008, X-care)

Figure 6 and Figure 7 show the arrival of urgent and emergency surgeries throughout the year. For the urgent surgeries we see a decrease in the arrivals per unit of time in the summer months. However, these months are reduction months, meaning the OR department works at a reduced capacity, and no emergency session is available during reduction months. Therefore this has no influence on the performance of the emergency session. The arrival pattern of emergency surgeries throughout the year appears to be erratic. However, because of the low number of total emergency surgeries, we cannot say anything conclusive about possible seasonal influences. Furthermore, in order to say anything conclusive about the existence of a seasonal trend, one needs at least 3 years of data [Silver, Pike, and Peterson, 1998].

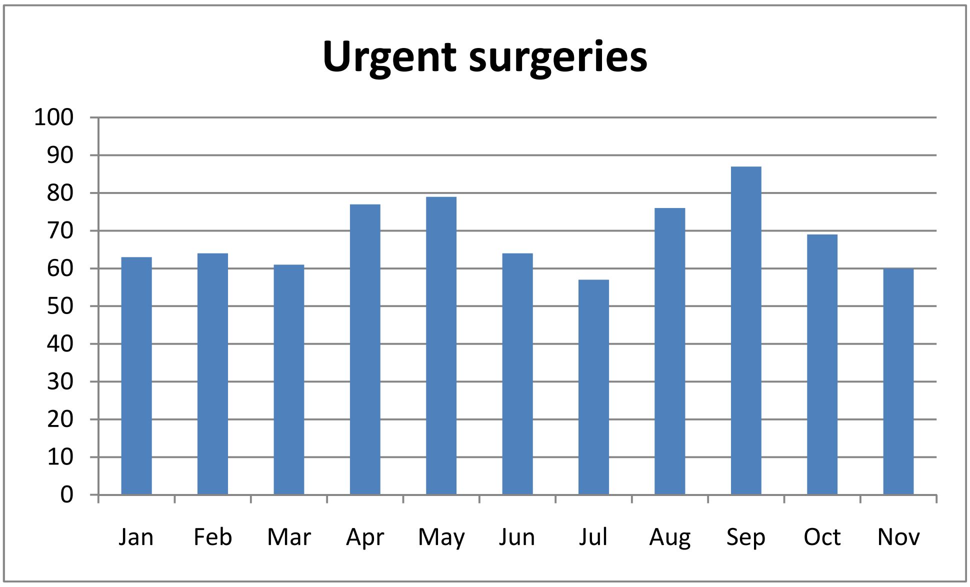

Figure 6: Number of urgent surgeries during working hours per month (N=769. Jan-Nov 2008, X-care)

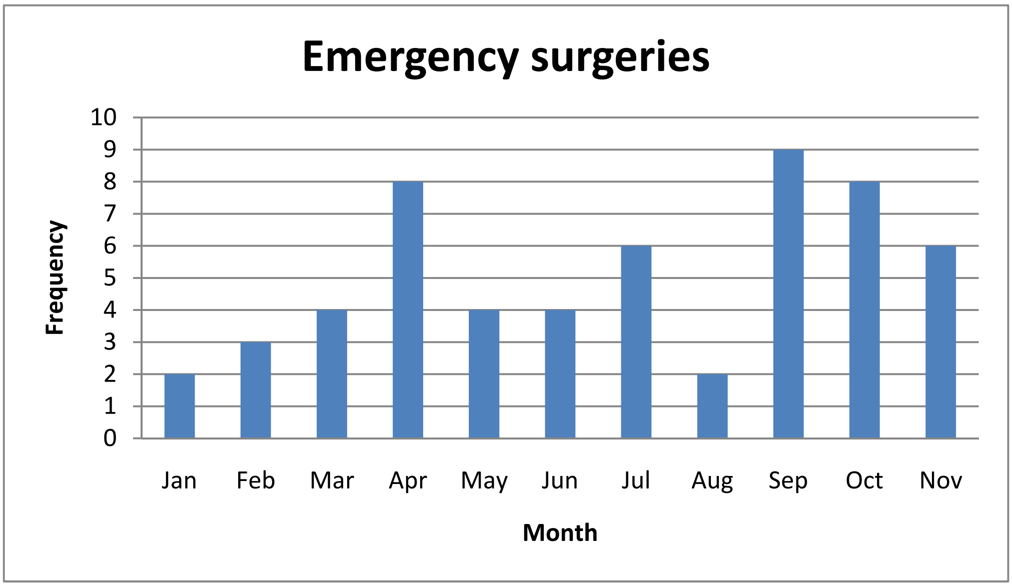

Figure 7: Number of emergency surgeries during working hours per month (N=56. Jan-Nov 2008, X-care)

2.1.2 Resources

For the surgeons to be able to perform surgeries they need resources. We will now briefly describe these resources. We give an overview of the equipment and the personnel working at the OR department or otherwise involved with the OR department.

Equipment

The OR department contains 8 ORs of which 2 were added a few years ago. These ORs (OR 7 and OR 8) are equipped to perform endoscopic surgeries. Every weekday one OR serves as an emergency OR in the afternoon. It differs from day to day and from week to week which OR serves as the emergency OR.

Patients arrive at the holding were the anesthesiologist checks the patient. The anesthesiologist checks for example if the procedure must be performed on the left or on the right side of the patient. When everything is in order, the patient is brought to the OR. After the surgery the patient is taken to the recovery. When the situation of the patient is stable and there is room in the nursery, the patient is brought to the nursery.

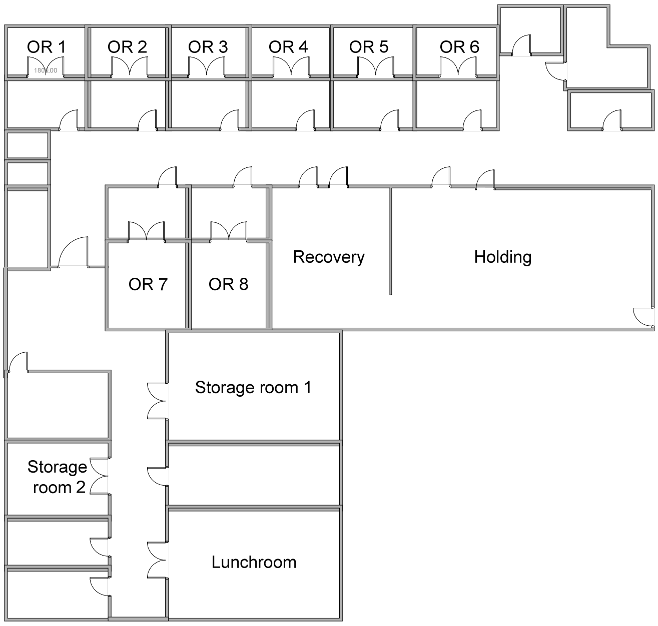

Figure 8: Layout of OR department Scheper hospital

Figure 8 shows the layout of the OR department. Instrument trays are stored in storage room 1. This room is restocked daily. Instrument trays necessary for the surgeries of the day are moved into trolleys. These are wheeled to the OR before the start of the surgery. After the surgery, the instruments are sterilized by the central sterilization department of the hospital and returned to storage room 1 the next day. Certain equipment not needed for every surgery, such as microscopes, is stored in storage room 2.

X-care is the scheduling software used by the hospital to plan the surgeries. The hospital stores, among other information, planned and realized surgery durations, the surgeon performing the surgery, urgency level of the surgery, and the surgery type. The planner uses Monaco III, developed by I.C. systems, for personnel planning.

Personnel

We describe the personnel involved with the OR department, using the division introduced by Glouberman and Mintzberg [2001]. The authors describe the way in which four major groups involved with the hospital work together. The four groups are the Doctors, Nursing, Trustees/ Board, and Administrators. Since this division in groups is also applicable to OR departments, we will now use it to describe the personnel involved with the OR department. We will, however, not describe the" Trustees/ Board" group of Scheper hospital because this falls outside the scope of our research. We start with the surgeons and anesthesiologist, both part of the group Doctors.

Surgeons

Specialties are autonomous entities managed by the surgeons. Around 41 surgeons make use of the OR department. Table 4 shows the average number of surgeons per specialty. Anesthesiology also performs a small number of minor surgeries. These surgeries are performed in the holding and sometimes in an OR.

Table 4: Number of Surgeons per Specialty

Specialty	Number of surgeons
General Surgery	9
Orthopedics	4
Gynecology	6
Plastic Surgery	3
ENT	3
Urology	3
Neurosurgery	2
Anesthesiology	5
Dentist	1
Ophthalmology	4
Oral Surgery	1
Total	41

Anesthesiologists

Tasks of the anesthesiologist are, among others, monitoring vital signs of patients during surgery and administering anesthesia. With the help of assistants the anesthesiologist is able to monitor two ORs simultaneously. Anesthesiologists can either be employed by the hospital or they can be self-employed. In recent years, there has been an increase in the number of self-employed anesthesiologists at Scheper hospital. The reason for this is an increase in salary.

Nursing

The OR assistants group consists of 56.95 full-time equivalents (FTEs) divided in two main groups: 40.06 FTEs of operating assistants and 16.89 FTEs of Anesthesia assistants. A further 9.8 FTEs work at the recovery. There is currently a shortage of assistants in the Netherlands. Consequently, it is challenging to keep assistants working for the hospital, as well as attracting extra personnel.

Administrators

The OR manager is responsible for the smooth functioning of the OR department and represents the interests of the hospital. The OR manager frequently meets with representatives of the different specialties performing surgeries. The responsibility of the OR planner is to manage the day-to-day personnel planning as well as the surgery planning.

2.2 Planning and control

Houdenhoven et al. [2007a] introduced the hospital planning and control framework. We will use this framework to analyze the resource capacity planning and control of the OR department at Scheper hospital. We begin with a description of the framework.

2.2.1 Hospital planning and control framework

Houdenhoven et al. [2007a] present the hospital planning and control framework as depicted in Figure 9. This framework spans all planning and control activities in hospitals and is also applicable to OR departments.

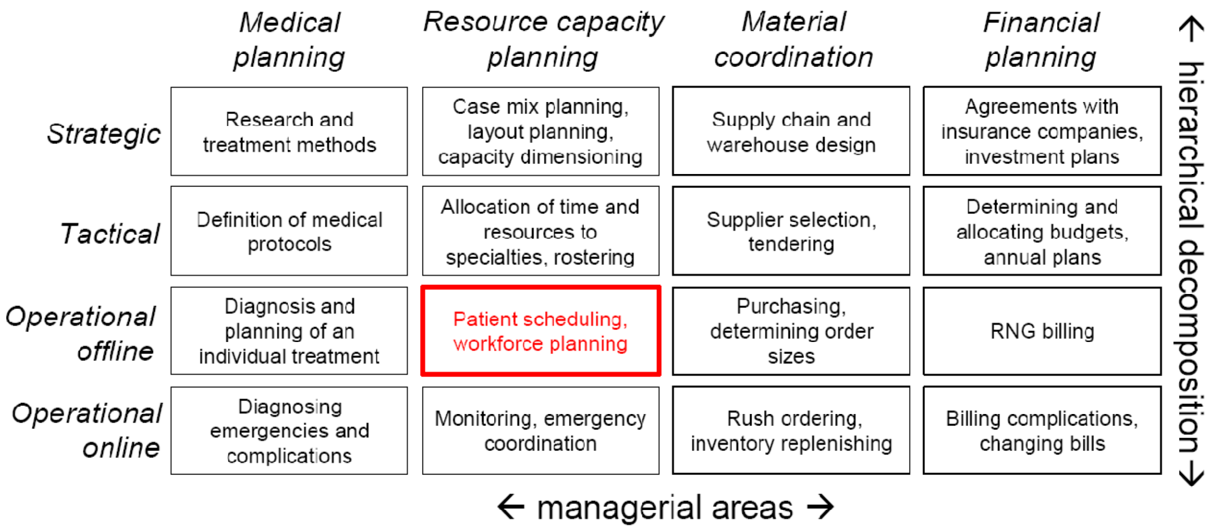

Figure 9 Hospital planning and control framework [Houdenhoven et al., 2007a]

The framework distinguishes four managerial areas. Each managerial area has its own distinct planning, namely medical planning, resource capacity planning, material coordination, and financial planning. Medical planning is concerned with the planning of medical activities and is performed by the doctors. Resource capacity planning aims at the efficient use of hospital resources, such as OR personnel and operating rooms. Material coordination deals with the coordination of instruments, blood, et cetera. Financial planning encompasses all financial functions in the hospital.

Next to the differentiation into four managerial areas, the framework discerns four hierarchical levels. Strategic planning deals with the long term, setting objectives and determining the investments needed to reach these objectives. Tactical planning translates the strategic objectives into medium term objectives. Houdenhoven et al. [2007a] give as an example the resource capacity planning. Strategic planning uses long term forecasts of patient volumes to set objectives whereas tactical planning deals with actual patients. Operational planning also deals with actual patients. The difference between tactical planning and operational planning is that there is more flexibility on the tactical level. This flexibility is achieved by, for example, temporarily hiring more personnel or working in overtime. The framework makes a further distinction into offline and online operational planning. While both deal with short term planning, online planning reacts to unforeseen events as they happen, for example the arrival of an emergency surgery. Operational offline planning deals with patient scheduling and workforce planning for the next planning cycle, e.g. the OR schedule for next week.

We continue with an application of the framework to the situation at the OR department of Scheper hospital. Our research focuses on the resource capacity planning and control on a tactical level, however, we will also describe the planning on a strategic level and on an operational level.

2.2.2 Strategic

The OR manager together with the manager of the surgery department and the board of directors of the Leveste foundation is responsible for the strategic management of the OR. In 2004, Leveste management decided to open 2 extra ORs, resulting in a total of 8 ORs. This was done in light of increasing health care demand in the future due to an aging population. In the same year, the Dutch department of health started with an ambitious improvement program aimed at hospitals in the Netherlands, called "Sneller Beter" (Faster Better). 24 hospitals, around 20% of the total number of hospitals in the Netherlands, where selected to take part in this project [Vos et al., 2008]. The management of Scheper hospital decided to participate in this program. This resulted in Scheper hospital taking part in the second session of the program, running from 2005 to 2007. Among the many different sub projects embedded in Faster Better, one is relevant to our research, namely "OK oké" (OR okay). The goal of *OR okay* was to improve the efficiency of the OR by 30%. During the project it became clear that this goal was too ambitious. Instead it was set at an increase in efficiency of 10%. Just prior to starting with the program, management decided to close 1 OR due to a limited availability of patients, resulting in poor efficiency. Closing this OR resulted in an increase in efficiency. This OR, however, was reopened a few years later.

The project's main results are a clear definition of emergency surgeries and performance indicators. It was also decided to allow elective surgeries in the emergency session in case the emergency session was empty. Unfortunately the project did not result in the desired increase in efficiency. After the *Faster Better* program Scheper hospital continued seeking ways to improve the efficiency of the OR.

Currently there is a project underway to map the clinical pathways. Furthermore, recent investigations have made clear that the capacity at the wards is a bottleneck, resulting in cancelations of surgeries at the OR. Therefore, management is currently looking at ways to optimize the OR planning with regards to the ward utilization.

2.2.3 Tactical

The OR department uses a cyclic schedule with a cycle length of a week to plan surgeries, a so called room opening plan (ROP). In this ROP each specialty has one or several (half) OR days. An OR day is a combination of a day and an OR. At the end of each year, the OR planner makes a draft of the room opening plan for the next year. The different specialties have the possibility to comment on this draft. After incorporating these comments, the room opening plan is final. From 2009 on, the OR department will readjust the room opening plan once a quarter instead of once a year. Table 5 gives the room opening plan as of October

2008. To clarify: Oral Surgery has 1 session a week 3 weeks in a row, after which Ophthalmology has 1 session 1 week.

Table 5: Room opening plan

		General Surgery	Orthopedics	Gynecology	Plastic Surgery	ENT	Urology	Neurosurgery	Anesthesiology	Dentist	Ophthalmology	Oral Surgery	Emergency	Total
Monday	morning	3	2	1		1		1						8
	afternoon	2	2	1		1							1	7
Tuesday	morning	3	2		1		1	1						8
	afternoon	2	2		1		1						1	7
Wednesday	morning	3	1	1	1	1	1							8
	afternoon	2	1	1	1		1		1				1	8
Thursday	morning	2	2	1			1			1				7
	afternoon	2	1	1	1		1						1	7
Friday	morning	2	3	1	1						¼	¾		8
	afternoon	2	2	1	1								1	7
Total		23	18	8	7	3	6	2	1	1	¼	¾	5	75

The OR department makes a distinction between mornings and afternoons. In this way, an OR that serves one specialty in the morning can serve another in the afternoon. The border between mornings and afternoons is formed by the lunch break from 12:15 to 13:00. Three ORs keep running during lunch breaks and serve only one specialty per day. It differs from day to day and from week to week which specialties make use of these full OR days.. Furthermore, next to having one half OR day per week, Anesthesia also performs certain minor procedures in the holding.

During weekdays the OR department reserves one afternoon session for unplanned surgeries. Consequently, there is also one OR team on standby. Unplanned surgeries that arrive outside the opening hours of the emergency session will have to either wait until the emergency session starts, or they will be treated by the evening or night shift. These shifts are in place to deal with emergency surgeries arriving outside regular working hours. Unplanned cases that arrive in the morning will generally have to wait until the emergency session starts in the afternoon. However, it is possible that a patient cannot wait that long. Therefore, the OR department uses a four grade classification of unplanned patients, depending on the urgency of the surgery. Table 6 shows these urgency levels and the time before which the patient must be operated. The highest urgency level is reserved for emergency patients for whom surgery has to start within 30 minutes.

Table 6: Urgency levels

Urgency level	Maximum waiting time
1	30 minutes
2	6 hours
3	24 hours
4	48 hours

In October 2008 the management of the OR expanded the number of sessions per week (resulting in the room opening plan shown in Table 5). Unfortunately, the overall number of surgeries did not increase due to limited availability of Anesthesia assistants. Furthermore certain specialties experienced difficulties filling their sessions due to a limited waiting list. For this reason, the management of the OR proposes the reduction in the available number of sessions per week shown in Table 7. Ophthalmology no longer has a session. Instead, Ophthalmology surgeries will be planned on a case by case basis in the remaining sessions. Dentist and Oral Surgery will share a session, meaning each has 1 session every two weeks.

Table 7: Proposed change in ROP

Specialty	Current # of sessions	Proposed # of sessions
General Surgery	23	21
Orthopedics	18	16,5
Gynecology	8	7
Plastic Surgery	7	6,5
ENT	3	2,5
Urology	6	5
Anesthesiology	1	0
Neurosurgery	2	1,5
Ophthalmology	¼	0
Dentist/ Oral Surgery	1 ¾	1
Emergency	5	5
Total	75	66

Using the performance indicators described in Section 2.3.1 the OR department will, in the near future, readjust the room opening plan. The goal is to increase the number of sessions to 75, as it used to be, as soon as possible. For this purpose the OR department and the specialties will discuss the situation monthly. If the capacity regarding Anesthesia assistants increases, the number of sessions will be expanded. The decision which specialty will receive extra capacity is made using the performance indicators.

2.2.4 Operational offline

Every year different specialties perform a range of surgeries on patients. These patients do not just show up at the OR department at the day of surgery. Instead they undergo a number of steps before they reach the operating table. These steps are globally described in Figure 10. Each specialty has its own waiting list. It is the responsibility of the specialty to fill its waiting list with surgeries. For this reason surgeons need to see new patients, mostly referred to them by general practitioners. In an outpatient clinic the surgeon examines the patient during consulting hours. If surgery is deemed necessary, the specialist sends the patient to the Intake office. Here the patient has to fill in an admission form and is put on the waiting list of the relevant specialty. When the patient has reached the top of the waiting list, he or she will be called to attend a pre-operative screening. This screening is generally performed by an Anesthesiologist. If the patient is deemed fit for surgery the inpatient offices plans the patient for surgery in the hospital planning system X-care.

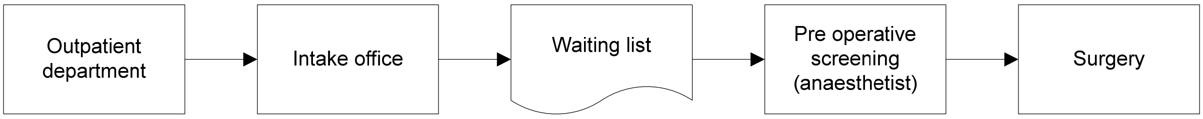

Figure 10: Pre operative process

The Intake office plans surgeries using average historical operating times for the different procedures and surgeons in the last three months. This information is automatically generated by the hospital planning software X-care. Every Wednesday the Intake office establishes the OR schedule for the following week. Surgeries longest on the waiting list are planned first, although any gaps remaining in the schedule can be filled with shorter surgeries that are lower on the waiting list. This way the Intake office tries to fill the schedule as much as possible. The Intake office has to take a number of (soft) constraints into consideration, such as (for a complete overview of the constraints we refer to Appendix C):

- Surgeries requiring only local anaesthesia are performed at the end of the program
- Children under the age of 16 are planned at the beginning of the program
- Outpatients are planned at the beginning of the program

Figure 11 describes the short term planning of the OR department. The starting point of the OR planning is the weekly planning generated by the Intake office. Although surgeries are planned using historical operating times based on procedure and surgeon, surgeons are able to indicate a different operating time. In that case the surgeon will give the reason for deviating from the average historical duration. If a surgeon does not approve the concept weekly planning, the surgeon will meet with the management of the OR to come to a solution. After this the week program is final. It can, nevertheless, be necessary to adjust the program due to previously unforeseen issues like patients not being fit enough to go into surgery. Therefore it is possible to adjust the day program for the next day. Deadline for these adjustments is 11:00. This day program is then executed the next day.

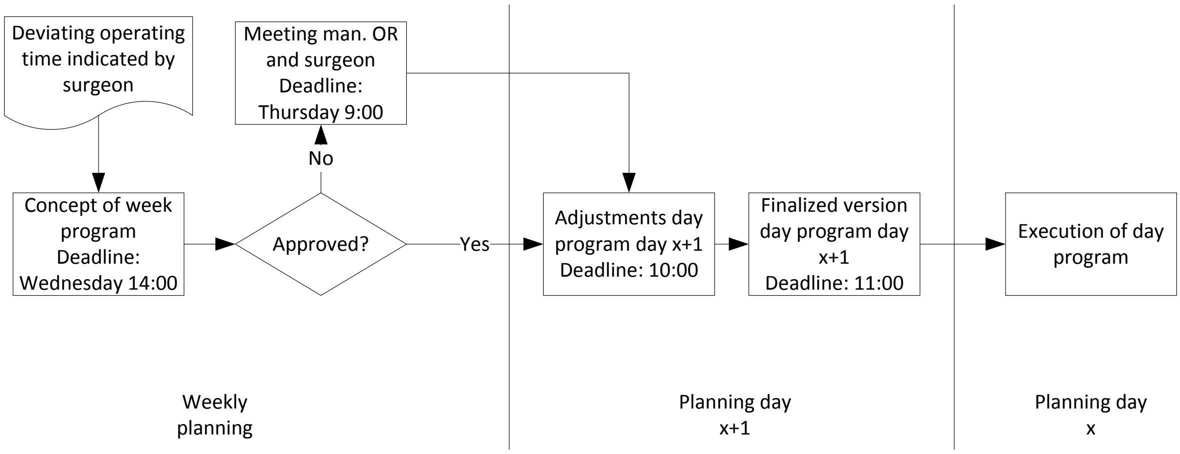

Figure 11: Short term OR planning

2.2.5 Operational online

Every day the planner spends a significant amount of time dealing with operating rooms not running according to schedule. Whenever a surgery is taking longer than scheduled, the planner has to take action by informing both the next surgeon using the operating room and the next patient. He can also decide to diverge one or more surgeries to other operating rooms or cancelling elective surgeries. However, specialties have a guarantee from the OR department they can perform the planned elective surgeries unless certain last minute changes arise. These changes are change of patient, change of surgeon, change of surgery, exceeding the planned operating time in the session by more than half an hour, and stagnation in the allotment of IC- beds.

The arrivals of emergency surgeries have a similar effect on the planning in that planned surgeries have to be cancelled or delayed if there is no available (emergency) OR. The procedure in case an unplanned patient (either urgent or emergency) arrives during working hours is:

1. The specialist registers the unplanned patient with the OR planner and the anesthetist on duty.
2. The OR planner asks the specialist what the urgency of the patient is and asks additional questions in order to determine the necessary amount of time and resources.
3. The specialist determines the urgency and discusses with the Anesthesiologist on duty.
4. In case more than one unplanned patient is registered for the emergency OR, the Anesthesiologist on duty and the OR planner, together with the specialist, determine the sequence in which the patients will be operated. This sequence is based on the urgency of the patient. In case of equal urgency the patients will be treated on a first come, first serve basis.
5. The OR planner makes sure the patient is added to the OR schedule of that day and he makes sure all those involved are informed.

2.3 Current performance

We now introduce performance indicators used by the OR department. Combined with the performance indicators we have found in the literature, we will compare possible interventions in Chapter 6.

2.3.1 Performance indicators

The management of Scheper hospital uses a combination of utilization of sessions (Dutch: benutting), utilization of session time (Dutch: bezetting), and the waiting lists as performance indicators of the OR department. Management primarily uses these indicators to periodically adjust the number of sessions available to each specialty. We will introduce three additional performance indicators.

Utilization of sessions

Scheper hospital defines utilization of the number of sessions as follows:

*((Total number of used sessions) / (Total number of available sessions))*100%*

A used session is a planned session in which there is a surgery. The hospital makes no distinction between morning, afternoon, and day sessions.

Utilization of available session time

The definition of utilization of available session time is:

*((Total operating time + changeover time) / (Total available session time))*100%*

Only operating time inside the available session time plus changeover time between surgeries is included in the total operating time (i.e. overtime is excluded). We only look at realized operating time, not planned operating times.

Waiting list

Each specialty has its own waiting list with patients. Scheper hospital uses the so called Treek norm to analyze the length of these waiting lists. The Treek norm specifies that 80% of all clinical patients should be treated within 5 weeks and that all patients should be treated within 7 weeks of receiving a diagnosis. In our simulation study we will not take into account waiting lists. Instead, we will plan an average number of procedures each week.

Overtime

As stated in the problem description [Section 1.2] the management of the OR department, the specialists using the emergency session, and the OR personnel dislike working in overtime. We therefore use overtime as a performance indicator and define it as:

*((Total surgery time outside regular working hours or during the lunch break)/ (Total surgery time))*100%*

The total surgery time is including overtime, excluding idle time at the beginning and end of the program, and including changeover time.

Disturbance elective program

As stated in the problem description [Section 1.2], the introduction of the emergency session resulted in a reduction in the number of disturbances in the elective program; an effect valued by the specialists using the emergency session, as well as the OR personnel. If an emergency surgery arrives, an elective surgery might have to be postponed in order to make room for the emergency patient. We call this a disturbance. To put the number into perspective we divide the total number of disturbances by the total number of emergency surgeries:

*((Total number of disturbances)/ (Total number of emergency surgeries performed))*100%*

2.3.2 Performance of the OR department

We now continue with an analysis of the performance of the OR department using the performance indicators utilization of sessions, utilization of available session time, disturbance of elective program, and overtime. We do not have current performance figures for disturbance of the elective program. We will, however, use this performance indicator to present the results of the simulation study in Chapter 6. Next, in Section 2.3.3, we analyze the performance of the emergency session in particular.

Utilization of sessions

To determine the utilization we compare the planned sessions with the realized surgeries in order to determine the realized number of used sessions. If there is at least 1 surgery realized in a planned session, the session is used. This results in the utilization numbers shown in Table 8. From the table it is clear that the utilization of sessions is above 90% for almost all specialties. Only the specialties Dentist and Oral Surgery have a utilization of sessions below 90%. As already mentioned in Section 2.2.3, as of 2009 the specialties Dentist and Oral Surgery share 1 session; meaning the specialty Dentist gets an OR session in the even weeks and the Oral Surgery specialty gets a session in the uneven weeks. The Ophthalmology specialty does not have a session anymore in 2009.

Table 8: Utilization of sessions (Jan-Nov 2008, X-care)

Specialty	# of sessions	# of empty sessions	Utilization
General Surgery	804	21	97.4%
Orthopedics	576	20	96.5%
Gynecology	261	12	95.4%
Plastic Surgery	149	6	96.0%
ENT	121	3	97.5%
Urology	131	7	94.7%
Neurosurgery	74	3	95.9%
Dentist	36	4	88.9%
Ophthalmology	15	1	93.3%
Oral Surgery	15	2	86.7 %

Utilization of available session time

Table 9: Utilization of the specialty ORs (Jan-Nov 2008, X-care)

Specialty	Surgery time (min)	Changeover time (min)	Available time (min)	Utilization
General Surgery	145,518	14,910	194,370	82.5%
Orthopedics	102,986	12,069	151,620	75.9%
Gynecology	47,717	6,784	66,120	82.4%
Plastic Surgery	37,390	5,681	56,430	76.3%
ENT	19,077	2,850	26,220	83.6%
Urology	38,286	2,816	49,590	82.9%
Neurosurgery	12,865	1,022	19,380	71.7%
Dentist	6,686	711	9,690	76.3%
Ophthalmology	2,094	320	3,585	67.3%
Oral Surgery	1,601	168	7,267.5	24.3%
Total Elective	414,220	47,331	584,272.5	79.0%

Table 9 shows the utilization of available session time. The available time includes cancelled sessions. For example: The available time for General Surgery is the number of General Surgery morning sessions per week (13) * 38 weeks * 4.25 hours per session *60 minutes per hour + number of afternoon sessions per week (10) * 38 weeks * 3 hours * 60 minutes = 194,370 minutes. The quoted surgery time excludes changeover times and surgeries performed in the emergency session. For the changeover times we calculated the total number of changeovers and multiplied this number with the average changeover times [Table 3].

Overtime

Table 10 Overtime (Jan-Nov 2008, X-care)

Specialty	Overtime (min)	Total surgery time including changeover time (min)	Overtime (%)
General Surgery	9,077	160,428	5.7%
Orthopedics	7,005	115,055	6.1%
Gynecology	3,403	54,501	6.2%
Plastic Surgery	2,298	43,071	5.3%
ENT	1,083	21,927	4.9%
Urology	2,520	41,102	6.1%
Neurosurgery	378	13,887	2.7%
Dentist	270	7,397	3.7%
Ophthalmology	163	2,414	6.8%
Oral Surgery	46	1,769	2.6%
Total	26,243	461,551	5.7%

Table 10 shows the percentage of total surgery time performed in overtime. As explained in Section 2.3.1 overtime includes morning surgeries finishing after 12:15, morning surgeries starting before 08:00, afternoon surgeries starting before 13:00, and afternoon surgeries finishing after 16:00. We note that only the surgery time actually performed in overtime is included. Ophthalmology performs the largest portion of total surgery time in overtime, 6.8% Neurosurgery and Oral Surgery both perform well on this performance indicator with 2.7% and 2.6% of total surgery time performed in overtime.

2.3.3 Performance of the emergency session

We will now analyze the performance of the emergency session. Before we do this we note the following: In the period January to November 2008 there was no afternoon emergency session on certain days for a number of reasons. One of the reasons is the reduction weeks. During reduction weeks there is no emergency session in the afternoon. During the period January to November 2008 there were 240 working days. From this 240 we subtract 50 because of the reduction weeks. This leaves 190 days. Furthermore 23 emergency sessions were cancelled because of holidays and limited availability of OR personnel. This leaves a total of 167 emergency sessions. We now give the utilization figures of these emergency sessions.

Utilization of sessions

Table 11 shows the utilization of the emergency session. This utilization is, compared to the utilization of the elective sessions, low. For almost all specialties the used number of sessions was above 90% [Table 8]. However, of a total of 167 emergency sessions, 53 were left empty resulting in a utilization of 68.3%.

Table 11: Utilization of the emergency session (Jan-Nov 2008, X-care)

# of sessions	167
# of empty sessions	53
Utilization	68.3%

Utilization of available session time

From Table 12 we conclude that the utilization of available session time of the emergency session is 50.9%. The surgery time quoted is the surgery time performed in the emergency session during opening hours (13:00 – 16:00) of the emergency session. For example, for surgeries starting at 15:50 and ending at 16:40, only the first 10 minutes are counted. The total available time (30,060 minutes) is the number of minutes in an hour (60) * the number of hours per day the emergency session is open (3) * the total number of emergency sessions in the period January - November 2009 (167) = 30,060 minutes.

Table 12: Utilization of the emergency session (Jan-Nov 2008, X-care)

Specialty	In emergency (min)
General Surgery	3,812
Orthopedics	261
Gynecology	59
Plastic Surgery	153
ENT	46
Urology	82
Neurosurgery	0
Anesthesiology	0
Dentist	124
Ophthalmology	0
Oral Surgery	64
Subtotal Elective	4,601
Emergency (< 30 min)	537
< 8 hours	6,421
< 24 hours	3,322
< 48 hours	413
Subtotal emergency and urgent	10,693
Total	15,294
Total available	30,060
Utilization	50.9%

If we look at the utilization of available session time of the emergency session contributed by the urgent and emergency surgeries, the utilization of available session time is only 35.6% (10,693/30,060). If the emergency session would have been only available for emergency surgeries this figure would have been only 1.8% (537/30,060). The potential utilization of available session time of the emergency session, if we would perform all emergency surgeries between 13:00 and 16:00 and all urgent surgeries performed between 08:00 and 16:00 in the emergency session, is 58.5% [Table 13]. This potential utilization can, however, never be achieved due to the irregular arrival pattern of these surgery types combined with the fact that these surgeries cannot always wait until there is room in the emergency session.

Table 13: Potential utilization if only urgent and emergency surgeries are allowed in the emergency session

(Jan-Nov 2008. X-care)

Urgency level	min
Emergency (30 min)	1,579
< 8 hours	9,836
< 24 hours	5,141
< 48 hours	1,037
Total	17,593
Total available	30,060
Potential Utilization	58.5%

Overtime

Table 15 presents the overtime of urgent surgeries. We do not look at emergency surgeries because these do not adhere to the regular opening hours, whereas the urgent surgeries, to a certain extent, do. Appendix A explains which urgent surgeries we include. From Section 2.3.1 we know the definition of overtime. To clarify, the total surgery time is the sum of the surgery times of all surgeries starting between 08:00 and finishing before midnight. Overtime is the surgery time performed after 16:00.

Table 14 Overtime urgent surgeries (Jan-Nov 2008, X-care)

Urgency level	Overtime (min)	Total surgery time (min)	Overtime (%)
< 8 hours	19,771	35,777	55.3%
< 24 hours	3,695	11,057	33.4%
< 48 hours	443	2,108	21.0%
Total	23,909	48,942	48.9%

Table 14 shows a high percentage of surgeries is performed in overtime and this percentage decreases as the urgency level decreases. This is to be expected since the two lowest urgency level surgeries can be postponed until the next day, or even two days later for the lowest urgency level. The high overtime percentage for the urgent surgeries which have to start within 8 hours after arrival can be partly explained by surgeries arriving between 16:00 and midnight; these surgeries could not be postponed until the next day and therefore it was not possible for these surgeries to be performed during regular working hours. Unfortunately, we do not have information concerning the actual time the patient arrived at the hospital. Therefore, we cannot say anything conclusive about the influence of these surgeries on the overtime percentage of urgent surgeries that have to start within 8 hours after arrival.

2.4 Conclusion current performance and problem analysis

We now have an understanding of the context of our research. We have analyzed the current performance of the OR department and the emergency session in particular.

Scheper hospital uses two relevant performance indicators to measure performance of the OR department, namely “utilization of sessions” and “utilization of session time”. We gave a formal definition of both performance indicators. The performance indicator “waiting list” does not apply to our simulation study since the simulation model does not take into account waiting lists. We have introduced two additional performance indicators, namely “disturbance elective program” and “overtime”. The OR department does not use these performance indicators. They do, however, capture two important issues for the people working at the OR department. The utilization of available session time of the emergency session is 51%. This includes elective surgeries performed in the emergency session. If only unplanned surgeries would have been allowed to be performed in the emergency session the utilization would drop to 35%. The potential utilization of available session time, when only unplanned surgeries were allowed in the emergency session, is almost 59%. This figure is, however, unreachable because of the irregular arrival pattern of these types of surgeries. In fact, almost 40% of all unplanned surgeries were performed outside the emergency session. For this reason, besides the reasons given by the literature, we will investigate whether it is possible to work without the emergency session and what the consequences will be of working without the emergency session.

The OR department currently works with a lunch break from 12:15 to 13:00. This lunch break has a negative effect on the total capacity of the OR department. The management of the OR department wants to know what the advantages will be of cancelling the lunch breaks. Therefore, we will investigate the consequences of working without a lunch break. We have already seen that in reality there is a drop in the number of surgeries starting just before and during the lunch break and an increase in the number of surgeries starting just near the end of the lunch break and just after the lunch break.

We analyzed the current situation at the OR department of Scheper hospital and found a number of performance indicators. We also found a possible intervention, namely working without lunch breaks. The next chapter continues with a literature review to find more interventions and performance indicators.

3. Literature

We continue with an overview of methods for dealing with unplanned surgeries found in the literature. We also give an overview of performance indicators used in the literature, some of which we will also use in our research.

3.1 Interventions

The literature describes different ways of dealing with unplanned surgeries. One way is using dedicated emergency sessions where no elective surgeries are scheduled. Emergency sessions can decrease overtime for the elective program and the number of urgent surgeries performed after working hours [Lovett and Katchburian, 1999]. This is an important reason for having emergency sessions. Furthermore, emergency sessions help reduce the amount of cancelled or rescheduled elective surgeries. The downside of having one or more emergency sessions is a low utilization of the OR [Barlow et al., 1993]. Cardoen et al. [2008] discern between two types of unplanned surgeries, namely urgent and emergency surgeries. We will also use this classification in our research. Urgent surgeries can be postponed for a short time, whereas emergency surgeries have to start as soon as possible. Cardoen et al. [2008], furthermore, give a review of the literature concerning operating room planning and scheduling. They attend different fields of operating room planning and scheduling, one of which is dealing with unplanned surgeries. We will now present a selection of articles relevant to our research. An additional literature review specifically aimed at the subject of our research resulted in 2 more papers which we will also discuss.

Bhattacharyya et al. [2006] performed a retrospective analysis for two 1 year periods, before and after the introduction of a session for unplanned orthopedic patients at the Massachusetts General hospital. This session is available for urgent and emergency cases from 7:45 to 17:00 6 days per week. The introduction of the session resulted in a reduction in urgent orthopedic cases performed at night and the proportion of hip fractures performed after 17:00 reduced by 72%. Furthermore, there was a 6% reduction in elective surgeries starting after 17:00, because elective surgeries did not have to be postponed due to the arrival of emergency patients. The utilization of the session was comparable to that of the elective sessions (82% versus 79%).

Bower and Mould [2004] researched the effects of allowing elective surgeries being scheduled in orthopedic trauma sessions. Elective patients were selected using different rules such as longest surgery first and selecting random surgeries. These elective surgeries can, however, be cancelled in case there is a high number of trauma sessions on a particular day. There is a relation between the number of hours of elective surgery planned in the trauma sessions and the chance of elective surgeries being cancelled. In a simulation study, Bower and Mould found that if a 15% chance of postponement to a later day is acceptable, a 2 hour elective list can be scheduled in a 7 hours trauma session. The simulation model described a District General hospital in the United Kingdom with a mean annual orthopedic trauma demand of 735. Finally, the researchers refer to a well known characteristic of packing problems that *"wastage is reduced as the bin size increases"* [Bower and Mould, 2004]. For

OR departments this means that the utilization of available session time increases as session time increases.

Persson [2007] proposes so called stand by patients. If there is capacity available due to, for example, cancelled patients, these patients can be called upon. The advantage for these patients is that they can be operated on sooner by avoiding the waiting list. These patients are prepared for surgery at home or at their workplace.

Houdenhoven et al. [2007b] describe the relation between overtime, the patient mix, and utilization. By defining an accepted risk of overtime, the OR department is able to determine a norm utilization. This norm utilization varies between specialties and between hospitals and is dependent on the patient mix, more specifically the standard deviation of surgery durations. By defining an accepted risk of overtime, which is a choice of the management, it is possible to calculate the norm utilization. This norm utilization can then be used as a performance measure in the form of a maximum for the achievable utilization, given a patient mix and it can be used to evaluate and steer performance.

Hans et al. [2006] use the concept of norm utilization and extend on it by introducing planned slack. When we have a closed form probability distribution for the sum of the surgery durations we can use a general formula to calculate the amount of planned slack that ensures a certain chance of overtime that is equal for all specialties. This formula is:

Equation 1 Planned slack

$$slack = \beta * \sqrt{\sum_{i=1..n} {\sigma_i}^2}$$

In this formula σ_i is the standard deviation of surgery i. By summing the square of the standard deviations, the variation, of all the surgeries performed in the same OR on the same day and taking the square root of this sum, we get the standard deviation of the sum of these surgery durations. By multiplying this standard deviation with β, the slack factor, we are able to determine the amount of planned slack necessary to achieve a desired overtime chance. In case the sum of the surgery durations is normally distributed, a β of 0.5 results in an overtime chance of 30.85%.

Wullink et al. [2007] report results from a simulation study performed for Erasmus MC, a large academic hospital in the Netherlands with on average 12 general ORs available per day. General ORs are available to all specialties. They compared using 1 dedicated emergency session to reserving time in all sessions and closing the emergency session. They found that by closing the emergency session, waiting time for emergency surgery went down from 74 minutes to 8 minutes. Furthermore overtime was reduced by 20% and overall OR utilization increased by approximately 3%. Based on these results, the Erasmus MC decided to close their emergency session. Wullink et al. note that implementation of the policy that reserves capacity for emergency surgeries in all ORs requires full commitment of all specialties, especially when the hospital is dealing with dedicated ORs (i.e. ORs that are exclusively used by one specialty). If one specialty does not reserve capacity it will be able to perform more surgeries, leaving the other specialties to deal with emergency surgeries. This is, however, not beneficial for all surgical specialties together, the so-called prisoners dilemma.

Lans et al. [2006] show, using computational experiments, that unplanned surgeries can be anticipated best by allocating slack for unplanned surgeries to all operating rooms and thus allowing urgent surgery to interfere with the elective schedule. They come to this conclusion using the performance indicators waiting time, utilization, and overtime. Unplanned surgery waiting time can be further limited by spreading break-in-moments evenly over the day. Break-in-moments are those moments at which an unplanned surgery can start (just after the completion of an elective surgery). The advantage of optimizing break-in-moments diminishes as time progresses. This is because of disturbances in the schedule due to surgery duration variability and the arrival of urgent surgeries. The effect of optimizing break-in-moments limiting urgent surgery waiting times is largest for hospitals with a surgical case mix with long surgeries with a high variability. The researchers did not take into account the availability of scarce resources such as microscopes, preferences of surgeons for the sequence of surgeries, and set-up times in between elective surgeries. Finally the model assumes that all urgent surgeries can be performed in all operating rooms.

Barlow [1993] describes the district general hospital of Taunton and Somerset. This hospital serves a population (at the time of the research) of 300,000 and the operating theatre performed 1087 surgeries [Barlow, 1993]. During a one year trial the hospital worked with an afternoon emergency session. The emergency session was available for emergency General Surgery, Gynecology, Urology, Ear-Nose-Throat Surgery, and Oral Surgery, although urgent and elective surgeries where also sometimes allowed in the emergency session. The hospital used NCEPOD[1] definitions to classify patients as emergency, urgent, scheduled, or elective. The goal of the trial was to reduce emergency surgeries performed outside working hours. The afternoon emergency session was created by cancelling an elective session. The emergency session resulted in a 33% reduction of the number of emergency surgeries performed after midnight. During the trial only 37% of the available emergency session time was utilized. Furthermore, of the general surgeries performed at the emergency session, 2% was classified as emergency, 61% as urgent, and 31% was elective.

Lovett and Katchburian [1999] describe Newham general hospital, a district general hospital with 600 beds, performing 6000 surgeries in 1995. In this year, the hospital experimented with an afternoon emergency session for three weeks. The introduction of the emergency session reduced the amount of urgent surgeries performed after 17:00 from 88% to 53% and the number of urgent surgeries performed after 22:00 was cut from 40% to 12%.

[1] National Confidential Enquiry into Patient Outcome and Death

3.2 Performance indicators

Section 3.1 already introduced a number of performance indicators. To get a complete overview of performance indicators, we again turn to Cardoen et al. [2008]. They identify the 8 main performance indicators shown in Table 15. The first performance indicator, *waiting time*, can apply to elective patients placed on a waiting list for a certain procedure as well as to surgeons waiting to start surgery. The second performance indicator, *throughput*, is connected to waiting time via Little's law. If the work in process stays equal, increasing throughput lowers waiting time and vice versa. *Utilization* is frequently used as a performance indicator, as we have already seen in Section 3.1 where utilization always applies to the available OR time. Utilization can, however, also be applied to other resources such as X-ray machines or ICU beds. The fourth performance indicator, *leveling*, refers to the leveling of resource usage, preventing peaks in, for example the bed occupancy. *Makespan* is defined as the time between the entrance of the first patient of the day and the finish of the last patient of the same day, and can be defined for a single OR or an OR department. Patient *deferral* or *refusal* is concerned with cancelled operations due to capacity problems, for example bed shortage. *Financial* performance indicators try to capture the performance of the OR department or the hospital in terms of costs and revenues. OR personnel as well as surgeons can have *preferences* concerning OR planning. A surgeon for example might not like to operate on Mondays. Patients might also have preferences regarding the timing of their operation. This brings us to the stakeholders.

There are a number of stakeholders involved with the performance of the OR department. These stakeholders can have different preferences. The main stakeholders are the surgeons, the OR personnel, the patients, and the management of the hospital.

Table 15 Performance indicators from the literature [Cardoen et al., 2008]

Performance indicators
Waiting time
Throughput
Utilization
Leveling
Makespan
Patient deferral/ refusal
Financial
Preferences

This overview is very general and therefore not very practical for our purposes. Therefore we turn to the *Faster Better* program. As described in Section 2.2.2, the Dutch government initiated this program to improve the health care in the Netherlands. The *OR okay* part of this program specifically aimed at improving the performance of the OR department. Scheper hospital also took part in this program. Therefore, the hospital is familiar with the performance indicators used in this program which helps the stakeholders in the hospital to understand the performance indicators and the conclusions drawn from these performance indicators. The department of health, together with professionals in the field, developed a set of performance indicators to measure the effectiveness of the program. These indicators are:

1. Number of procedures per FTE OR personnel
2. Number of procedure minutes per FTE OR personnel
3. Utilization of sessions
4. Utilization of session time
5. Average overtime per session
6. Average idle time at the end of a session
7. Average overtime
8. Percentage of procedures performed during the night (24:00 – 08:00)
9. Percentage of cancelled procedures

We will formally define the indicators relevant to our research in Section 6.1. Here we will also make a selection from the performance indicators, using qualifications for performance indicators from the literature. The literature gives a wide variety of qualifications for performance indicators. We select from these a set of qualifications for our research [Pullen, 2005]:

1. Relevant: The indicator should have a clear purpose and added value
2. Transparent: The indicator gives a true representation of the actual performance
3. Comparability: The indicator is measured in a consistent way making it possible to compare different measurements made at different points in time or at different locations (hospitals)
4. Measurability: The indicator is measurable without the need for additional data gathering
5. Changeable: It is possible to influence the performance measured by the indicator
6. Normative: It is possible to define a goal value for the indicator

3.3 Conclusion literature

This chapter gave an overview of the literature about unplanned surgeries and on performance indicators. From the different and sometimes conflicting performances presented in the literature we conclude that it is dependent on the situation what will work best, either working with or without an emergency session. Furthermore, the literature also gives different ways on *how* to work with or without an emergency session.

The authors from the literature present their results using a number of performance indicators. The most frequently used performance indicator is utilization. Furthermore, Cardoen et al. [2008] present a general overview of relevant performance indicators. Finally, from the *OR okay* program we find a number of additional performance indicators. In Section 6.1 we will use qualifiers from the literature to make a selection from these performance indicators and from the indicators currently used by the OR department.

We now have several different methods of dealing with unplanned surgeries. We will evaluate these different methods, applied to the situation at the OR department of Scheper hospital, using a computer simulation model. We obtain performance indicators from the literature. Finally, we obtained a number of performance indicator and qualifications for performance indicators. In Chapter 6, we will use these qualifications to make a selection from the performance indicators from the literature and from Scheper hospital. We now continue with a description of the selected interventions.

4. Possible interventions

Chapter 3 presented a summary of the recent literature dealing with unplanned surgeries. This literature, however, is mostly case specific and therefore we cannot assume that the conclusions made in these articles apply to the situation at Scheper hospital as described in Chapter 2. Moreover, we have identified a number of issues in Chapter 2 that we will address in our research. These issues are the low utilization of the emergency session and the loss in production due to the lunch break. From the literature we have a number of alternative ways of dealing with unplanned surgeries, namely closing the emergency session and using planned slack and optimizing break-in-moments. We present an addition to working with planned slack, namely planning surgeries based on their standard deviation.

4.1 Planned slack

In Chapter 3 we presented the concept of planned slack. Using Equation 1 we can calculate the amount of planned slack we need to reserve to ensure we do not exceed a predetermined overtime probability. We note that the overtime probability is based on the assumption that the surgery durations are normally distributed. As we show in Appendix D, however, most of our surgery durations are actually better described by a lognormal distribution. In this case there is no exact way of establishing the overtime probability but it is still possible to approximate it [Hans, 2006].

Ideally the allowed overtime probability would be set by management. However, management has not set an allowed overtime probability. In fact, the Intake office currently tries to schedule as much surgeries as possible without planning overtime [Section 2.2.4]. Therefore, we will compare the current situation with planning slack. We choose a slack factor of 0.5 which results in an overtime probability of 30.85%. This is the slack factor used in Erasmus hospital in Rotterdam, the Netherlands [Hans et al., 2006]. However, because we are only interested in the difference between scheduling with and without slack, the choice of which slack factor to use is of minor importance and can later be decided on by management in case they choose to incorporate planned slack. What is important is to quantify the difference between planning with and without slack. Furthermore, in Section 6.2 we will investigate the sensitivity of our conclusions regarding planned slack to this slack factor.

With the allowed overtime probability, management can set individual targets for the utilization of available session time. This is the norm utilization described by Houdenhoven et al. [2007b].

4.2 Working without an emergency session

Scheper hospital uses an afternoon emergency session to deal with unplanned surgeries. When it would decide to work without this session, all unplanned surgeries will have to be dealt with in the elective program. A possibility is to reserve capacity, emergency slack, for these unplanned surgeries. We have to decide if we reserve all emergency slack in 1 General OR session per day, 2 General OR sessions per day, or in all General OR sessions (we do not have more than 3 General OR sessions on average per day). For the other specialties with emergency and urgent surgeries we do not have enough sessions per day to distinguish between 1 session per day or all sessions per day. The amount of emergency slack is equal to the average total surgery duration per day of both urgent and emergency surgeries.

4.3 Scheduling based on standard deviation

Scheper hospital currently schedules their surgeries based on a first come first serve basis. As explained in Section 2.2.4, every Wednesday the Intake office establishes the OR schedule for next week, selecting surgeries that are longest on the waiting list. Which surgeries are performed is therefore a direct consequence of the arrival sequence of patients. This arrival sequence is inherently random.

We are going to investigate if it is better to sequence surgeries based on their duration's standard deviation. In this way we take advantage of the portfolio effect. If we plan surgeries with similar standard deviations in the same OR, the total standard deviation decreases compared to planning surgeries randomly. Table 16 illustrates the portfolio effect [Houdenhoven, 2007c]. By scheduling the surgeries with the same standard deviation in the same OR (scenario 1) the resulting total standard deviation is lower than when we do not take into account standard deviation during the scheduling of surgeries (scenario 2). This is, however, only true if the surgeries are independent and identically distributed. We will compare scheduling surgeries with similar standard deviations in the same session to scheduling surgeries randomly, as it is currently done.

Table 16 The portfolio effect

	Scenario 1		Scenario 2	
	OR1	OR 2	OR 2	OR 2
St dev	100	10	100	100
St dev	100	10	10	10
Tot St dev	155.6		201.0	

4.4 Break-in-moments optimization

Lans et al. [2007] introduce the concept of break-in-moments (BIMs). Chapter 3 explained that a break-in-moment is the moment in between two consecutive surgeries in the same OR. At this moment it is possible for an emergency surgery to break into the elective program. We will apply BIM optimization techniques developed by Lans et al. [2007] to our situation. Lans et al. [2007] performed their study at a large academic hospital, whereas Scheper hospital is relatively small with less ORs. It is not clear whether optimizing BIMs in smaller hospitals will result in the same benefits. We will therefore examine the effects of BIM optimization for the specific case of Scheper hospital. To illustrate the effect of optimizing BIMs we now give an example of BIM optimization applied to the OR schedule of Scheper hospital

Figure 12 Example of BIM optimization

Figure 12 shows a random day before and after BIM optimization. On the left hand side we see a typical schedule before BIM optimization, on the right hand side is the schedule after BIM optimization. On the left of each schedule we see a red line. This is the interval considered for BIM optimization. It runs from the start of the first surgery in the morning until the finish of the last surgery in the afternoon. The length of this interval is a determinant for the effectiveness of the BIM optimization. If one OR is scheduled to finish early, this limits the added benefit of BIM optimization because after the last surgery finishes in this OR, the OR is available for emergency surgeries.

Directly next to the red line we see a large number of black horizontal stripes. These represent the BIMs (expected surgery completion times). BIM optimization tries to distribute these BIMs evenly throughout the day. The result is a reduction in the largest BIIs as shown in Table 17. Here we see the largest, second largest, and third largest break in interval (BII) before and after BIM optimization. All 3 have been reduced by BIM optimization.

Table 17 Example of BIM optimization

	Before BIM optimization	After BIM optimization
Largest BII	60.7	38.3
2nd largest BII	36.5	34.2
3rd largest BII	34.2	29.1

4.5 Working without lunch breaks

As explained in Section 2.2.3, three ORs currently work without a lunch break. The remaining ORs close between 12:15 and 13:00. We will investigate the benefits of working without a lunch break compared to working with a lunch break in all ORs. We will do this both for the current situation, as well as for the situation where all ORs work without a lunch break.

Working without a lunch break results in a capacity increase of 45 minutes per OR per day. This is, however, not the only benefit of working without a lunch break. From Bower and Mould [2004] we know that the utilization of available session time increases as session time increases because there is now more flexibility in scheduling the surgeries.

Since we do not have a fixed ROP for working with 3 or more ORs without a lunch break per day, we have to create these ourselves. Currently the OR department works with 3 ORs without lunch breaks. However, as we have explained in Section 2.2.3, it differs from day to day and from week to week as to which specialties work with a full OR day. Because we want to work with a fixed ROP in our simulations, we choose to allocate these full OR days to specialties proportional to the capacity the specialties have in the original ROP [Table 5]. This results in the ROP shown in Table 18. We do not incorporate the 4 smallest specialties in our simulations. See Section 5.1 for an explanation.

Table 18 ROP with 3 full OR days

3 full OR days and half OR days		General Surgery	Orthopedics	Gynecology	Plastic Surgery	ENT	Urology	Neurosurgery	Total (sessions)
Monday	morning	2	2					1	5
	afternoon	1	2						3
	full	1		1		1			3
Tuesday	morning	3	1					1	5
	afternoon	2	1						3
	full	1	1				1		3
Wednesday	morning	2		1		1	1		5
	afternoon	1		1			1		3
	full	1	1		1				3
Thursday	morning	1	1				1		3
	afternoon	1			1		1		3
	full	1	1	1					3
Friday	morning		2	1	1				4
	afternoon		1	1	1				3
	full	1	1		1				3
Total (sessions)		19	16	8	5	3	4	2	57

For the scenario where we work without a lunch break in all ORs, we assign full day sessions, so sessions from 8:00 to 16:00 without a lunch break, to a specialty proportional to the OR capacity they have in the original ROP [Table 5]. This results in fractional numbers of sessions for the specialties. Therefore, we round to the nearest integer. A test simulation run shows us that ENT is limited in its capacity. ENT had 3 morning sessions which were highly utilized in 2008 [Table 9] and therefore we have enough reasons to increase the capacity for ENT from 1 to 2 full OR days. Table 19 shows the resulting ROP.

Table 19 ROP working without lunch break, 6 OR days

	Monday	Tuesday	Wednesday	Thursday	Friday	Total (sessions)
General Surgery	3	2	2	2	2	11
Orthopedics	2	1	1	1	1	6
Gynecology	1	1	1	1	1	5
Plastic Surgery	0	0	1	1	0	2
ENT	0	1	0	0	1	2
Urology	0	1	1	1	0	3
Neurosurgery	0	0	0	0	1	1
Total	6	6	6	6	6	30

Table 20 shows an alternative ROP with 7 ORs per day. We will also simulate using this ROP and compare the performance with the 6 OR day ROP and the base scenario.

Table 20 ROP working without lunch break, 7 OR days

	Monday	Tuesday	Wednesday	Thursday	Friday	Total (sessions)
General Surgery	3	2	2	3	2	12
Orthopedics	2	2	1	1	3	9
Gynecology	1	1	1	1	1	5
Plastic Surgery	0	1	1	0	1	3
ENT	1	0	1	0	0	2
Urology	0	1	0	2	0	3
Neurosurgery	0	0	1	0	0	1
Total	7	7	7	7	7	35

Impact of working without a lunch break on personnel planning

Working without a lunch break has an impact on personnel planning. The OR department currently works without a lunch break in 3 ORs. We will compare the impact on personnel planning of working in 3 ORs without a lunch break and working without a lunch break in all ORs to working with a lunch break in all ORs. Working without a lunch break requires the OR department to keep performing surgeries during the lunch break. This requires additional OR personnel to relief personnel during the lunch break. We will now quantify this additional requirement. Before we do this we look at the legal requirements concerning lunch breaks and coffee breaks for OR personnel.

According to the labor act, an employee has the right to a break of at least half an hour if the person has to work for 5 ½ hours or longer per shift. If the person has to work for more than 10 hours he or she is entitled to 45 minutes of rest, to be divided in breaks of 15 minutes or longer. Furthermore the collective labor agreement for healthcare professionals entitles OR personnel to a coffee break of 15 minutes per part of the day (morning, afternoon, evening, and night) [Collective labor agreement, 2009-2011].

Scheper adheres to these guidelines during regular working hours by granting OR personnel a lunch break of half an hour between 12:15 and 13:00 and 2 coffee breaks of 15 minutes; one in the morning and one in the afternoon. The coffee breaks are performed during surgeries by temporarily relieving OR personnel during relatively quiet moments in surgery. As we have already explained, the lunch breaks are currently taken in between 2 surgeries, resulting in empty ORs for the duration of at least the lunch break. In the new situation the OR personnel will have to be relieved during surgery, just as is currently done for the coffee breaks. The consequences of working without a lunch break in all OR days are that all OR personnel will now have to be relieved during surgery. This can only be done by increasing the OR personnel capacity.

We will now determine the impact of working without a lunch break on the number of FTEs OR personnel. Table 21 presents the additional required FTEs in case we work with 3 full OR days and half OR days, 6 full OR days, or 7 full OR days, compared to the situation where we work without full OR days. We note that all scenarios are including an afternoon emergency session. In the situation without full OR days, the OR capacity is 262.25 hours instead of 273.75 hours due to the 4 specialties not taken into account in our simulation model [Section 5.1].

Table 21 shows that the OR capacity differs between the scenarios. We first calculate the change in required OR personnel due to this change in OR capacity. We compare the scenarios with 3 or more full OR days to the scenario without any full OR days. We will establish the personnel requirements for the lunch breaks later on. Therefore, we subtract the OR capacity gained by working during lunch breaks from the total OR capacity per week. The resulting OR capacity is shown in the third column of Table 21. For the scenario with 6 full OR days the OR capacity decreases by 262.25 – 232.5 = 29.75 hours less capacity per week. This results in 29.75 (hours) * 3 (assistants) / 36 (hours per FTE) = 2.48 less FTEs. Table 21 shows the additional personnel requirements for all scenarios.

Table 21 Change in personnel requirements (1)

	OR capacity (OR hours per week)	OR capacity (excl. lunch breaks)	Additional personnel (FTE)
No full OR days	262.25	262.25	
3 full OR days	273.5	262.25	0
6 OR days (all full)	255	232.5	-2.48
7 OR days (all full)	295	268.75	0.54

We continue with the additional personnel requirements due to working during lunch breaks. If ORs work without interruption during the day, we need an OR team to relieve the people working at the OR department during the lunch break. Because this relief team cannot work at all 6 or 7 ORs at the same time we will have to distribute the lunch breaks. Table 22 shows the resulting lunch break schedule when working with 1 relief team. We see that only three ORs can be relieved by 1 relief team, otherwise the OR personnel working in the first OR would be forced to take their lunch break at 10:00 and the last team would finish their lunch break at 14:45. In case we work with 7 ORs per day the last OR team would finish their lunch break at 15:30, only half an hour before the OR closes. We therefore conclude that we need 2 relief teams for the scenarios with only full OR days.

Table 22 Working with one relief team

	OR 1	OR 2	OR 3	Relief team
11:45	lunch			
12:00	lunch			
12:15	lunch			
12:30		lunch		
12:45		lunch		
13:00		lunch		
13:15				*coffee*
13:30			lunch	
13:45			lunch	
14:00			lunch	

Table 23 and Table 24 give the schedules for working with 2 relief teams. We note that the relief teams have a coffee break from 13:15 until 13:30 in the scenario with 6 OR days. In the scenario with 7 OR days the relief teams have a coffee break from 13:00 to 13:15.

Table 23 Working with 2 relief teams and 6 OR days

	OR 1	OR 2	OR 3	OR 4	OR 5	OR 6	Relief team
11:45	lunch			lunch			
12:00	lunch			lunch			
12:15	lunch			lunch			
12:30		lunch			lunch		
12:45		lunch			lunch		
13:00		lunch			lunch		
13:15							*coffee*
13:30			lunch			lunch	
13:45			lunch			lunch	
14:00			lunch			lunch	

Working with relieve teams requires 2 teams of OR personnel for the duration of 2 hours and 30 minutes for the scenario with 6 OR days. For the scenario with 7 OR days one team stays an extra 45 minutes. This results in 2.5 (hours) * 2 (teams) * 3 (assistants) * 5 (days per week) = 75 hours per week for 6 OR days. For the scenario with 7 full OR days we require 86.25 hours per week extra. This results in 75 (hours) / 36 (hours per FTE) = 2.08 FTEs extra for the scenario with 6 OR days. For the scenario with 7 OR days we require 86.25 / 36 = 2.40 FTEs extra. Finally, for the scenario with 3 full OR days and half OR days we require only 1 relief team per day [Table 22]. This results in 2.5 (hours) * 1 (team) * 3 (assistants) * 5 (days per week) = 37.5 hours per week or 1.04 FTE.

Table 24 Working with 2 relief teams and 7 OR days

	1	2	3	4	5	6	7	Relief team
11:30	lunch			lunch				
11:45	lunch			lunch				
12:00	lunch			lunch				
12:15		lunch			lunch			
12:30		lunch			lunch			
12:45		lunch			lunch			
13:00								*coffee*
13:15			lunch			lunch		
13:30			lunch			lunch		
13:45			lunch			lunch		
14:00							lunch	
14:15							lunch	
14:30							lunch	

Table 25 shows the resulting change in FTEs required. Because the 6 OR day scenario requires less OR time (2.48 FTE less, Table 21) we need 2.48 - 2.08 = 0.4 FTE less in total. For the scenario with 7 OR days we need 0.54 + 2.40 = 2.9 FTEs more. Finally, for the scenario with 3 full OR days, we need 0 + 1.04 = 1.0 FTE more.

Table 25 Change in personnel requirements (2)

	Additional personnel (FTE)
3 full OR days	1.0
6 OR days (all full)	-0.4
7 OR days (all full)	2.9

In reality it is possible to shift around OR personnel between ORs in a more elaborate manner, for instance working with a form of leap frog. A relief team relieves OR 1. After their lunch break, the OR personnel from OR 1 relieves OR 2, etc. This, however, does not change the FTE requirements. It can serve to deal with personnel restrictions such as training of OR personnel. Not every assistant is trained to work with every specialty.

The number of required FTEs increases by 1.0 when working with 3 full OR days and half OR days. The number of FTEs required when working with 7 full OR days is 2.9 higher than in the scenario without full OR days. The number of FTEs for working with 6 full OR days is 0.4 less.

We have introduced 5 interventions. These interventions are planning slack, working without an emergency session and planning emergency slack, scheduling surgeries based on their standard deviation, break-in-moments optimization, and working without lunch breaks. Chapter 5 continues with the description of the simulation model we will use to test the effectiveness of these interventions.

5. Experimental design

Now that we have a clear understanding of the current situation and the possible interventions, we can develop a fitting simulation model. We will use this simulation model to test the effects of different interventions on the performance of the OR department [Chapter 6].

5.1 Simulation model

We built our simulation model using and expanding software developed by E.W. Hans, called the *Operating Room Management Game* (OR game). For the simulation model to fit reality we use actual surgery durations from the period January to November 2008, as described in Section 5.2. We use an event based model to simulate the reality. As the name suggests an event based model is based on events. In our case these events are, among others, the start of a surgery and the arrival of an emergency. These events cause the state of the system, in our case the OR department of Scheper hospital, to change. The input of our discrete event simulation is the surgery durations as described in Section 5.2.

There are a number of simplifications in our model. We do not incorporate departments that deal with the patients before and after their stay at the OR department. In other words, we assume infinite capacity at the wards, the outpatient departments, and the Intake office. Furthermore we do not take into account resource constraints such as a limited number of X-ray machines. Finally, in reality the OR planner can decide to cancel the emergency session on certain days. In the simulation model, the afternoon emergency session is in place every day. From Section 2.3.3 we know that 23 of the 190 sessions (12%) were cancelled due to holidays or personnel shortage. In our simulation research we will compare the performance of the OR department with an afternoon emergency session to the performance without an afternoon emergency session. In order to have two distinct scenarios we choose not to cancel emergency sessions in our simulation study.

We do take into account the ROP, including lunch breaks, with a modification. In reality, the ROP is frequently changed. This poses an issue because we will simulate using a fixed ROP. We do this because we will compare the performance of this ROP to the performance of alternative ROPs [Section 4.5]. We choose to use the ROP as it was since October 2008, with a small modification. This is the ROP presented in Table 5. We have excluded the four smallest specialties. These specialties are Anesthesiology, Ophthalmology, Dentist, and Oral surgery. The impact of these specialties is limited. Together, these specialties account for less than 3% of the total surgery time. Also, these specialties together only accounted for 3 sessions per week in the old ROP, and for only 1 session in the proposed ROP due to the capacity reduction described in Section 2.2.3. Table 26 shows the resulting ROP we use to simulate the current situation.

Table 26 ROP used to simulate current situation

		General Surgery	Orthopedics	Gynecology	Plastic Surgery	ENT	Urology	Neurosurgery	Emergency	Total
Monday	morning	3	2	1		1		1		8
	afternoon	2	2	1		1			1	7
Tuesday	morning	3	2		1		1	1		8
	afternoon	2	2		1		1		1	7
Wednesday	morning	3	1	1	1	1	1			8
	afternoon	2	1	1	1		1		1	7
Thursday	morning	2	2	1			1			6
	afternoon	2	1	1	1		1		1	7
Friday	morning	2	3	1	1					7
	afternoon	2	2	1	1				1	7
Total		23	18	8	7	3	6	2	5	72

5.2 Data

The surgeries performed in the period January to November 2008 form the basis of our simulations. We performed a data query at the start of December 2008 and therefore we have no data for the last month of 2008. In total the OR department performed 7542 elective surgeries in this period. To determine the number of elective surgeries for our simulation we exclude the surgeries performed in the 10 reduction weeks and in the weekends leaving 6444 surgeries performed in 38 weeks. Furthermore we only consider the specialties displayed in the first column of Table 27 resulting in a total of 6118 surgeries. This makes 8372 elective surgeries per year divided over 7 specialties. Table 27 shows the percentages of the total number of surgeries each specialty performs.

Table 27 Specialties in simulation

Specialty	% of total
General surgery	31.9%
Orthopedics	26.6%
Gynecology	15.4%
Plastic surgery	8.1%
ENT	8.3%
Urology	6.7%
Neurosurgery	3.0%

These specialties perform various surgery types [Appendix B]. However, some surgery types are only performed a couple of times per year. Because of this we only distinguish surgery types performed more than 50 times and we put the remaining surgeries together in 1 group.

For certain surgery types we distinguish the specialist performing the surgery. Again we only do this if the surgery type – specialty combination occurred more than 50 times. This results in 43 groups.

Our simulation model uses average surgery durations and the standard deviations of the average durations, combined with a theoretical distribution. Appendix D describes how we derive these characteristics from the data. These surgery durations are excluding changeover times. For this reason, we add average changeover times to the average durations in our simulation model. We use the average changeover times presented in Table 3.

To establish the average durations and the standard deviations of the surgeries, we use all surgeries instead of only those performed outside the reduction weeks. The same is true for the urgent and emergency surgeries.

To establish the number of emergency surgeries per year we exclude all surgeries performed outside regular working hours and all urgent surgeries performed in the weekends. Furthermore, we exclude all surgeries performed in reduction weeks. This leaves the number of surgeries presented in Table 28. For our simulations we extrapolate these numbers to account for a full year. To establish the mean durations of the urgent and emergency surgeries we again use all available data. We distinguish 3 types of urgent surgeries, namely Gynecology surgeries, Orthopedic surgeries, and General surgeries combined with the remaining urgent surgeries. Gynecology unplanned surgeries can only be performed in Gynecology sessions, Orthopedic surgeries only in Orthopedic sessions, and General surgeries and rest only in General sessions. We distinguish 2 types of emergency surgeries, Gynecology surgeries and General combined with the remaining urgent surgeries.

Table 28 Number of emergency and urgent surgeries

	# of emergency surgeries	# of urgent surgeries
Gynecology	31	80
Orthopedics		94
General surgery	18	407
Rest		39

Our simulation model works with statistical distributions and therefore uncertainty plays a role. Nonetheless, we want to make sure that the results of our simulations are reliable. In order to get results with sufficient precision we have to make enough runs, with one run representing one year. Using the sequential procedure from Law and Kelton [2002] we determine the required number of runs to achieve a level of confidence of 95% to be 94 for the performance indicator "mean waiting time of emergency surgeries". The required number of runs, in order to achieve the same level of confidence for the other performance indicators is smaller than 94.

5.3 Validation

To ensure that our simulations are representative of reality we validate our simulation model. We do this by comparing the performance of the OR department in our simulation with the performance of the OR department in reality

Conclusions based on our simulation model are only valid when the simulation model itself is valid. In other words we have to validate our simulation model. A good place to start validating the model is by asking the experts of the real situation, the OR department of Scheper hospital. Therefore, we have presented the model [Figure 13] to the people working at the OR department. The experts agreed the model described reality accurately.

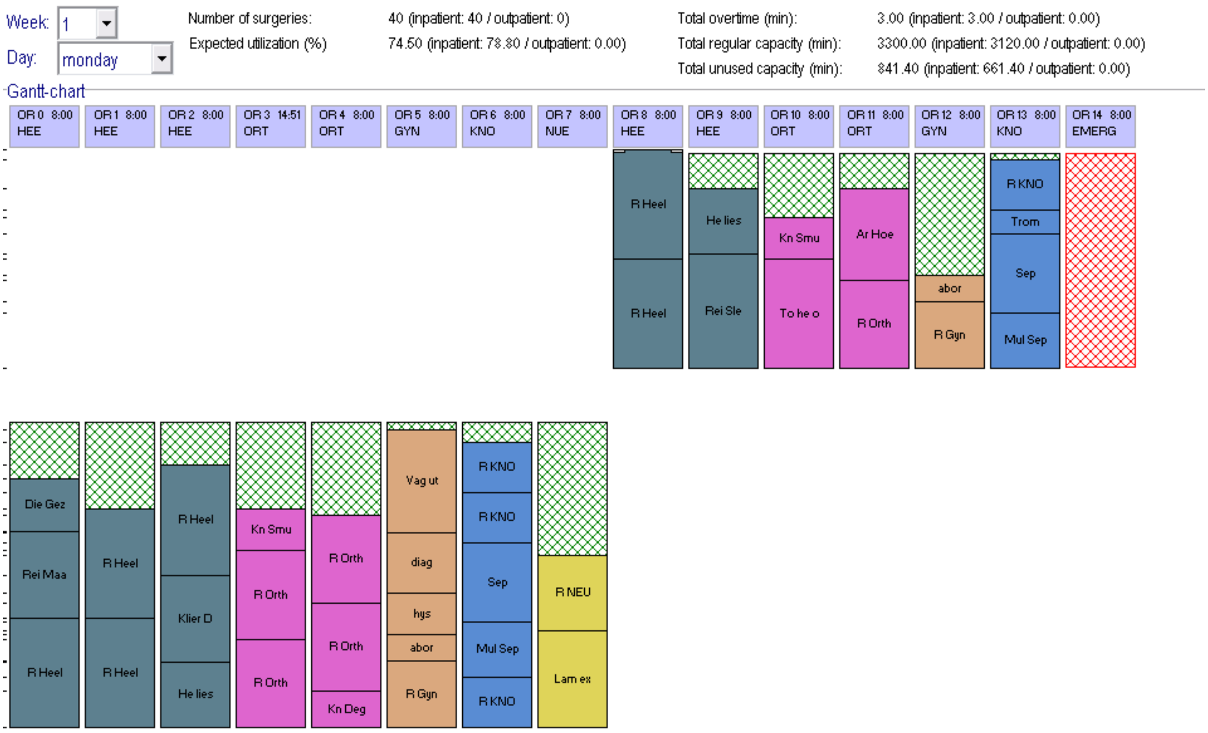

Figure 13 Simulation model

We continue our validation by comparing reality and simulation model using a number of indicators. We use, when possible, the same indicators presented in Section 2.3.1 to describe the current situation of Scheper hospital. We also introduce a number of additional indicators to get a more detailed comparison. Table 29 presents this comparison.

Table 29 Validation of the simulation model (1)

	Reality (Source: X-care)	Simulation	Difference (Reality - Simulation)	Relative difference (Reality - Simulation)/ Reality
Capacity per year (min.)	771,420	771,420	0	0%
Elective surgery duration (min.)	642,398.4	640,962.6	1,435.9	0%
Elective during regular time (min.)	575,389.6	589,807.3	-14,417.8	-3%
Elective overtime (min.)	67,008.8	51,155.2	15,853.6	24%
Utilization (%)*	78.2%	81.7%	-3.5%	
Emergency surgery (min.)	3,982.6	4,018.2	-35.7	-1%
Urgent surgery (min.)	56,155.9	56,682.1	-526.2	-1%
Urgent during regular time (min)	27,862.4	40,590.8	-12,728.3	-46%
Urgent overtime (min.)	28,293.5	16,091.3	12,202.2	43%
Overtime elective (%)	10.4%	8.0%	0.0	
Overtime urgent (%)	50.4%	28.4%	0.2	
Total av. elective overtime p/d (min)	257.7	196.8	61.0	24%
Total av. urgent overtime p/d (min)	108.8	61.9	46.9	43%
Number of elective surgeries	8,372.0	8,375.8	-3.8	0%
Number of urgent surgeries	864.8	862.0	2.9	0%
Number of emergency surgeries	67.1	66.8	0.2	0%

**Utilization of available session time, including emergency sessions.*

A number of issues catch our attention. First of all the number of surgeries does not seem to match the number of surgeries presented in Chapter 2. This is because in Chapter 2 we presented the number of surgeries in the period January - November 2008. In our simulation model we simulate an entire year, so we have to extrapolate the numbers presented in Chapter 2. Furthermore, in Chapter 2 we included reduction weeks. In our simulations we do not include reduction weeks. This means that we extrapolate the numbers in chapter 2 excluding reduction weeks. We do this because we want to simulate the behavior of the OR department in a normal week. As explained, our simulation model works with an average number of patients arriving each week. If we would include reduction weeks, the average number of patients would be lower than it is in reality in a normal week. We therefore work with the average number of patients arriving per week in the period January – November 2008, excluding reduction weeks and weekends.

Secondly we see a large difference in overtime between reality and simulation, both for elective surgeries and for urgent surgeries. We determine that this difference occurs during the lunch break. If we do not refer to surgery time between 12:15 and 13:00 as overtime, both in reality and in the simulation model, the difference in overtime almost disappears for elective surgeries [Table 30].

Table 30 Validation of the simulation model (2)

	Reality (Source: X-care)	Simulation	Difference (Reality - Simulation)	Relative difference (Reality - Simulation)/ Reality
Capacity per year (min.)	771,420	771,420	0	0%
Elective surgery duration (min.)	642,398.4	640,962.6	1,435.9	0%
Elective during regular time (min.)	612,211.1	610,918.6	1,292.4	0%
Elective overtime (min.)	30,187.4	30,043.9	143.4	0%
Utilization (%)	83.2%	85.5%	-2.26%	
Emergency surgery (min.)	3,982.6	4,018.2	-35.7	-1%
Urgent surgery (min.)	56,155.9	56,682.1	-526.2	-1%
Urgent during regular time (min)	29,864.4	48,558.0	-18,693.6	-63%
Urgent overtime (min.)	26,291.5	8,124.1	18,167.4	69%
Overtime elective (%)	4.7%	4.7%	0.0	
Overtime urgent (%)	46.8%	14.3%	0.3	
Total av. elective overtime p/d (min)	116.1	115.6	0.6	0%
Total av. urgent overtime p/d (min)	101.1	31.2	69.9	69%
Number of elective surgeries	8,372.0	8,375.7	-3.7	0%
Number of urgent surgeries	864.8	862.0	2.9	0%
Number of emergency surgeries	67.1	66.8	0.2	0%

We contribute the remaining difference to rounding errors and the fact that the simulation model does not incorporate online rescheduling of surgeries. If we look at Figure 14 we see a clear example of this. The left half of Figure 14 shows the schedule while the right half shows the realisation of this schedule in our simulation model. In reality the last surgery performed in OR 0 would have been moved to OR 1 as indicated by the arrow.

Table 30 also shows that the difference for urgent surgeries remains. We know from Section 2.1.1 that almost half of the urgent surgeries start after 16:00. Until now, we assumed that all these surgeries arrived during working hours but were postponed until after 16:00. Based on the large difference between simulation and reality, this does not seem to be a likely assumption anymore. We therefore analyze which type of urgent surgeries starts in the evenings. If these are urgent surgeries that have to start within 8 hours of arriving at the hospital, we can assume that a significant number of these surgeries arrived after 16:00. Because these surgeries cannot wait until the next day, they have to start in the evening. In fact, of the urgent surgeries starting after 16:00, 82% has to start within 8 hours of arriving at the hospital.

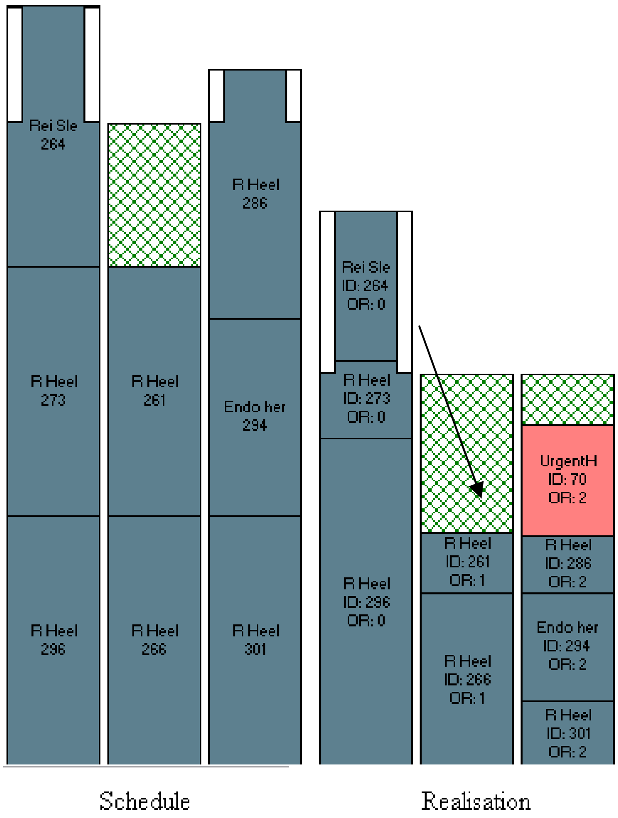

Figure 14 Example of online rescheduling

To further investigate our hypothesis we look at the time between the last elective surgery and the first urgent surgery of each day. If there is a gap of more than 6.8 minutes between these 2 surgeries we can assume that the urgent surgery arrived after 16:00. We choose 6.8 minutes because this is the average changeover time. If it arrived before 16:00, the surgery would have started right after the last elective surgery. Therefore we include all urgent surgeries starting after 16:00 and within 6.8 minutes of the last elective surgery of that day finishing. Table 31 shows the resulting differences between reality and simulation for urgent surgeries. Section 6.3 presents a sensitivity analysis of the number of urgent surgeries included in our simulation model.

Table 31 Validation of the simulation model (3)

	Reality (Source: X-care)	Simulation	Relative difference (Reality - Simulation)/ Reality
Urgent surgery (min.)	34,176.3	34,564.1	-1%
Urgent during regular time (min)	29,864.4	29,768.9	0%
Urgent overtime (min.)	4,311.9	4,795.3	-11%
Total av. urgent overtime p/d (min)	16.6	18.4	-11%
Number of urgent surgeries	510.4	509.3	0%
Utilization (%)	83.2%	83.1%	0%

We still see differences between reality and simulation; however, these differences are much smaller than before. The first difference we see is in the total surgery duration. This is 1% lower in the simulation. This is caused by rounding errors. As explained before, the simulation model uses an exponential distribution to describe the urgent and emergency arrivals. For this we need the average duration of the surgeries. We round these figures to 3 decimals, resulting in small differences between simulation and reality. The second difference is in the amount of overtime. Here we see a difference of 11%. Because the amount of overtime is low compared to the total surgery time, the percentage difference is higher for overtime than for surgery time in regular time. However, both are connected in that overtime is equal to total surgery time minus surgery time in regular duration. Therefore, we are looking at slightly less overtime in the simulation model, compared to reality. To put this in perspective, the average duration of a General urgent surgery is 71.06 minutes while the difference in total average overtime per day due to urgent surgeries is only 1.9 minutes. Finally, a portion of this overtime can be attributed to the fact that we have a slightly higher total surgery duration in the simulation.

We conclude that our simulation model is valid. The model agrees with reality on all indicators. However, the issue of the lunch breaks remains. Because in reality the lunch break does not start at exactly 12:15 and does not finish exactly at 13:00, we found a large difference in overtime during the lunch break between reality and simulation. Because we have an intervention specifically aimed at the lunch break we do want to incorporate overtime during lunch break in our simulation model. For this to be possible we have to determine the average duration of a lunch break in reality. We do this by calculating the average length of changeover times larger than 20 minutes between 11:00 and 14:00. We assume that these are the lunch breaks. We arrive at an average changeover time of 50 minutes. This proves that in reality there is indeed consistently a lunch break. Therefore we will work with a lunch break of 45 minutes in our simulations. We will not work with a lunch break of 50 minutes, in which is included the changeover time between the last surgery in the morning and the first surgery in the afternoon. This changeover time is already accounted for in the average surgery duration as explained in Section 5.2.

We have described our simulation model and proven its validity. We will now present the results concerning the possible interventions. These results were obtained using the simulation model described in this chapter.

6. Results

In order to compare the interventions we introduced in Chapter 4 we need performance indicators. These performance indicators come both from the literature and from Scheper hospital. Section 6.1 gives a short summary of the performance indicators that we will use to compare the interventions. Section 6.2 evaluates the possible interventions.

6.1 Performance indicators

Section 3.2 gives an overview of different performance indicators form the literature. Combined with the performance indicators that are in place at the OR department of Scheper hospital, we develop a set of performance indicators with which we will evaluate the effectiveness of the different possible interventions. We use the qualifications for performance indicators described in Section 3.2 to determine which performance indicators we will use in our research.

We have the following performance indicators from the literature:

1. Number of procedures per FTE OR personnel
2. Number of procedure minutes per FTE OR personnel
3. Utilization of sessions
4. Utilization of session time
5. Average overtime per session
6. Average idle time at the end of a session
7. Average overtime
8. Percentage of procedures performed during the night (24:00 – 08:00)
9. Percentage of cancelled procedures
10. Waiting time
11. Throughput
12. Utilization
13. Leveling
14. Makespan
15. Patient deferral/ refusal
16. Financial
17. Preferences

The first 9 indicators are from the *OR okay* program. The first qualifier for indicators is relevance. In our research we want to measure the performance of the OR department from a scheduling perspective. From this perspective the purpose of the indicators from the *OR okay* program is clear. They measure a specific aspect of the logistical performance of the OR department. The first 2 indicators measure the effective use of OR personnel. In our study the number of procedures and procedure durations will not change. However, the number of FTEs will change. Therefore we only need 1 of the 2 indicators. We choose for indicator 1. Furthermore, the purpose of indicator 6 in our research is not clear because the idle time at the end of the program is already covered by indicator 4, utilization of session time. To keep the number of indicators to a minimum we choose to abandon indicator 6. For the same reason we abandon indicator 7 because it is already covered by indicator 5. In our research we are only interested in the performance during regular working hours. Therefore, we will not use indicator 8. Finally, in our simulation model we do not cancel sessions. Therefore, indicators 3 and 9 have no relevance.

Performance indicators 10 to 17 are from Cardoen et al. [2008]. The first indicator, waiting time, is relevant for our research. Because canceling the emergency session will probably result in longer waiting times for urgent surgeries. Throughput, defined as the number of patients per year, is almost always input for our simulation model, except for the case where we examine the effects of planning slack. Utilization, in our case utilization of session time, is already covered by indicator 4. Indicators 13 to 16 are either not relevant for this research or not within our scope and we will therefore not use these indicators. Finally, indicator 17 concerns the preferences. These preferences can concern any of the stakeholders involved. We have one clear preference of the OR personnel, surgeons, and OR planner. They all dislike changes in the schedule due to the arrival of an emergency surgery [Section 1.2]. Therefore, we will use the indicator "disturbance of the elective program". The relevance of the indicator is clear. The indicators relevant to our research are therefore 1, 4, 5, 10, 11, and 17.

We have determined which indicators are relevant to our research. However, Pullen [2005] gives 5 more qualifiers for performance indicators. These qualifiers are Transparency, Comparability, Measurability, Changeability, and Normative [Section 3.2]. If we apply these qualifiers to our performance indicators we see that the indicators relevant to our research are also transparent; the indicators give a true representation of the actual performance. The comparability is also clear. Furthermore, we will not use the indicators to compare performances of different hospitals but we will use the indicators to compare different scenarios. We do not need to collect any additional data for the indicators relevant to our research and the indicators are therefore measurable. It is possible to influence the performance measured by the indicators relevant to our research, and we will do so in our research. Finally, the indicators are normative; it is possible to set a goal for the indicators relevant to our research.

We also have a number of performance indicators used by the OR department of Scheper hospital [Section 2.3.1]. Table 32 gives an overview of these performance indicators.

Table 32 Performance indicators used by Scheper hospital

Utilization of sessions
Utilization of available session time
Waiting list
Overtime

We will not include the first indicator, utilization of sessions, for the same reason we abandoned it from the set of performance indicators from the literature. Since we do not cancel sessions in our simulation we will not use this performance indicator. In reality sessions are cancelled due to a lack of patients on the waiting list or unavailability of resources (for example unavailability of personnel or surgeons). Our simulation model does not incorporate waiting lists or the availability of resources and therefore sessions will not be cancelled in our simulation model. The reason they are not part of our simulation model is that we are primarily interested in the handling of unplanned surgeries. Furthermore, because we do not incorporate waiting lists in our simulation model we will not use the performance indicator "waiting list". The remaining performance indicators from Scheper hospital are similar to the indicators we have selected from the literature.

This results in a set of 6 indicators from the literature that we will use to compare interventions. We continue with a summary of these indicators and their formal definition.

6.1.1 Number of procedures per FTE OR personnel

We will only use this indicator if the number of FTEs changes. This is only the case when the ROP changes [Section 4.5].

6.1.2 Utilization

We use the same definition for utilization of available session time as the OR department of Scheper hospital. From now on we will simply call this utilization. From Section 2.3.1 we know that this definition is:

(Total operating time +changeover time) / total available session time

Previously we made a distinction between the utilization of the emergency session and the elective sessions. From now on when we talk about utilization, we mean the utilization of all the sessions. This makes it easier to compare scenarios with and without an emergency afternoon session. A consequence of this is that we include urgent surgeries in the total operating time. Again, we note that only operating time inside the available session time plus changeover times between surgeries is included in the total operating time.

6.1.3 Overtime elective and overtime urgent

In Section 2.3.1 we introduced the definition of overtime we use in our research. We chose to define overtime as a percentage of the total operating time resulting in the following definition. However, to evaluate the effectiveness of possible interventions we will define overtime as the total average overtime per day. In our simulations we always perform the same number of operations with the same durations and therefore we can use this definition. The added advantage of using this performance indicator is that it is more tangible. The literature defines overtime as overtime per session. However, because we have a varying number of sessions in the different ROPs it would not be possible to compare different ROPs with this definition of overtime. Therefore we define overtime per day instead of per session. Furthermore, because we have a specific interest in urgent surgeries, we define overtime for both elective surgeries and urgent surgeries. The formal definition is:

Total average surgery time outside regular working hours or during the lunch break per day

6.1.4 Waiting time urgent patients and waiting time emergency patients

Waiting time is measured from the time the patient arrives to the starting time of the surgery. We take into account waiting time for urgent patients and waiting time for emergency patients. The former has to be smaller than 8 hours, the latter smaller than 30 minutes. This is the maximum allowed waiting time. Performances of alternatives are regarded superior when waiting times are lower.

Max (start time – start waiting, 0)

6.1.5 Throughput

We define throughput as the number of surgeries per year. We will only use this performance indicator when the number of surgeries is different for the scenarios we are comparing. For the most part, however, the number of elective surgeries per year will be as defined in Section 5.3.

6.1.6 Disturbance elective program

This performance indicator is aimed at measuring the disturbance of the elective program due to the arrival of emergency patients. Surgeons, as well as OR personnel and the OR planner, dislike online changes in the elective program. In Section 2.3.1 we introduced the following indicator to measure the disturbance of the elective program:

*((Total number of disturbances)/ (Total number of emergency surgeries performed))*100%*

6.2 Comparison of interventions

We now evaluate the effectiveness of the possible interventions introduced in Chapter 4. Table 33 summarizes these possible interventions.

Table 33 Possible interventions

Intervention	Abbreviation
Planned slack	PS
Emergency slack	ESL
Working without afternoon emergency session	ES
Working without lunch breaks	LB
BIM optimization	BIM
Scheduling based on standard deviation	SD

Planned slack

Table 34 shows that planning slack reduces the number of patients per year. We compare planning slack with a slack factor of 0.5 [Section 4.1] to scheduling surgeries without planning slack. As we have explained in Section 2.2.4 the OR department tries to fill the schedule as much as possible. In fact, in our simulation model we have to plan a small amount of overtime to be able to schedule 8372 surgeries. This difference compared to reality is caused by the Intake office topping of the schedule with surgeries having a short duration

[Section 2.2.4]. However, this difference is very small and in fact it comes down to only 2.1 minutes of planned overtime per OR day.

Table 34 Planned slack

	Without slack	With planned slack (31% probability of overtime)
Number of surgeries	8,372	7,206
Total surgery time (hours)	10,607.0	8,961.3
Total OR capacity (hours)	12,857	12,857
Total overtime (hours)	121.9	0
Total free capacity (hours)	2,245.0	2,340.6
Total planned slack (hours)	0	1,555.2
Utilization (%)	79.2%	70.5%
Overtime elective (min. per day)	198.6	79.5
Overtime urgent (min. per day)	65.2	45.5

Table 34 shows that planning slack comes down to a tradeoff between overtime and utilization. By planning slack we reduce overtime but also utilization. Using planned slack it is possible for management to set an allowed overtime probability and consequently know what the expected utilization will be and what the number of surgeries will be. In our simulations each specialty performed a fixed fraction of the total surgeries per year. However, in reality it is of course possible to alter these fractions. Specialties performing surgeries with lower duration's standard deviations will be able to achieve a higher utilization with the same overtime probability, compared to specialties performing surgeries with higher duration's standard deviations [Section 3.1]. Consequently the performances of specialties can be compared, taking into account an important characteristic of the surgeries they perform. However, before this can be done the management of the OR department, in conjunction with the board of Scheper hospital, will have to set an allowed overtime probability. To illustrate the effects of setting an allowed overtime probability we introduce Figure 15 and Figure 16.

Figure 15 shows the influence of the allowed overtime probability on the utilization and the overtime. It is clear that decreasing the allowed overtime probability results in less overtime and a lower utilization of available OR time. This is a direct result of the lower number of surgeries scheduled per year. Figure 16 shows that the number of surgeries varies from more than 8000 per year with an allowed overtime probability of 50%, to a little over 7200 with an allowed overtime probability of 16%.

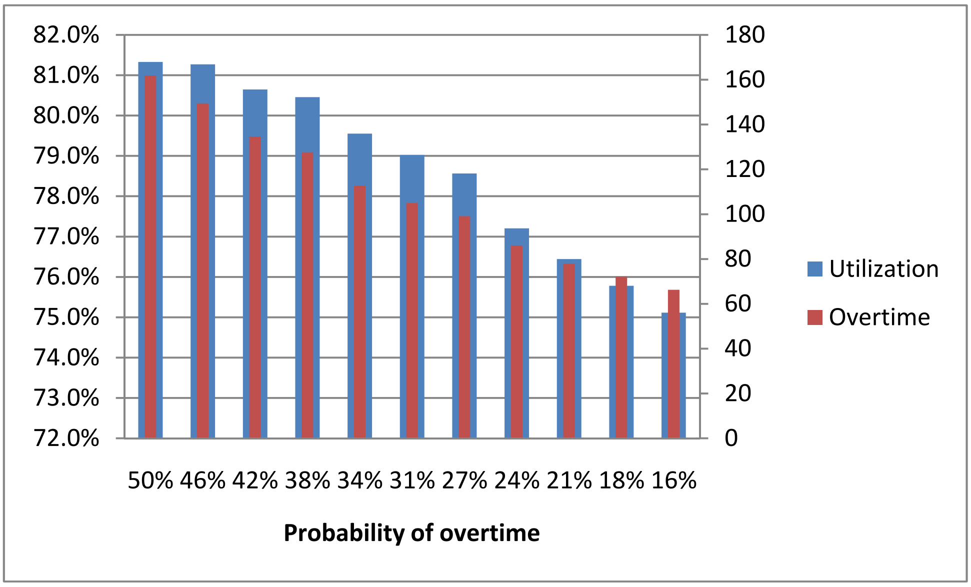

Figure 15 Allowed overtime probability vs. utilization and overtime

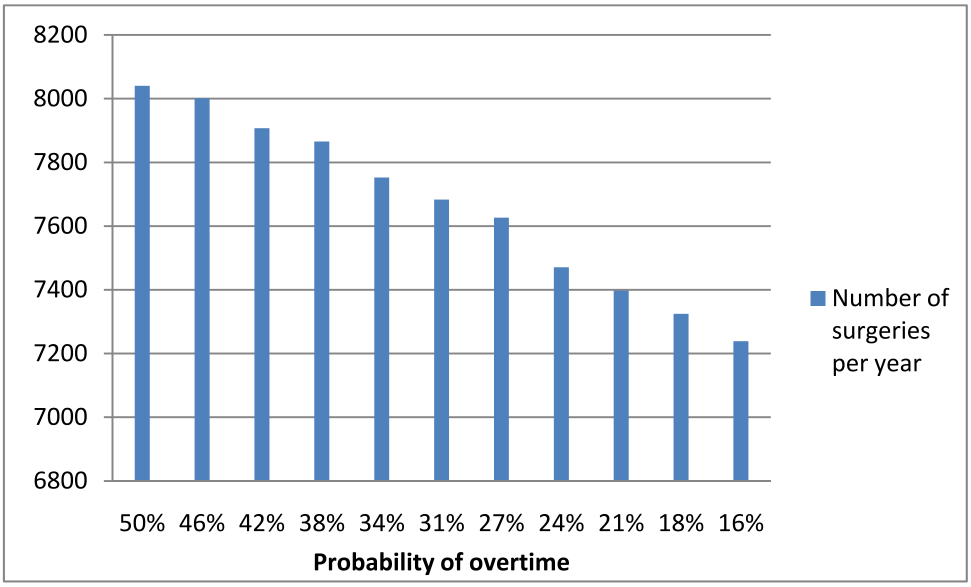

Figure 16 Allowed overtime vs. number of surgeries per year

Planning emergency slack

We compare working with an afternoon emergency session to working without an afternoon emergency session and instead, reserving emergency slack. Before we can make this comparison we will first determine where we can best reserve this emergency slack. We distinguish between reserving emergency slack in all general ORs, reserving emergency slack in 1 general OR per day, and reserving emergency slack in 2 general ORs per day. For the Orthopedic and Gynecology ORs we only consider reserving emergency slack in all ORs due to the limited number of ORs of these specialties per day. For an explanation why we only consider these scenarios we refer to Section 4.2.

Table 35 shows a comparison between planning emergency slack in 2 General ORs each day, planning emergency slack in 1 General OR each day, and planning emergency slack in all ORs. If we look at planning emergency slack in 2 General ORs each day, the results are inconclusive. For the ROP with 7 full OR days working with emergency slack in all ORs seems to perform better. On the other hand, in case we work with 6 full OR days, planning slack in only 2 General ORs performs slightly better on all performance indicators. Another possibility would be to plan emergency slack in just 1 General OR per day.

In this case, we see the waiting time for emergency and urgent surgeries decreases for all OR days. Also, the overtime for urgent surgeries decreases. However, the utilization decreases and the elective overtime increases. Reserving emergency slack in only 1 General OR each day means that we schedule less elective surgeries in this OR. Because we keep the total number of surgeries equal this results in more surgeries being scheduled in the remaining General ORs. Concequently we see higher elective overtime.

Table 35 Emergency slack (2)

OR days	Scenario	Available OR time (hours per week)	Utilization (%)	Overtime elective (min. per day)	Overtime urgent (min. per day)	*Waiting emergency (min. per surgery)*	*Waiting urgent (min. per surgery)*	*Disturbance (%)*
6 full OR days	ESL	240	83.3%	165.0	49.6	*13.6*	*164.8*	*55.7%*
6 full OR days	ESL1	240	82.9%	184.9	42.5	*13.0*	*147.7*	*53.1%*
6 full OR days	ESL2	240	83.4%	163.8	48.2	*13.5*	*164.8*	*55.2%*
7 full OR days	ESL	280	75.2%	57.9	28.9	*11.7*	*160.1*	*49.7%*
7 full OR days	ESL1	280	74.7%	77.7	24.1	*10.8*	*138.7*	*45.6%*
7 full OR days	ESL2	280	75.1%	61.2	27.3	*11.2*	*156.7*	*48.3%*
3 full OR days	ESL	258.5	78.4%	126.8	55.2	*12.4*	*146.7*	*40.3%*
3 full OR days	ESL1	258.5	77.8%	159.7	41.9	*10.6*	*129.3*	*33.5%*

ESL: Emergency slack in all OR days
ESL1: Emergency slack in 1 General OR each day
ESL2: Emergency slack in 2 General ORs each day

With the absence of an emergency session urgent, surgeries have to wait until the elective program finishes in an OR before they can start. The lower urgent waiting times and less overtime due to urgent surgeries are caused by the fact that these surgeries can start earlier in the OR with emergency slack, where the elective program generally finishes early. Furtermore, if there are no urgent surgeries, emergency surgeries can start immediately in the OR with emergency slack if that OR finished the elective program. This is the reason for the slightly lower emergency waiting times.

Choosing between reserving emergency slack in only 1 General OR or in all General ORs comes down to choosing between elective overtime with utilization on the one hand and overtime due to urgent surgeries, combined with urgent and emergency waiting time, on the other. Because the average waiting times are still well below their allowed maxima we chose to work with emergency slack in all ORs because this results in a slightly higer utilization. We now continue with comparing reserving emergency slack in all ORs to having an afternoon emergency session.

Working without an afternoon emergency session

Table 36 Emergency session

OR days	Scenario	Available OR time (hours per week)	Utilization (%)	Overtime elective (min. per day)	Overtime urgent (min. per day)	*Waiting emergency (min. per surgery)*	*Waiting urgent (min. per surgery)*	*Disturbance (%)*
Base scenario	ES	262.25	75.5%	203.3	37.2	*8.5*	*48.4*	*27.5%*
Base scenario	ESL	247.25	79.1%	204.1	62.3	*12.5*	*125.6*	*42.3%*
6 full OR days	ES	255	79.5%	162.7	18.3	*11.3*	*105.3*	*51.4%*
6 full OR days	ESL	240	83.3%	165.0	49.6	*13.6*	*164.8*	*55.7%*
7 full OR days	ES	295	71.8%	57.5	15.1	*10.0*	*93.6*	*47.1%*
7 full OR days	ESL	280	75.2%	57.9	28.9	*11.7*	*160.1*	*49.7%*
3full OR days	ES	273.5	74.9%	126.7	31.6	*9.5*	*65.0*	*33.0%*
3full OR days	ESL	258.5	78.4%	126.8	55.2	*12.4*	*146.7*	*40.3%*

ES: Afternoon emergency session
ESL: Emergency slack in all OR days

Table 36 shows that the advantage of having an afternoon emergency session is a reduction in the waiting times of urgent and emergency surgeries, as well as in the number of disturbances in the elective program due to the arrival of an emergency surgery, no matter what OR division is chosen. For the base scenario this reduction comes down to 10 disturbances per year. The overtime due to urgent and emergency surgeries stays roughly the same. Furthermore, the overtime due to urgent surgeries decreases. However, having an afternoon emergency session decreases the overall OR utilization. This is, at least partly, due to the increase in OR capacity in the form of 1 extra afternoon emergency session, while the total number of surgeries remains the same. Therefore, to examine the effects of an afternoon emergency session further, we compare scenarios with an afternoon emergency session with scenarios without an afternoon emergency session and instead with an afternoon general session. In this case the total number of OR hours per day are the same for both scenarios. Table 37 presents the results of this comparison.

Table 37 Emergency afternoon session versus extra General afternoon session

OR days	Scenario	Available OR time (hours per week)	Utilization (%)	Overtime elective (min. per day)	Overtime urgent (min. per day)	*Waiting emergency (min. per surgery)*	*Waiting urgent (min. per surgery)*	*Disturbance (%)*
Base scenario	ES	262.25	75.5%	203.3	37.2	*8.5*	*48.4*	*27.5%*
Base scenario	Gen	262.25	76.2%	172.4	44.8	*10.2*	*100.6*	*34.1%*
3full OR days	ES	273.5	74.9%	126.7	31.6	*9.5*	*65.0*	*33.0%*
3full OR days	Gen	273.5	75.5%	99.6	39.4	*10.0*	*115.3*	*34.5%*

ES: Afternoon emergency session
GEN: Afternoon General session

As is to be expected, the afternoon emergency session results in an increase in the overtime for elective surgeries and a decrease in the overtime for urgent surgeries. Table 37 further shows a higher utilization for the scenarios with an afternoon General OR session. For both ROPs the average waiting times for urgent and emergency surgeries is shortest for the scenario with an afternoon emergency session. However, because the waiting time for urgent and emergency surgeries stays well below the allowed maximum, we conclude that working without an afternoon emergency session is the best choice, based on the higher OR utilization.

Working without a lunch break

In the base scenario the OR department works with a lunch break from 12:15 to 13:00. We compare this scenario with a scenario without a lunch break and 6 full OR days. Additionally we compare both scenarios with and without an afternoon emergency session. The OR schedule without a lunch break consists of 7.25 OR hours per week less.

Table 38 Lunch break (1)

OR days	Scenario	Available OR time (hours per week)	Utilization (%)	Overtime elective (min. per day)	Overtime urgent (min. per day)	*Waiting emergency (min. per surgery)*	*Waiting urgent (min. per surgery)*	*Disturbance (%)*
Base scenario	No ES	247.25	79.1%	204.1	62.3	*12.5*	*125.6*	*42.3%*
6 full OR days	No ES	240	83.3%	165.0	49.6	*13.6*	*164.8*	*55.7%*
Base scenario	ES	262.25	75.5%	203.3	*37.2*	*8.5*	*48.4*	*27.5%*
6 full OR days	ES	255	79.5%	162.7	18.3	*11.3*	*105.3*	*51.4%*

ES: With afternoon emergency session
No ES: Without afternoon emergency session

From Table 38 we conclude that working without a lunch break results in a higher utilization and less overtime, regardless of whether we work with or without an afternoon emergency session. Furthermore, Table 38 shows an increase in the waiting time for urgent and emergency surgeries. We think this is due to urgent and emergency surgeries starting in the morning after the elective morning program has finished. Another cause could be the reduced number of OR hours per week. We therefore also created an ROP similar to the 6 full OR days schedule but with one extra OR day of 7.25 hours per week. Table 39 shows a comparison of this ROP with the base scenario, again with and without an afternoon emergency session.

Table 39 Lunch break (2)

OR days	Scenario	Available OR time (hours per week)	Utilization (%)	Overtime elective (min. per day)	Overtime urgent (min. per day)	*Waiting emergency (min. per surgery)*	*Waiting urgent (min. per surgery)*	*Disturbance (%)*
Base scenario	No ES	247.25	79.1%	204.1	62.3	*12.5*	*125.6*	*42.3%*
6 full OR days	No ES	247.25	81.8%	150.1	38.5	*12.3*	*142.4*	*52.8%*
Base scenario	ES	262.25	75.5%	203.3	37.2	*8.5*	*48.4*	*27.5%*
6 full OR days	ES	262.25	77.8%	150.0	16.4	*10.7*	*97.0*	*49.3%*

ES: With afternoon emergency session
No ES: Without afternoon emergency session

The differences between working with and without a lunch break are now smaller but still the scenario without a lunch break results in a higher utilization and longer waiting times. Therefore we conclude that this effect is caused by the elimination of the lunch break and not by the difference in OR opening hours. We conclude that choosing whether or not to have a lunch break comes down to a tradeoff between utilization and overtime on the one hand and waiting times for urgent surgeries and disturbance of the elective program on the other. Because the average waiting times for urgent and emergency surgeries are well below the maximum allowed waiting time of 8 hours, it is clear that working without lunch breaks improves the performance. This comes, however, at a cost for the personnel because they cannot lunch in one large group. However, the OR department needs 0.4 FTEs less OR personnel [Section 4.5]. Finally, Table 39 shows an increase in the disturbance of the elective program.

Break-in-moments optimization

Table 40 BIM

OR days	OR time (hours per week)	*Waiting emergency (min. per surgery)*
6 full OR days	No BIM	13.6
6 full OR days	BIM	13.1
7 full OR days	No BIM	11.7
7 full OR days	BIM	11.4

BIM: with break-in-moments optimization
No BIM: without break-in-moments optimization

Our simulation model only allows us to perform BIM optimization for ROPs with full OR days. Therefore we can only present results for the ROPs with 6 and 7 full OR days. The goal of BIM optimization is to shorten the waiting time of emergency surgeries. Therefore we only present the results for this performance indicator.

Table 40 shows only a small improvement in the waiting time for emergency surgeries. Because the waiting times for emergency surgeries were short to start with, there was little room for improvement. Second, we note that in our simulation model all ORs start at 8:00. Therefore the first BII can only be as small as the shortest surgery. It is not possible to delay the start of surgeries in the morning in order to further optimize the BIMs. Third, we point out that ORs are sometimes scheduled to finish early because there are not enough surgeries. As explained in Section 4.4 this further limits the effectiveness of BIM optimization. Furthermore, the relatively small number of ORs compared to the number of ORs in the article of Lans et al. [2007] further diminishes the effect of BIM optimization. With more ORs there are more options to move around surgeries to decrease the BIIs. Finally BIM optimization is counteracted by the uncertainty in the surgery durations. We plan surgery durations based on their average duration. However, when the surgeries actually occur in our simulation model (and in reality) the surgery duration may differ from this planned duration. If this happens it changes the BIIs and thereby partially counteracts the BIM optimization. As the day progresses these differences between schedule en reality add up. Because the average surgery durations have rather large standard deviations this has a large influence on the effectiveness of the BIM optimization. Based on these results we conclude that applying BIM optimization at Scheper hospital will not result in a clear benefit for the OR department.

Scheduling based on standard deviation

Our simulation model only allows us to schedule surgeries based on their duration standard deviations for ROPs with only full OR days. Therefore we can only present results for the ROPs with 6 and 7 full OR days.

Table 41 Scheduling surgeries based on standard deviation

OR days	Scenario	Utilization (%)	Overtime elective (min. per day)	Overtime urgent (min. per day)
6 full OR days	SD	83.3%	161.7	50.6
6 full OR days	No SD	83.3%	165.0	49.6
7 full OR days	SD	75.0%	59.4	30.7
7 full OR days	No SD	75.2%	57.9	28.9

SD: Surgeries with similar standard deviations are scheduled at the same OR day as much as possible
No SD: Surgeries are scheduled randomly

We expect to see an increase in utilization and a decrease in overtime when scheduling surgeries based on standard deviation. Table 41 shows the results if we cluster surgeries with similar standard deviations in the same OR day. For the scenario with 6 full OR days, we see a small decrease in overtime of elective surgeries if we schedule based on standard deviation. However, for the scenario with 7 full OR days, the elective overtime increases slightly. We suspect the reason for this is the lower utilization of available OR time compared to the scenario with 6 full OR days. Furthermore, scheduling surgeries based on their standard deviation results in surgeries of the same type being performed on the same OR day. To make this possible, the OR department needs extra instrument trays. Therefore, we conclude that the introduction of planning surgeries based on their standard deviation will not improve the performance of the OR department.

6.2.1 Conclusion comparison of interventions

We started with 6 possible interventions [Table 33]. Of these, we have determined that 3 will not result in an increase in the performance of the OR department, namely ESL, BIM, and SD. Planning slack, however, is an intervention that can be of value for the OR department of Scheper hospital. Defining an allowed overtime probability makes the relation between overtime and utilization tangible and more importantly, it makes it possible to define norm utilizations for the different specialties [Section 3.1]. The remaining 2 interventions show an improvement on certain performance indicators and a worse performance on others. These interventions are ‘working without an afternoon emergency session’ and ‘working without a lunch break’. The decreased performance is for both interventions due to longer waiting times for urgent and emergency surgeries. However, the increase in waiting time for emergency surgeries is in both cases very small and still well below the maximum of 30 minutes. The waiting time for urgent surgeries also increases but the resulting waiting time is still well below the maximum of 8 hours. Since both interventions increase utilization and decrease overtime we conclude that these possible interventions will result in an improved performance of the OR department.

6.3 Sensitivity analysis

We will investigate the sensitivity of our findings on 3 different levels. We begin with a sensitivity analysis of the choice whether to work with 6 or 7 full OR days to the number of surgeries performed per year. Next, we investigate the choice to work with or without an afternoon emergency session relative to the number of surgeries per year. Finally we examine the sensitivity of our findings to the number of urgent surgeries performed during regular working hours.

Working with 6 or 7 full OR days

In 2004 Scheper hospital expanded their OR capacity with two new ORs in order to deal with an expected increase in care demand in the following years [Chapter 1]. The number of surgeries performed at Scheper hospital has increased in the period 2004-2009. However, this increase was not sufficient to justify the 2 extra ORs, as we have determined in the preceding section. The number of surgeries could, however, further increase in the future and therefore we examine whether working with 6 full OR days is still the best strategy if demand increases. We therefore simulate with 9000, 9500, and 10000 surgeries per year instead of the 8372 Scheper performs now.

Table 42, Figure 17, and Figure 18 show a steady increase in the utilization and in the overtime as the number of patients per year increases. This is true for the base scenario but also for the scenarios with 6 or 7 full OR days

From Figure 17 and Figure 18 we conclude that the ROP with 6 full OR days outperforms the base scenario both in utilization and in overtime, regardless the number of patients arriving per year and whether we work with or without an afternoon emergency session. Comparing the ROP with 6 OR days and that with 7 OR days we conclude that having only 6 full OR days results in higher utilization at the cost of more overtime. Therefore, we note again that it is a good idea to define an allowed overtime probability

Table 42 Sensitivity analysis, working with 6 or 7 OR days

ORs days	# of elective patients	Utilization (%)	Overtime elective (min. per day)	Overtime urgent (min. per day)	*Waiting emergency (min. per surgery)*	*Waiting urgent (min. per surgery)*	*Disturbance (%)*
Base scenario	8372	79.1%	204.1	62.3	*12.5*	*125.6*	*42.3%*
Base scenario	9000	82.8%	258.6	72.5	*12.9*	*141.6*	*48.1%*
Base scenario	9500	86.0%	316.6	79.3	*13.0*	*159.5*	*51.3%*
Base scenario	10000	88.5%	378.9	88.4	*13.7*	*178.7*	*55.1%*
6 full OR days	8372	83.3%	165.0	49.6	*13.6*	*164.8*	*55.7%*
6 full OR days	9000	86.6%	231.8	62.3	*14.4*	*192.7*	*61.2%*
6 full OR days	9500	89.3%	303.3	73.4	*15.0*	*213.1*	*65.5%*
6 full OR days	10000	91.2%	379.6	83.3	*15.9*	*235.2*	*70.2%*
7 full OR days	8372	75.2%	57.9	28.9	*11.7*	*160.1*	*49.7%*
7 full OR days	9000	79.4%	83.0	37.2	*11.9*	*179.4*	*54.3%*
7 full OR days	9500	83.0%	113.9	45.3	*13.1*	*196.0*	*59.1%*
7 full OR days	10000	85.9%	148.8	54.4	*13.7*	*215.9*	*64.1%*

Working with 7 OR days results in less overtime at the cost of a lower utilization compared to working with 6 OR days. However, it is of course possible to add just 1 session to the ROP with 6 OR days, thereby working with 7 OR days on 1 day in the week and 6 on the remaining days. In fact the number of sessions should be based on the demand per specialty combined with the norm utilizations for the specialties.

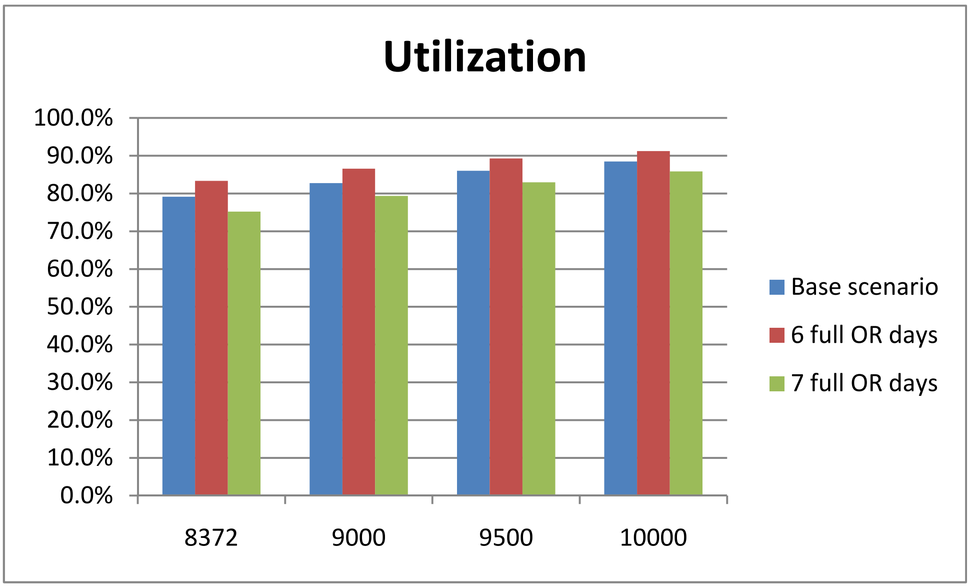

Figure 17 Sensitivity analysis working with 6 or 7 OR days, utilization

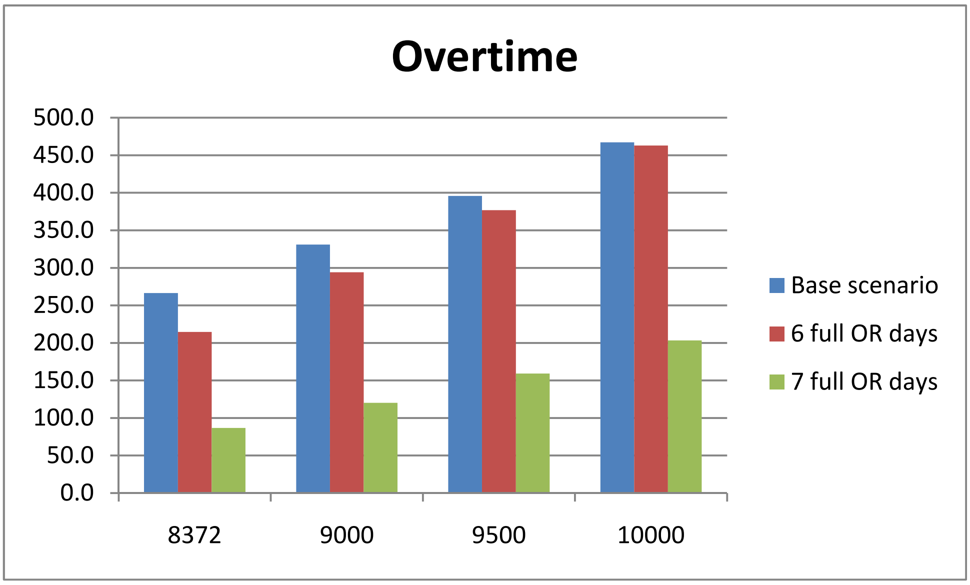

Figure 18 Sensitivity analysis working with 6 or 7 OR days, total overtime (elective + urgent)

Sensitivity of working without a lunch break

Figure 19 shows the utilization of session time for different numbers of patients per year for 2 different scenarios. The first scenario is the base scenario without an afternoon emergency session; the second is the base scenario with an afternoon emergency session. We see that the utilization of available session time remains higher for the ROP without an afternoon emergency session as the number of patients per year increases.

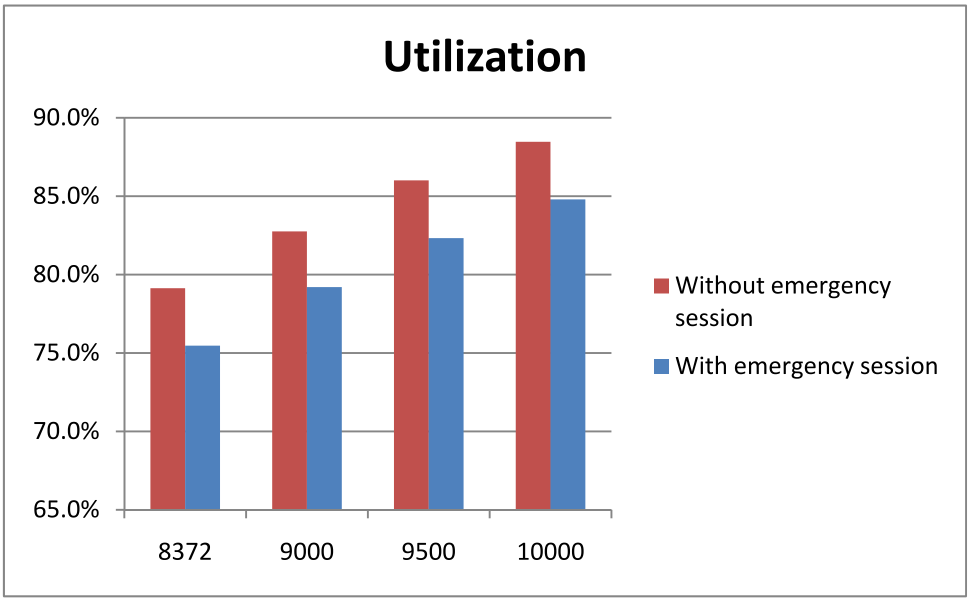

Figure 19 comparison of utilization with and without emergency session

Figure 20 shows that the increase in utilization is combined with more overtime due to urgent surgeries. Furthermore we see that this effect gets stronger as the number of surgeries per year increases. We note that the elective overtime does not depend on the presence or absence of an afternoon emergency session.

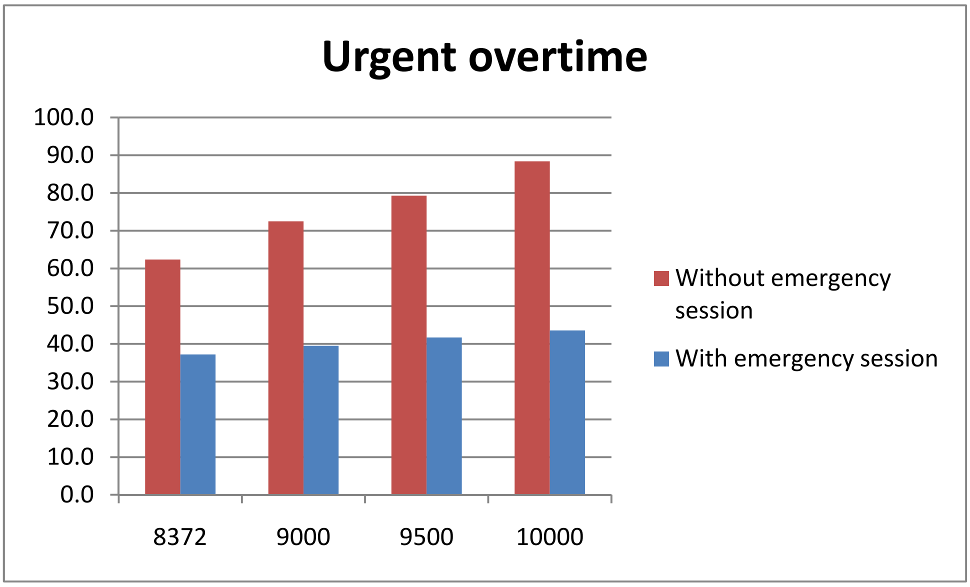

Figure 20 Comparison of overtime with and without emergency session

Sensitivity to the number of urgent patients per year

During the validation of our simulation model we encountered a difficulty in determining the number of urgent patients per year we should incorporate in our model. We decided to leave out a large portion of the urgent surgeries arriving after 16:00. We will now investigate the impact of this choice on our conclusions by simulating our scenarios including these urgent surgeries.

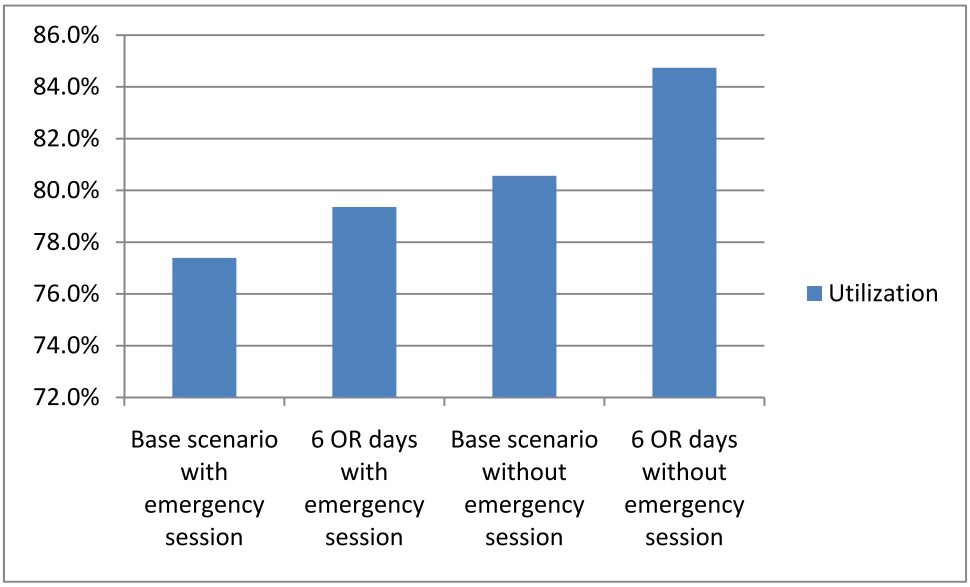

Figure 21 Sensitivity analysis for the number of urgent patients per year (1)

Figure 21 shows that the number of urgent patients does not influence our conclusions concerning the utilization of available session time. The left most column gives the utilization for the base scenario with an afternoon emergency session. The right most column gives the utilization for the scenario without a lunch break and without an afternoon emergency session. The second column gives the utilization if we work with the base scenario without a lunch break. The third column gives the utilization for the scenario with a lunch break and without an afternoon emergency session.

With the increased number of urgent patients, working without a lunch break increases utilization with 2%. Working without an afternoon emergency session further increases the utilization with 5.4%.

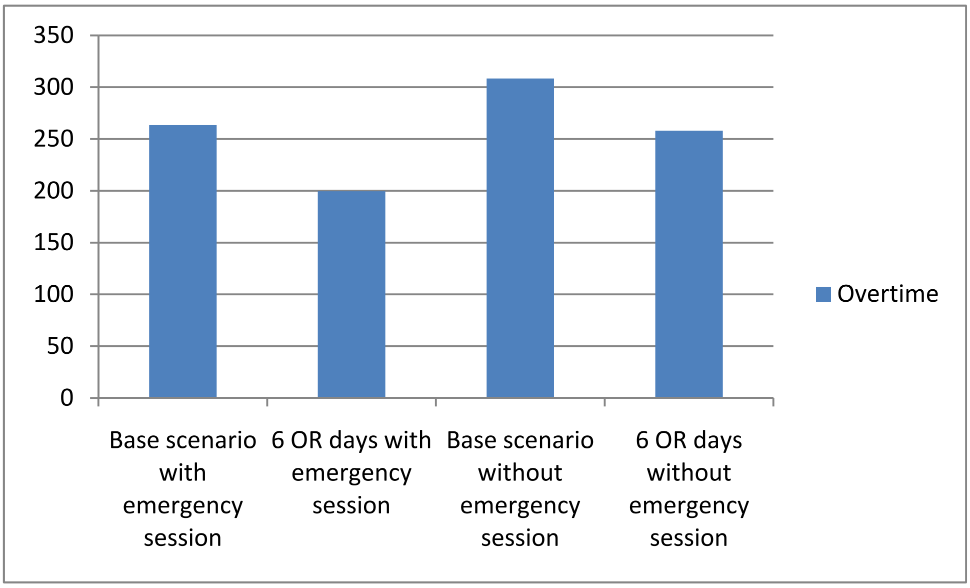

Figure 22 Sensitivity analysis for the number of urgent patients per year (2)

Figure 22 shows the overtime per day for the same scenarios. By comparing the first and the second column we see that working without a lunch break strongly decreases overtime. In fact, the overtime per day decreases by 63.8 minutes. However, if we look at columns 3 and 4 we see that this effect is counteracted by canceling the afternoon emergency session. Working without a lunch break, combined with working without an afternoon emergency session, decreases overtime per day by only 5.5 minutes compared to the base scenario.

The choice whether to work with 6 or 7 full OR days depends on the number of surgeries performed per year combined with the allowed overtime probability per day. Next we have shown that working without a lunch break outperforms the current situation, even if the number of patients per year increases. Furthermore, we have shown that working with or without an afternoon emergency session comes down to a tradeoff between overtime due to urgent surgeries and utilization, regardless the number of surgeries performed per year. Finally, the number of urgent surgeries arriving during regular working hours does not change our conclusions. Working without an afternoon emergency session combined with working without a lunch break still increases utilization and decreases overtime.

7. Implementation

In Chapter 6 we compared a number of possible interventions. Three of these interventions have shown potential to improve the performance of the OR department. This chapter describes how to implement these interventions. We begin with a stakeholder analysis where we describe the influence of the interventions on the stakeholders and we find possible issues the stakeholders might have with the interventions. In Section 7.2 we give an implementation plan for the interventions.

7.1 Stakeholder analysis

The main stakeholders of the OR department are the patients, specialists, OR personnel, the management of the OR department, and the board of the hospital. From Chapter 6 we have three possible interventions which have shown potential to improve the performance of the OR department. These interventions are using planned slack, working without an afternoon emergency session, and working without lunch breaks. Table 43 presents the consequences of these three interventions for each stakeholder. We use a number of parameters to measure the effects of the interventions.

Table 43 Stakeholder analysis

	Patients									Specialists			OR personnel			Management		
	Elective			Urgent			Emergency											
	PS	ES	LB	PS	ES	LB	PS	ES	LB	PS	ES	LB	PS	ES	LB	PS	ES	LB
Utilization	/	/	/	/	/	/	/	/	/	+	+	+	/	/	/	+	+	+
Disturbance elective program	+/-	-	-	/	/	/	/	/	/	+	-	-	+	-	-	/	/	/
Overtime	/	/	/	/	/	/	/	/	/	+	+	+	+	+	+	+	+	+
Waiting time urgent patients	/	/	/	+	-	-	/	/	/	/	/	/	/	/	/	/	/	/
Waiting time emergency patients	/	/	/	/	/	/	+	-	-	/	/	/	/	/	/	/	/	/

PS= Planned slack, ES= no afternoon emergency session, LB= no lunch break, /= Not of interest to the stakeholder, += Improvement compared to current situation, -= Worse compared to current situation

From Table 43 it is clear that the stakeholders will have a number of issues with the interventions. The first problem arises with the elective patients that will encounter a higher number of disturbances in the elective program, resulting in postponement or cancelation of elective surgeries. Specialists and OR personnel also see this as a problem. However, this is only a minor issue since the increase in disturbances is limited to only 10 per year. The second issue arises with the urgent and emergency patients who will have to wait longer before they are operated on. This issue is of course felt by the urgent and emergency patients. Furthermore, working without a lunch break will result in the OR personnel taking their lunch break at different times of the day and they will therefore lose the only moment of the day they can all be together. As a consequence communication between OR personnel, for instance to swap shifts, will suffer.

7.2 Implementation of interventions

Scheduling surgeries using planned slack requires a modification of the scheduling heuristics at the Intake office. Currently surgeries are scheduled on a first come first serve basis, meaning surgeries longest on the waiting list are scheduled first. The Intake office already uses historical operating times when scheduling surgeries and it should be a small step to incorporate planned slack with these historical times already present. However, the management of the OR department, together with the board of Scheper hospital, will have to decide on an allowed overtime probability.

Working without an emergency session requires more flexibility from the surgeons and the OR personnel. The OR planner his job will become even more demanding because all emergency arrivals require rescheduling of the elective program, whereas in the current situation it is sometimes possible to schedule these patients in the emergency session. Furthermore he has to decide where and when to perform urgent surgeries and by which surgeon, whereas currently he can simply plan the urgent surgeries in the emergency session. However, the OR department does have experience with working without an emergency session since there have been several days without an emergency session in 2008 [Section 2.3.3].

Currently a total of 66.75 full-time equivalents of OR personnel work at the OR department. Working with 6 full OR days does not require additional OR personnel. However, working with 7 full OR days requires 3 FTEs extra OR personnel. This might pose a problem since, as already explained in Section 2.1.2, there is currently a shortage of qualified OR personnel in the Netherlands. Furthermore, the specialists and the OR personnel have to be convinced of the advantages of working without lunch breaks. Finally, the OR personnel will have to be convinced of the persuaded because they will have to give up their combined lunch break.

For our interventions to work the OR department will have to hire extra OR personnel and convince the OR personnel to take their lunch break at different times of the day instead of all together. The task of the OR planner will become more demanding because he will have to perform more online scheduling. Finally, the Intake office has to incorporate planned slack and the management of the OR department together with the board of the hospital will have to decide on an allowed overtime probability.

8. Conclusion and recommendations for further research

From an analysis of the Operating Room (OR) department of Scheper hospital we find three issues that limit the utilization of the available OR time. The two main issues are the afternoon emergency session and the lunch break. The utilization of the afternoon emergency session is not as high as that of the elective sessions, making the OR department as a whole less efficient regarding utilization of available OR time. We also showed that working with a lunch break results in a decrease in utilization of available OR time. Because OR days are divided into 2 parts, namely a morning and an afternoon session, the Intake office has less flexibility when scheduling surgeries, resulting in gaps in the OR schedule, ultimately decreasing the utilization.

Working without an afternoon emergency session increases OR utilization by 3.6%, increases the overtime of urgent surgeries by 25.1 minutes per day while elective overtime stays equal. Working without a lunch break increases OR utilization by 4.2%, overtime of elective surgeries decreases by 39.1 minutes, and overtime of urgent surgeries decreases by 12.7 minutes per day. Together these interventions result in an increase in utilization of 7.8 %, a decrease in elective program of 38.3 minutes, and an increase in overtime due to urgent surgeries of 12.4 minutes. This is done with 7.25 OR hours less per week, no afternoon emergency session, and 0.4 full-time equivalents OR personnel less. The advantages of working with planned slack are clear utilization targets for specialties that take into account the characteristics of the surgeries performed by the specialties. However, before the OR department can work with planned slack the hospital has to decide on an allowed overtime probability.

Working without a lunch break requires a totally different Room Opening Plan (ROP) from the current ROP with morning and afternoon sessions. We developed 2 full OR day ROPs, one with 6 full day sessions per day and one with 7 full day sessions per day. A sensitivity analysis shows that the 6 OR day ROP results in a higher utilization and less overtime than the current ROP, even if the number of surgeries per year increases to 10000 per year. The ROP with 7 OR days results in the least amount of overtime. However, this comes at the cost of a low utilization. We recommend the management of the OR department to plan slack and to define a maximum allowed overtime probability. Using this maximum it is then possible to determine when it is necessary to open an additional OR. Furthermore, the manager of the OR department can set individual utilization targets for each specialty

Implementation of the three interventions will result in significant changes for the people working at the OR department. Specifically working without a lunch break will change the way work is organized at the OR department [Section 4.5] and should therefore be implemented with care. Fortunately, the OR department is currently experimenting with working with 3 full OR days which makes it possible for the personnel and the surgeons to get used to the idea. Finally, the OR department has some experience with working without an afternoon emergency session which also eases the transition to working without an afternoon emergency session. However, working without an emergency session does increase the number of disturbances in the elective program due to the arrival of an emergency.

Because of the limited number of emergency surgeries per year this increase is small, only around 10 disturbances per year.

Recommendations for further research

The board of Scheper hospital together with the management of the OR department should determine an allowed overtime probability. To help make this decision, Section 6.2 presents an overview of the expected consequences of varying overtime probabilities. With this allowed overtime probability it is possible to define norm utilizations for the specialties. This norm utilization takes into account the variation in the durations of the surgeries performed by the specialties and is therefore a fairer indicator to compare the performance of the specialties. The choice which overtime probability to use comes down to a tradeoff between utilization of available session time and the amount of overtime.

In our research we have only looked at the OR department. The OR department is, however, an integral part of the hospital and decisions made at the OR department have an influence on the rest of the hospital. Specifically the wards, Intensive Care Unit, and the outpatient department are directly connected to the OR department and therefore influenced by changes at the OR department. The board of Scheper hospital should therefore take into account the influence of our recommendations on the performance of the rest of the hospital.

The OR department distinguishes between 4 different levels of urgency of unplanned surgeries. During our research we discovered that a few surgeries were wrongly labeled. Surgeries were either registered with the wrong urgency level or surgeries without any urgency indication were labeled as urgent surgeries. There is a clear definition available at the OR department which surgeries should be labeled with a certain urgency level. To prevent surgeries being wrongly labeled this definition should be known by all surgeons.

We have not taken into account seasonal influences in our research. It is, however, interesting to investigate if there are seasonal influences on the length of the waiting lists for elective procedures and on the number of urgent and emergency surgeries. However, for this to be possible we need data for multiple years. The data used in our research was of a high quality. If the data stays of this high quality it can prove to be a valuable asset for the hospital. Therefore, the OR planner should be supported in his efforts to ensure the quality of the data.

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Appendices

Appendix A: Data Analysis

Appendix B: General Characteristics of Elective Program

Appendix C: Constraints on Planning

Appendix D: Surgery characteristics for simulation

Appendix A Data Analysis

Scheper hospital registers the operating times for all surgeries since January 2008. At the time of our data collection, 3 December 2008, this resulted in information on 7607 elective surgeries, 184 emergency surgeries, and 1041 urgent surgeries. Different specialties perform these surgeries. We will use this in our analysis. However, some specialties only perform a few surgeries per year (fewer than 12, see Table 44). These specialties do not have an OR day. For the sake of simplicity we remove these specialties from the data.

Table 44 Removed Specialties (Jan-Nov 2008, X-care)

Specialty	Frequency
Cardiology	1
Gastroenterology	3
Internal Medicine	4
Pediatrics	3
Pulmonary Surgery	11
Rehabilitative medicine	4
None	4
Total	30

For the purpose of our research we are not interested in weekends. Therefore, for the purpose of establishing the average number of surgeries per week, we remove surgeries performed in weekends (327). For the purpose of establishing the average duration of surgeries we do take into account these surgeries. We have no reason to assume these surgeries are any different from surgeries performed during regular working days and by taking them into account we get a more accurate estimate of the average surgery durations needed for our simulations.

Table 45: Removed Surgeries (Jan-Nov 2008, X-care)

			Urgent				
Type	Elective	Emergency	<8 hours	<24 hours	<48 hours	*Total Urgent*	Total
Total	7,607	184	763	241	37	*1041*	8,832
Removed specialties	28		5	1		*6*	34
Weekend	27	49	169	69	5	*251*	327
Time of day	10	79	15			*15*	104
	7,542	56	569	168	32	*769*	8,367

Emergency and urgent surgeries do not heed working hours; instead they arrive at all moments of the day. For our research we are only interested in emergency and urgent surgeries that need to be performed during regular working hours. Therefore we exclude all emergency surgeries starting after 16:00 and finishing before 8:00, and those performed in the weekend. We also exclude urgent surgeries performed during the weekend. Because urgent surgeries do not have to start immediately after arrival they can be postponed until after regular working hours. Therefore we also include the urgent surgeries performed outside regular working hours.

Appendix B: General Characteristics of Elective Program

Here we give frequencies and average surgery times for the more frequent surgery types (>1% of total number of surgeries performed by the specialty).

General			
Type	#	%	Av duration
Lap. chol. /Cholecystectomie per laparoscoop	247	13.1%	75.20243
Hernia inguinalis, liesbreuk.	170	9.0%	54.83582
Sleeve resectie / Gastric Sleeve.	121	6.4%	96.36364
Maagband, Gastric Banding Endoscopisch	96	5.1%	77.375
Diepe gezwellen verwijderen huid en sub-cutis.	71	3.8%	44.04348
Loc. exc. mammatumor / mamma sparende ok.	66	3.5%	45.27027
Aanleggen inwendige arterioveneuze shunt, cimino.	53	2.8%	93.30189
Endosopische operatie hernia inguinalis/ TEP.	51	2.7%	70.64706
Klierdissectie, axillair (okselklierdissectie).	42	2.2%	72.93182
Loc. excisie mammatumor + SWK.	32	1.7%	64.75
Carotis desobstructie.	25	1.3%	138.56
Fistula ani./ peri-anaal fistel.	24	1.3%	34.56757
Aanleggen femoro-popliteale bypass.	24	1.3%	206.25
Ablatio mamma + SWK.	22	1.2%	81.8
Operatie sinus pilonidalis.	21	1.1%	38.73529
Circumcisie, phimosis operatie.	20	1.1%	35.33333
Rec. perifere slagader met transplantaat/Denvershunt.	20	1.1%	137.4
Endoscopische operatie hernia cicatricalis.	19	1.0%	81.34783
Endovasculaire AAA.	19	1.0%	151.5789
Hemicolectomie, ileocoecaalresectie.	18	1.0%	134.25
Mastectomie/ablatio mamma(subcutane)amputatie.	18	1.0%	78.13043
Exerese v.d. ghe. V.S.M. lok. exc. van mul. varices.	18	1.0%	84.38889
Total	1892		

Orthopaedics			
Type	#	%	Av duration
Arthroscopie van de knie.	579	30.7%	30.51986
Totale knieprothese.	124	6.6%	98.18548
Totale heup, ongecementeerd.	79	4.2%	91.64557
Voorste kruisbandplastiek.	69	3.7%	89.31884
Arthroscopische decompressie schouder.	59	3.1%	74.28814
Totale heup gecementeerd.	47	2.5%	98.23404
Cuff repair arthroscopisch.	40	2.1%	164.525
Totale heup ceramic, Exceed	40	2.1%	85.825
Arthroscopie enkel.	38	2.0%	63.34211
Hallux valgus, Hohman, Akin.	38	2.0%	46.52632
Osteotomie os metatarsale of decapitatie os.	27	1.4%	60.51852
Verw. van een of meerdere schroeven uit een bot.	27	1.4%	39.2963
Diagnostische schouder scopie.	26	1.4%	72.92308
OS materiaal uit, cerclage.	26	1.4%	40.23077
Arthrodese van een interphalangeaal gewricht vd voet.	23	1.2%	68.21739
Arthroscopische cuff repair schouder	20	1.1%	137.25
Totale heup, resurfacing.	19	1.0%	105.8421
Verw. plaat en schroeven uit een bot.	19	1.0%	43.36842
Total	1883		

Gynecology			
Type	#	%	Av duration
Therapeutische hysteroscopie, klein.	109	9.8%	36.97248
Hysteroscopie + resectie , middel.	94	8.5%	34.21277
Vag. ut. + voor-+achterwandplastiek.	93	8.4%	86.32258
Sectio caesarea zonder voorbehandeling.	78	7.0%	51.88
Voor en achterwand plastiek.	73	6.6%	60.71233
Abortus verwijdering./ Missed abortion.	68	6.1%	22.47059
Diagnostische laparoscopie, incl. event.proefexcisie.	63	5.7%	50.51613
Vaginale uterus extirpatie.	56	5.1%	67.875
Abdominale uterus extirpatie.	50	4.5%	90.62
Adnex operatie, endoscopisch, dubbelzijdig.	34	3.1%	81.58824
AAP.	32	2.9%	21.40625
Laparoscopische uterus extirpatie ,lavh, lash.	29	2.6%	115.8276
TVT procedure/ IVS .	28	2.5%	43.28571
Hysteroscopie + resectie, groot.	28	2.5%	43.32143
Sterilisatie van de vrouw via lap.scopie of culdoscopie.	25	2.3%	39.92
Adnex operatie, endoscopisch, enkelzijdig.	24	2.2%	87.79167
Curettage.	19	1.7%	20
Sectio caesarea met voorbehandeling.	17	1.5%	53.86667
Verwijderen condylomata accuminata.	13	1.2%	27.23077
Adnex operatie.	11	1.0%	67.90909
Sterilisatie van de vrouw via laparotomie of colpotomie.	11	1.0%	35
Voorwandplastiek	11	1.0%	47.45455
Total	1108		

Plastic			
Type	#	%	Av duration
Mammareductie plastiek/reconstructie.	133	23.3%	106.6391
Dupuytren met 2 of meer stralen.	64	11.2%	47.96875
Matig grote en/of matig gecompl gesteelde transp./syndactyli	43	7.5%	65.53488
Grote en gecompliceerde gezwellen verwijderen.	31	5.4%	53.54839
Augmentatie (borstvergroting).	30	5.3%	80.23333
Straalsgewijze excisie fascia palmaris./Dupuytren.	26	4.6%	45.11538
Kleine en/of weinig gecompliceerde transplantatie.	25	4.4%	51.6
Buikwandcorrectie, incl. transpositie van de navel.	22	3.9%	123
Flapoorcorrectie	12	2.1%	65.91667
Verl, verk. of uitsnijden van pezen./ Relaese/ Evansplastiek	9	1.6%	36.44444
Facelift.	9	1.6%	110.8889
Arthrodese CMC 1.	7	1.2%	57
Buikwandcorrectie.	7	1.2%	126.2857
Grote en/of gecompliceerde transplantatie.	7	1.2%	66.85714
Carpaal tunnel syndroom.	6	1.1%	29.66667
Diepe gezwellen verwijderen huid en sub-cutis.	6	1.1%	37.33333
Mammareconstructie plast. dmv latissimus dorsi.	6	1.1%	248.1667
Total	580		

ENT			
Type	#	%	Av duration
Tonsillectomie bij personen van 16 jaar en ouder. TE	110	18.6%	41.05405
Septum correctie	110	18.6%	55.15455
Trommelvliesbuis, tbb.	61	10.3%	20.54098
Septumcorrectie + conchotomie.	47	7.9%	46.23404
Adenotomie.	45	7.6%	18.28889
Tonsillectomie (TE + AD)bij pers t/m 10 jaar.	41	6.9%	31.90244
Microlaryngoscopie	25	4.2%	34.36
Endonasale sinus ethmoidalis operatie/FESS.	23	3.9%	63.21739
Tonsillectomie (TE + AD) bij pers. van 11 t/m 15 jaar.	21	3.5%	39.33333
Antrostomie / Endonasale sinus maxillaris ok, bijv.claoue.	19	3.2%	45.05263
Diagn. dir. laryngosc. onder de operatie microsc.+ biopsie.	15	2.5%	31.86667
Tonsillectomie 11 tot 15jaar zonder adenotomie.	13	2.2%	41.38462
Conchotomie,christotomie, spinotomie chonca lux.	10	1.7%	31.9
Verw. van een of meerder neuspoliepen of choanaalpoliep.	9	1.5%	49.44444
Tonsillectomie t/m 10jaar zonder adenotomie	7	1.2%	34.42857
Total	592		

Urology			
Type	#	%	Av duration
Transurethrale res. v.blaas.TUR-B.	90	19.1%	38.6044
Transurethrale prostaatresectie.TUR-P. / TUMT.	75	15.9%	55.4
Circumcisie, phimosis operatie.	30	6.4%	44.33333
Orchidopexie.	29	6.1%	61.34483
URS Ureterorenoscopie+ evt biopten, proefexcisie's	26	5.5%	79.88462
Totale prostatectomie, endoscopisch.	25	5.3%	260.92
Plaatsen dubbel J catheter.	20	4.2%	44.45
Lapsc. lymklier-dissectie, endoscopisch.	15	3.2%	117
Hydrocele operatie, Winkelman	13	2.8%	57.76923
Nefrectomie, endoscopisch.	12	2.5%	177.25
Tot prostatectomie+pelv lymf kl dissec, endoscopisch.	10	2.1%	271.5
Lithotrypsie.	9	1.9%	44.77778
Pyelumplastiek, endoscopisch.	8	1.7%	182.875
Sachse vlgs- Urethrotomia interna A-vue,	8	1.7%	32.875
Spermatocele operatie.	6	1.3%	59.5
Totale prostatectomie, inclusief kapsel.	6	1.3%	221.5
Transurethrale res.v.d. blaash., TUR P + B.	6	1.3%	52
Nefrectomie, partieel, endoscopisch.	5	1.1%	184.2
Reluxbehandeling met teflon. endoscopisch.	5	1.1%	34.2
URS. steen verwijderen	5	1.1%	106
Total	472		

Neuro			
Type	#	%	Av duration
HNP, Hernia lumbalis	102	47.4%	75.67647
Laminectomie. extraduraal.	57	26.5%	80.96491
MTD	21	9.8%	77.90476
Nervus ulnaris, transpositie.	14	6.5%	45.5
Hemilaminectomie.	8	3.7%	71.33333
Eenvoudige neurolysen zonder operatiemicoroscoop.	5	2.3%	45.6
Nervus ulnaris transpositie , mbv operatiemicroscoop.	3	1.4%	51.66667
Total	215		

Appendix C: Constraints on Planning

- Surgeries requiring only local anesthesia are performed at the end of the program

- Children until the age of 16 are planned at the beginning of the program

- Outpatients are planned at the beginning of the program

- Maximum number of children

- Availability of equipment

- Availability of personnel

- Availability of instruments

- Availability of "C-arch"

- Small children as much as possible in OR 7 and OR 8

- Caesarian sections after daycare patients

- Intensive care patients after short procedure

- TE at the beginning of ENT program

- Intensive care patients in the morning sessions

- Large plastic surgeries not at the end of the program

- Sentinel node before 11 a.m.

- Endoscopic procedures in OR 7 and OR 8

- Carotid artery in ORs 1, 2, 7, or 8

- Implant surgery in OR 1 and OR 2

- Tur in OR 5

- At the start of the program not to many children at once

- MRSA patient last in program

- Latex allergy first in program

- Local anesthesia last in program

- Left and right in separate streets

Appendix D Surgery characteristics for simulation

For our simulations we divide our data according to surgery type. We take into account surgery types performed 40 times or more and group the remaining surgeries according to their specialties. This results in 43 different groups. For our simulations we need to create fictional surgery schedules based on the real life data we have extracted from the hospital information system. For this we need the distribution type, average surgery duration, and standard deviation of the average surgery duration for each group of surgeries. We will now determine the type of distribution for our groups.

According to Strum [2000] lognormal distributions are superior to normal distributions in describing surgery times. We therefore begin by testing our groups for lognormality. Appendix D1 gives 43 histograms. Because we want to test for lognormality we have taken the natural logarithm of the duration of the surgeries. Superimposed over each histogram is a normal curve with mean and standard deviation calculated from our data. We are looking for a good fit between the curves and the data columns. There is a good fit for most groups except for Urology rest [Figure 63]. Therefore, we test for normality [Figure 66] for this group. Unfortunately Urology rest does not show a better fit. If we look at the histogram more closely there appear to be 2 separate peaks, suggesting 2 distinctly different groups of surgeries. We separate the surgeries in 2 groups, one with surgery types that generally take more time per surgery and the other with surgery types generally taking less time. We again take the natural logarithm of the surgery durations. [Figure 67 and Figure 68] show the resulting histograms. The figures show a good math with the normal curve and we therefore continue our test for lognormality.

We continue with Q-Q plots of the groups to further test our groups for lognormality. Q-Q plots divide the data into equal quantiles, each quantile having the same number of data points. These are then plotted against the quantiles of the test distribution. Appendix D2 shows the resulting Q-Q plots. A straight line indicates a good match between the data and the test distribution. The Q-Q plots of Mammareductie plastiek/reconstructive by Braak and Mammareductie plastiek/reconstructive by Schweter [Figure 95 and Figure 96] do not show a straight line. Therefore, we will investigate if a normal distribution is a better fit for these 2 groups. The new histograms for these groups show a good fit between the data and the theoretical distribution [Figure 69 and Figure 70]. Also, the Q-Q plots show a better fit [Figure 115 and Figure 116]. We therefore continue with our final test, Kolmogorov-Smirnov.

To confirm our assumption that a lognormal distribution fits most groups and a normal distribution fits Mammareductie plastiek/reconstructive by Braak and Mammareductie plastiek/reconstructive by Schweter we perform the Kolmogorov-Smirnov test. This test looks for the largest difference between the data and the test distribution. The null hypothesis of the test is that the data and the theoretical distribution are the same, and the alternative hypothesis is that they are different. Table 46 shows the results of this test. We accept our null hypothesis if sigma is smaller than 0.05 resulting in a 95% confidence level. Appendix D3 presents the results of the Kolmogorov-Smirnov test.

We see a sigma <0.05 for 4 groups, namely "Arthroscopie van de knie by Degen", General surgery rest, Gynecology rest, and ENT rest. Strum [2000] gives a multitude of possible reasons for this. One important reason is that statistical tests tend to get more sensitive if sample sizes increase. Most tests are designed for small sample sizes of 100 or less. This is also the case for the Kolmogorov-Smirnov test. The test looks for the largest deviation of the data from the theoretical distribution and with large sample sizes this deviation can almost always be found [Dickinson, 1976]. To test if this is the case for the 4 groups with a sigma <0.05 we divide these groups into smaller groups and calculate the sigma value for these smaller groups. We do this by taking all surgeries performed on the same day of the week together. (For instance all surgeries performed on Mondays together in 1 group). The sigma values for these groups are all larger than 0.05. Therefore, we conclude that these 4 groups can be described by a lognormal distribution.

D1 Histograms

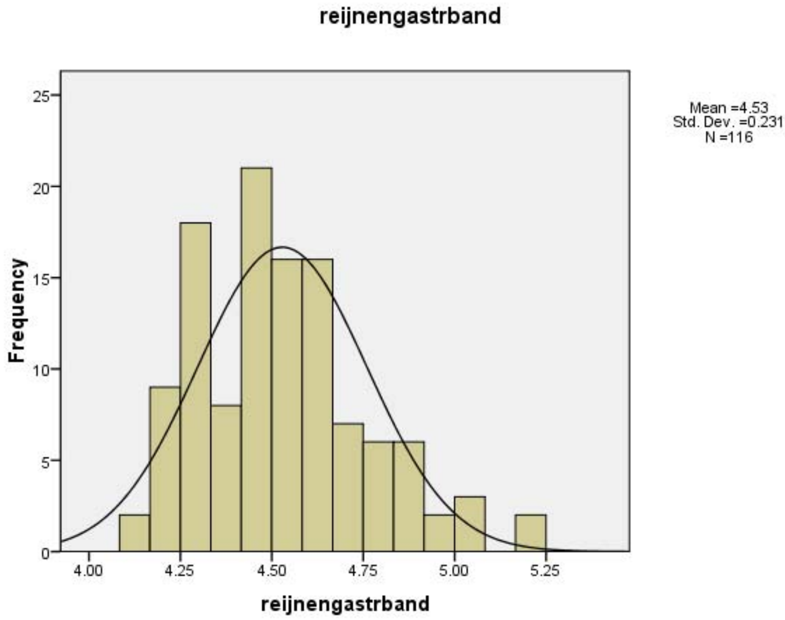

Figure 23 Histogram of Maagband, Gastric Banding Endoscopisch by Reijnen

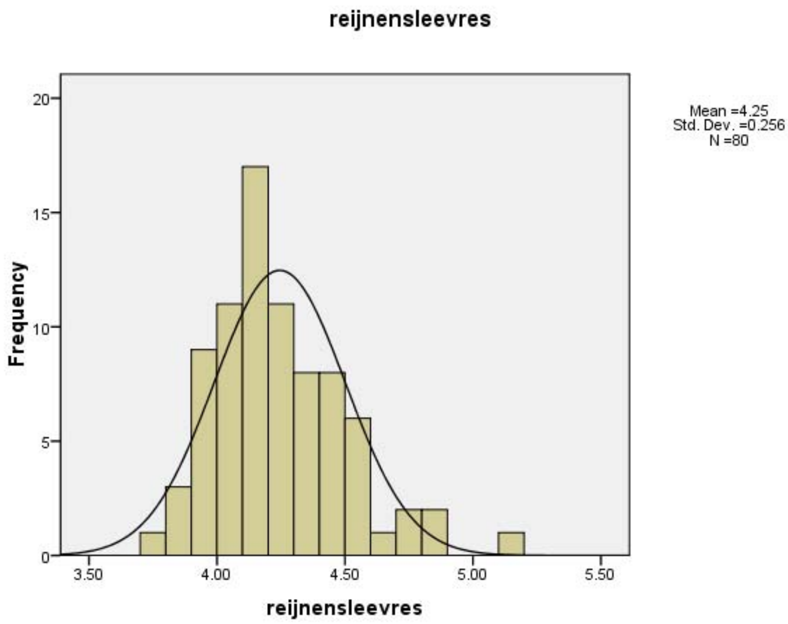

Figure 24 Histogram of Sleeve resectie / Gastric Sleeve by Reijnen

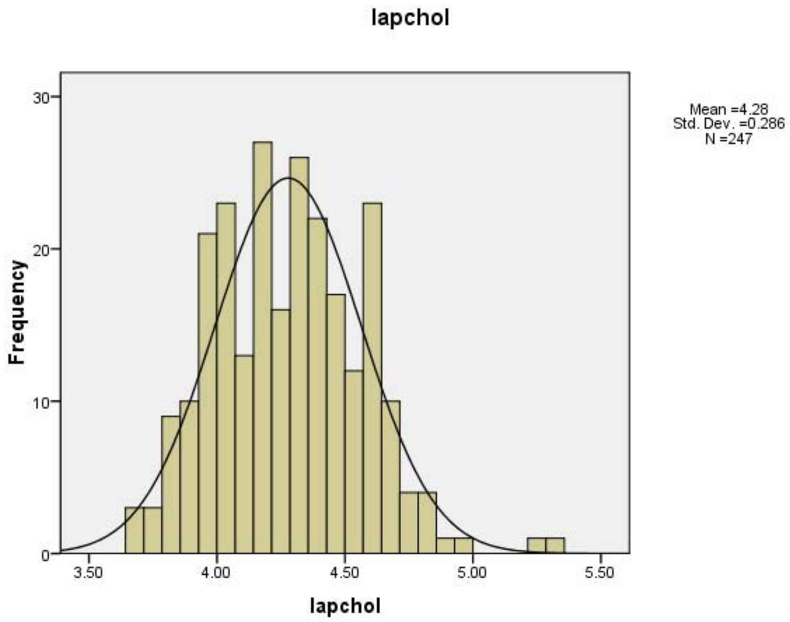

Figure 25 Histogram of Lap. chol. /Cholecystectomie per laparoscoop

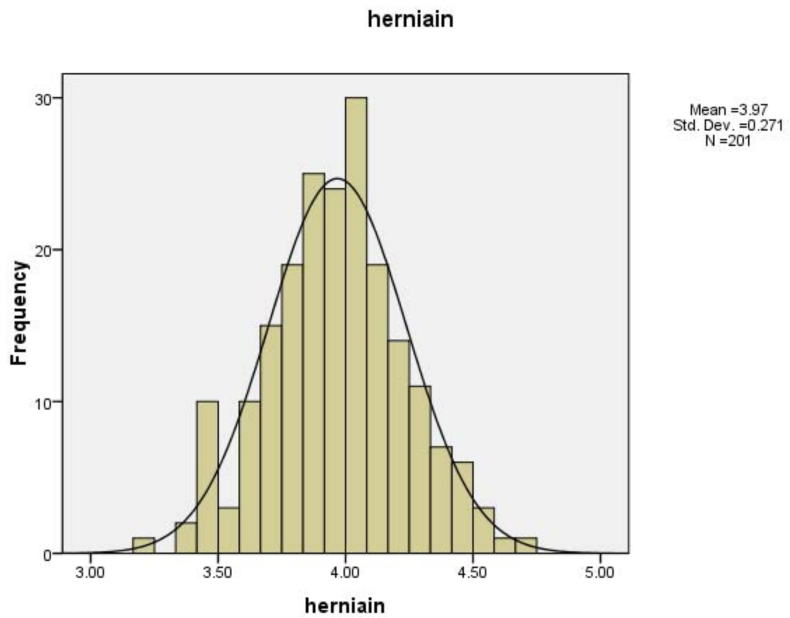

Figure 26 Histogram of Hernia inguinalis, liesbreuk

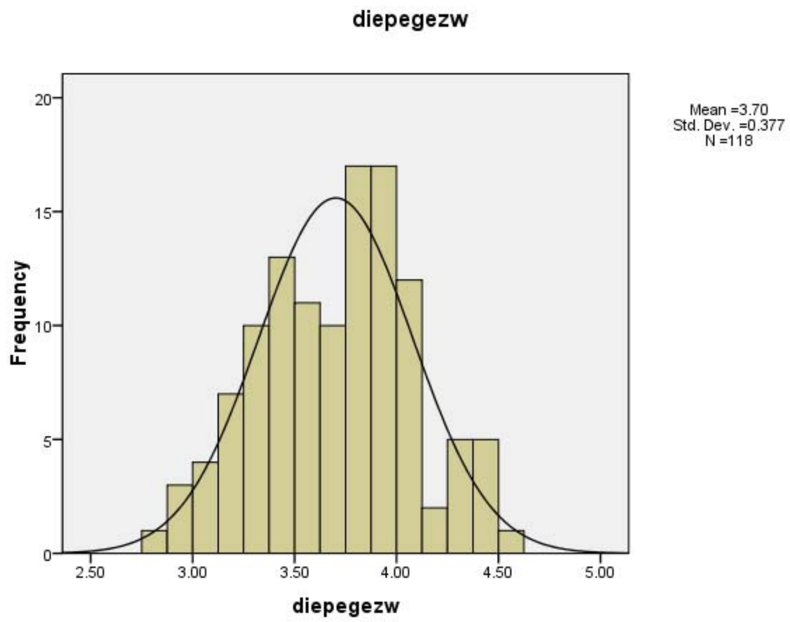

Figure 27 Histogram of Diepe gezwellen verwijderen huid en sub-cutis

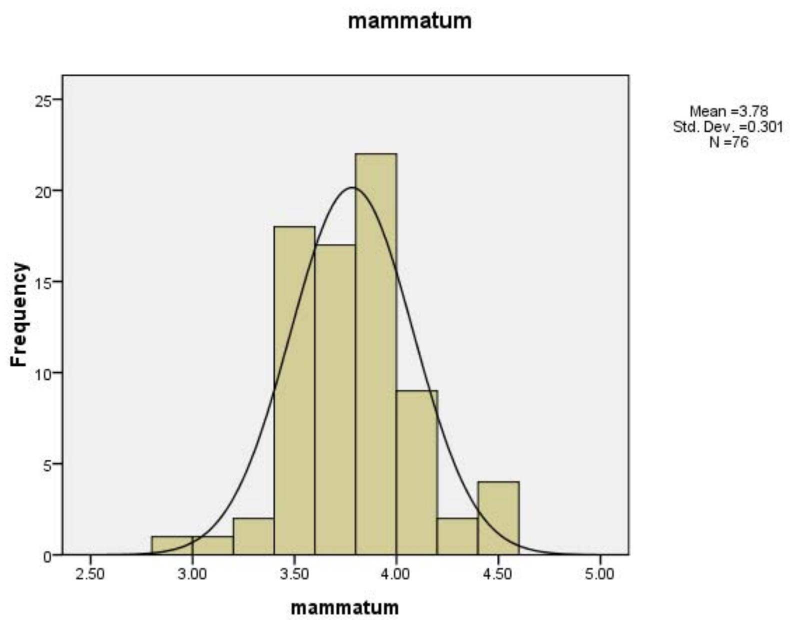

Figure 28 Histogram of Loc. exc. mammatumor / mamma sparende ok.

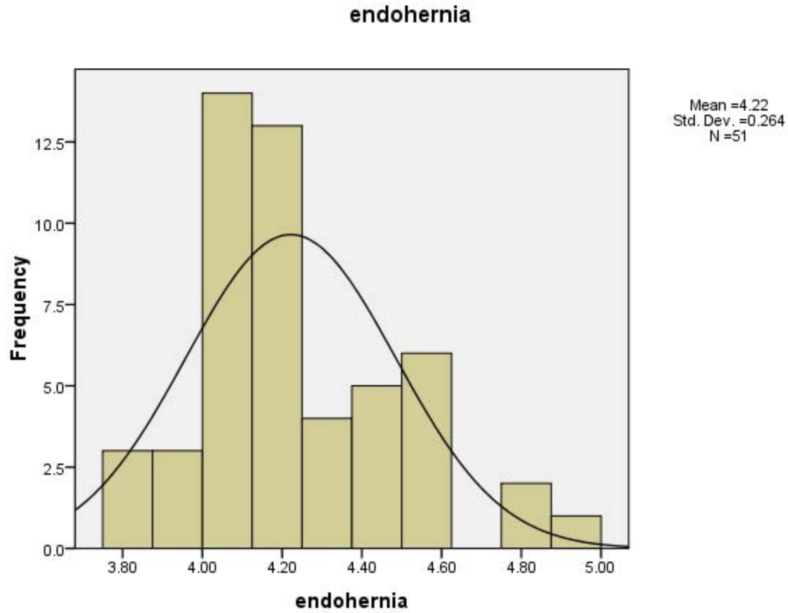

Figure 29 Histogram of Endosopische operatie hernia inguinalis/ TEP.

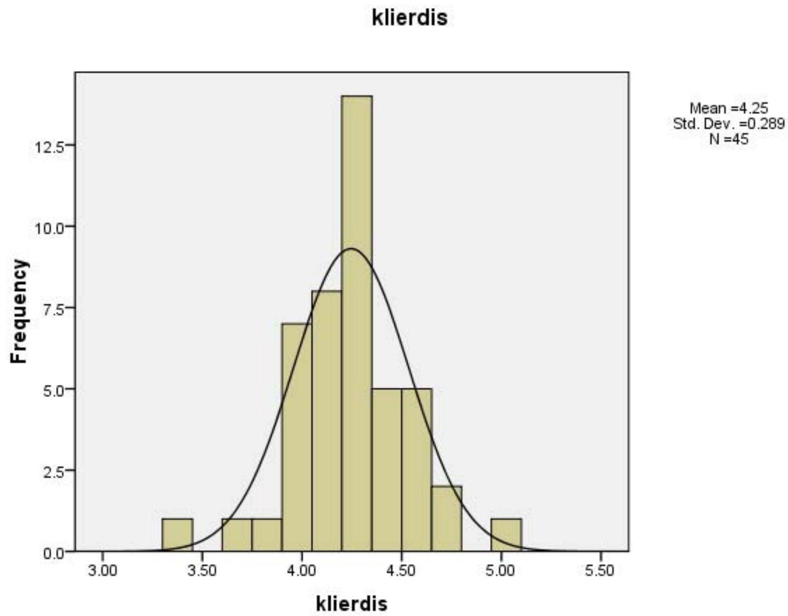

Figure 30 Histogram of Klierdissectie, axillair (okselklierdissectie)

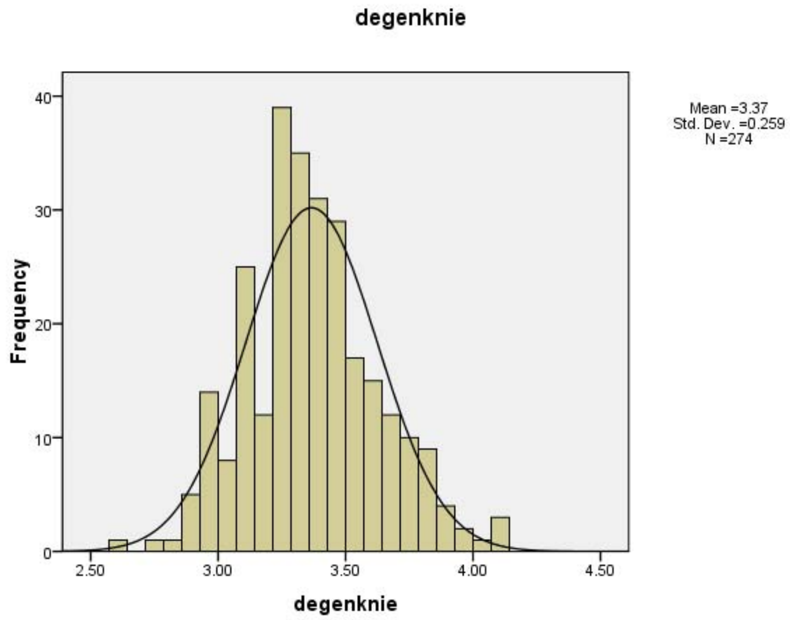

Figure 31 Histogram of Arthroscopie van de knie by Degen

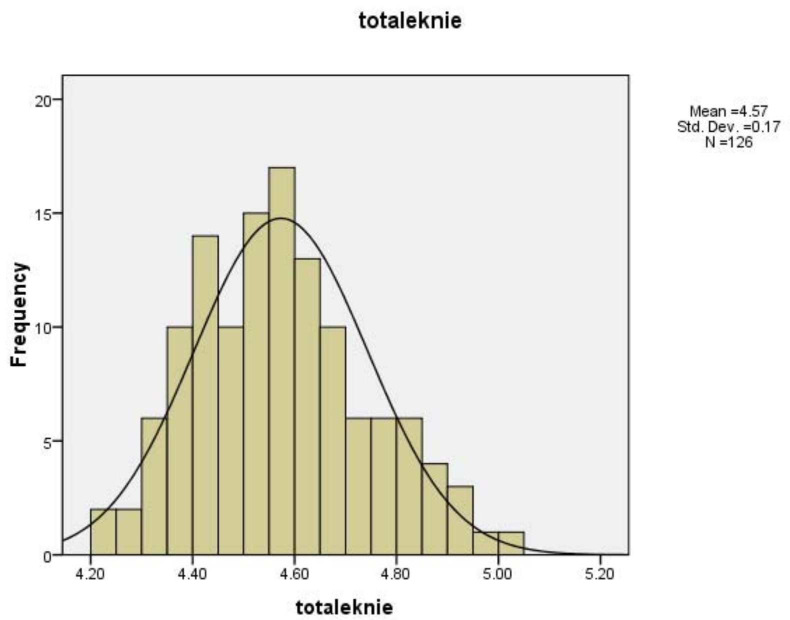

Figure 32 Histogram of Totale knieprothese

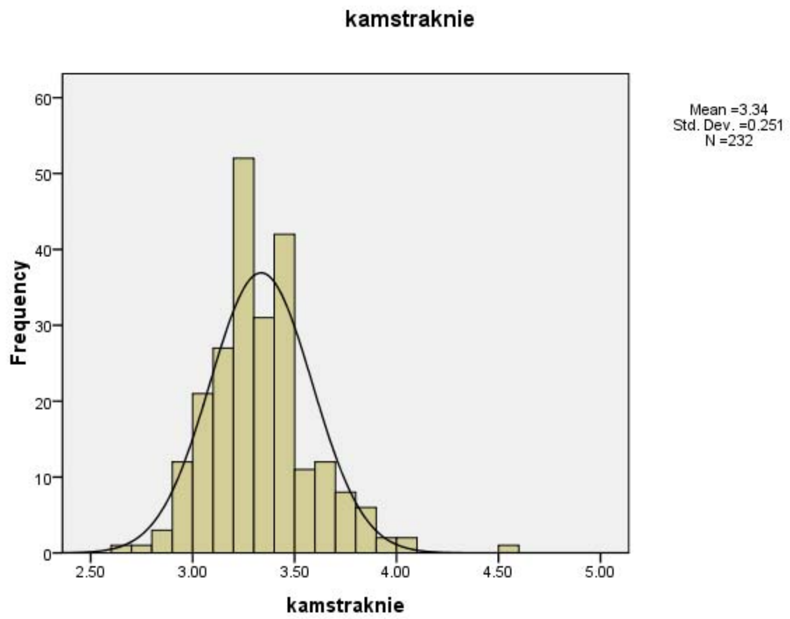

Figure 33 Histogram of Arthroscopie van de knie by Kamstra

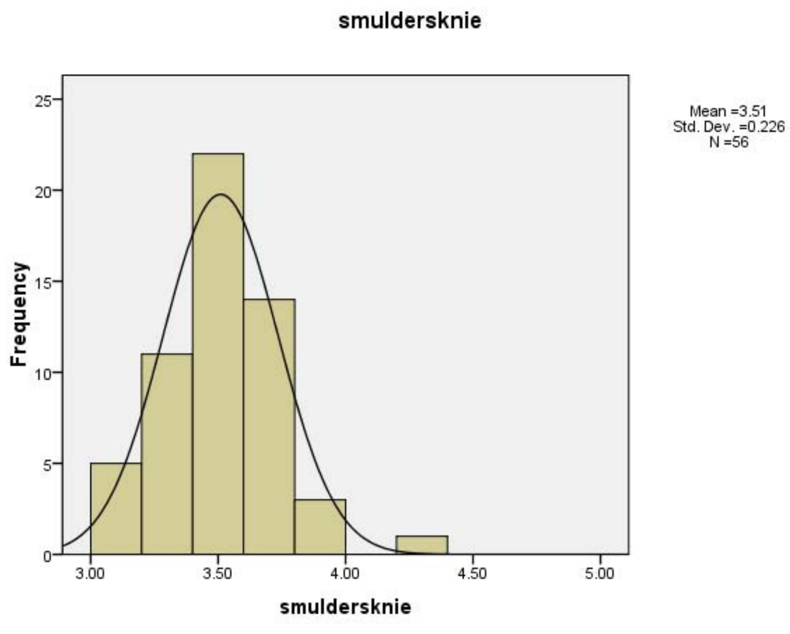

Figure 34 Histogram of Arthroscopie van de knie by Smulders

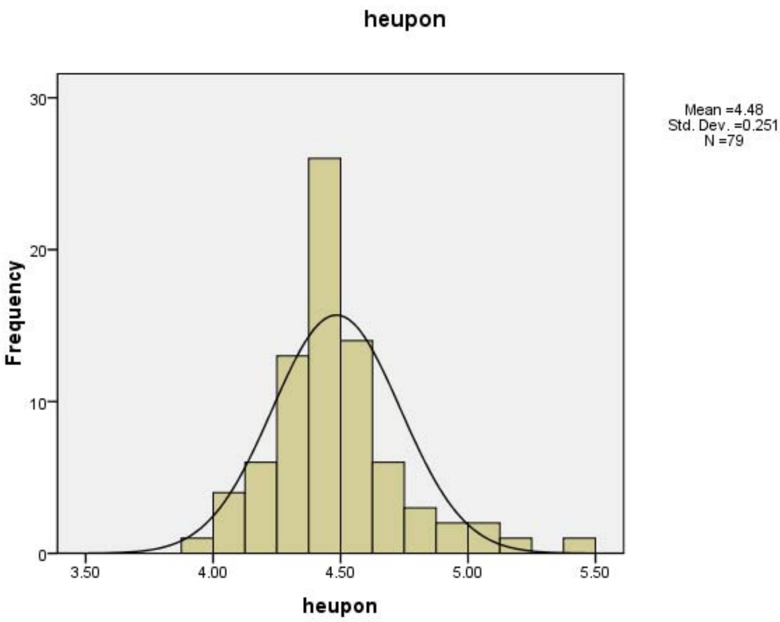

Figure 35 Histogram of Totale heup, ongecementeerd

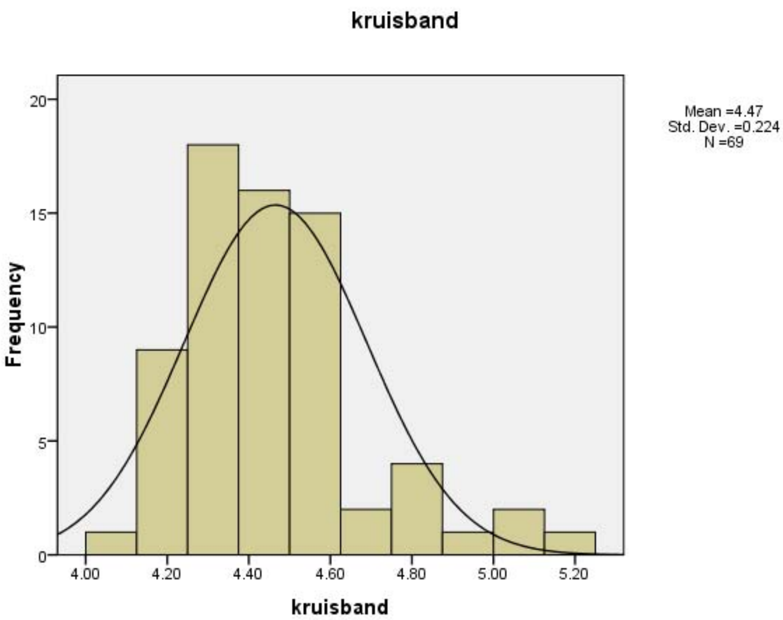

Figure 36 Histogram of Voorste kruisbandplastiek

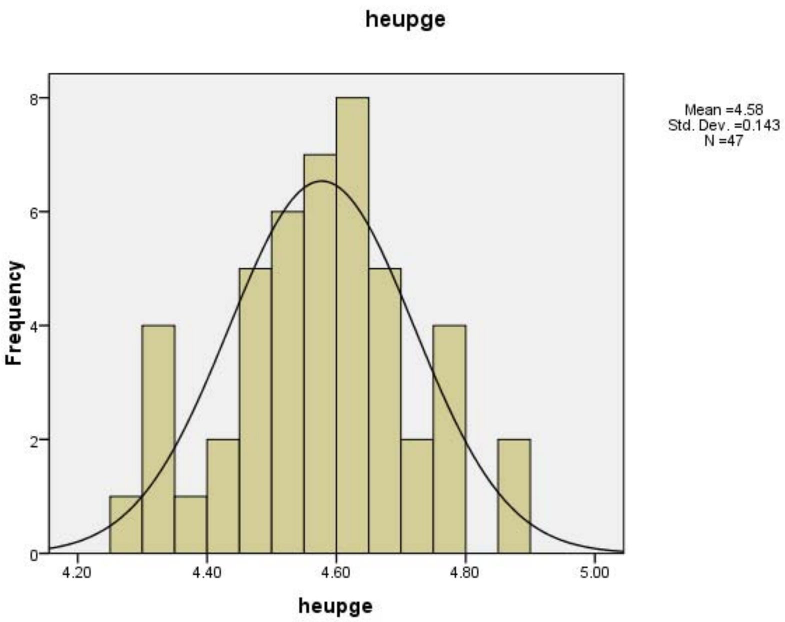

Figure 37 Histogram of Totale heup gecementeerd

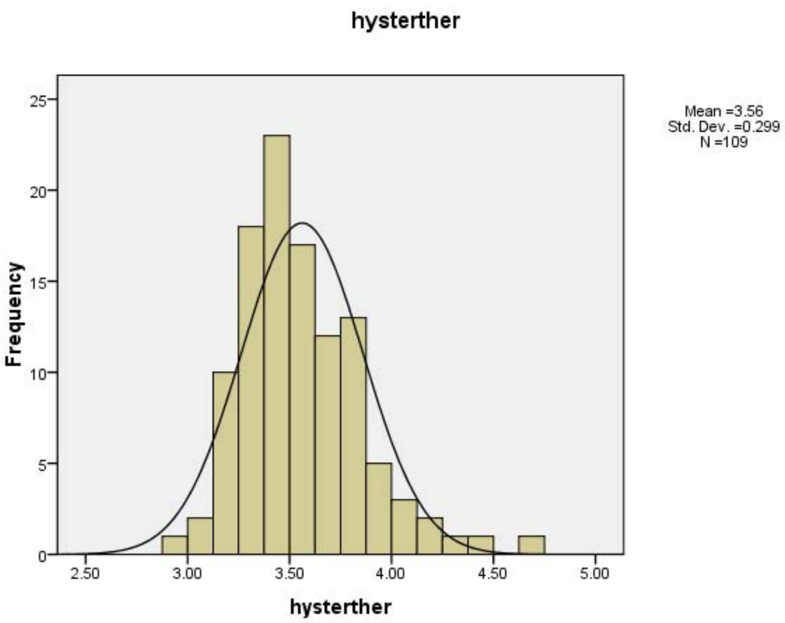

Figure 38 Histogram of Therapeutische hysteroscopie, klein

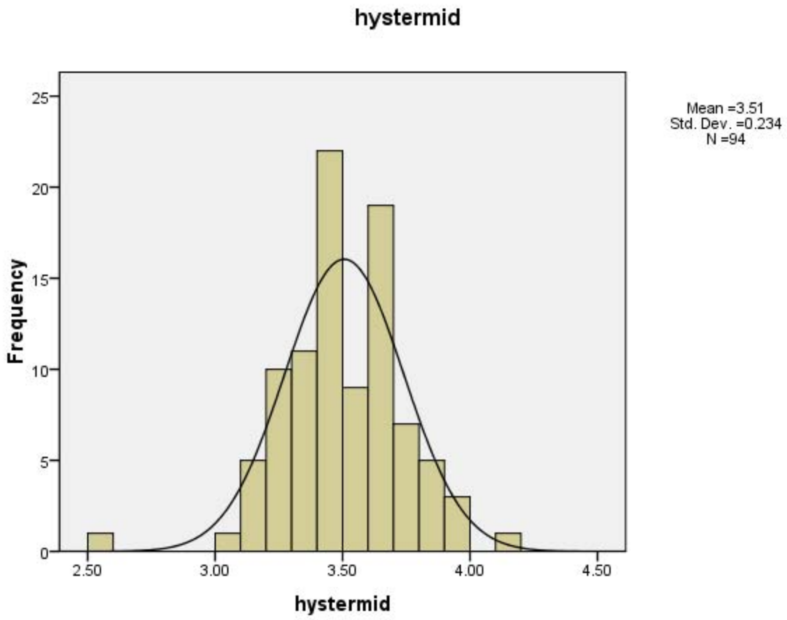

Figure 39 Histogram of Hysteroscopie + resectie , middel

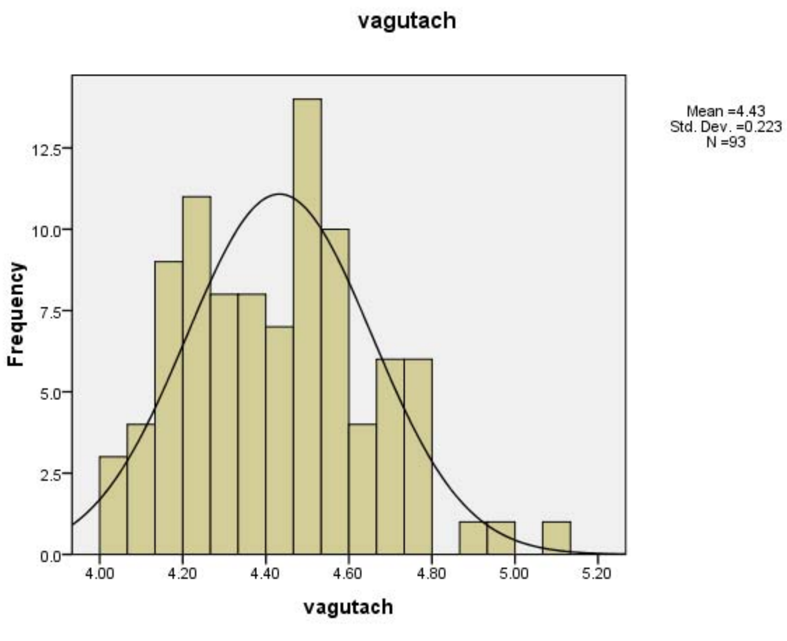

Figure 40 Histogram of Vag. ut. + voor-+achterwandplastiek

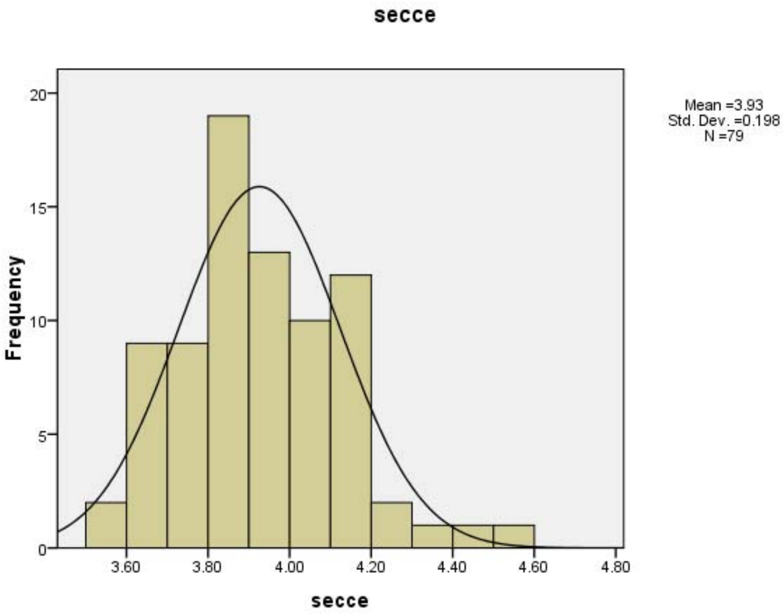

Figure 41 Histogram of Sectio caesarea zonder voorbehandeling

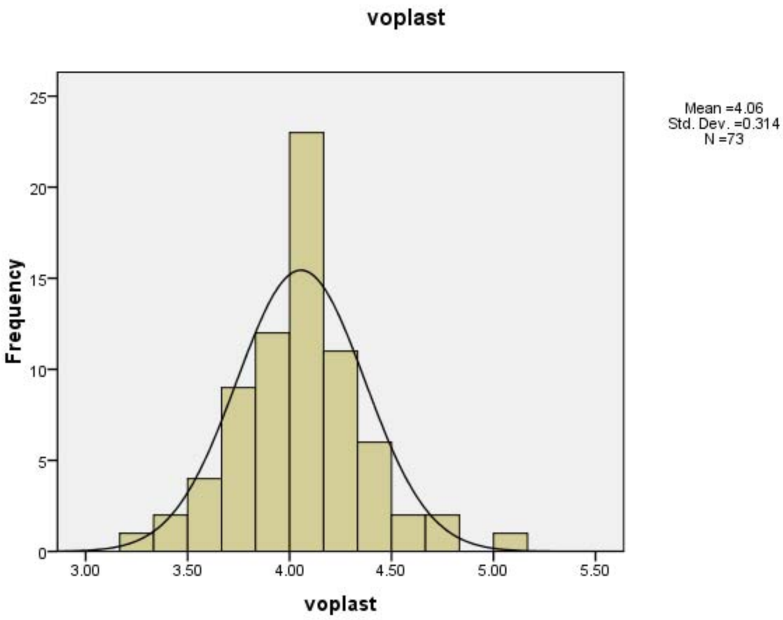

Figure 42 Histogram of Voor en achterwand plastiek

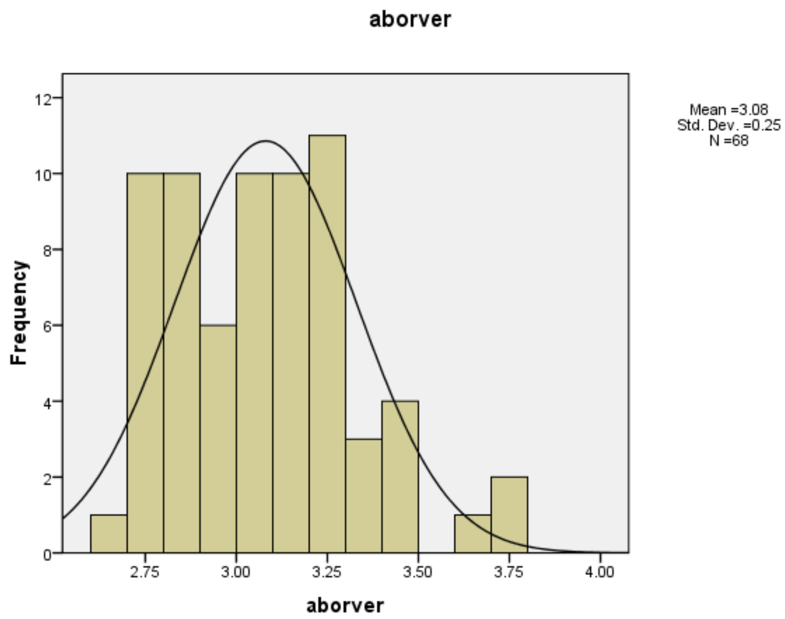

Figure 43 Histogram of Abortus verwijdering./ Missed abortion

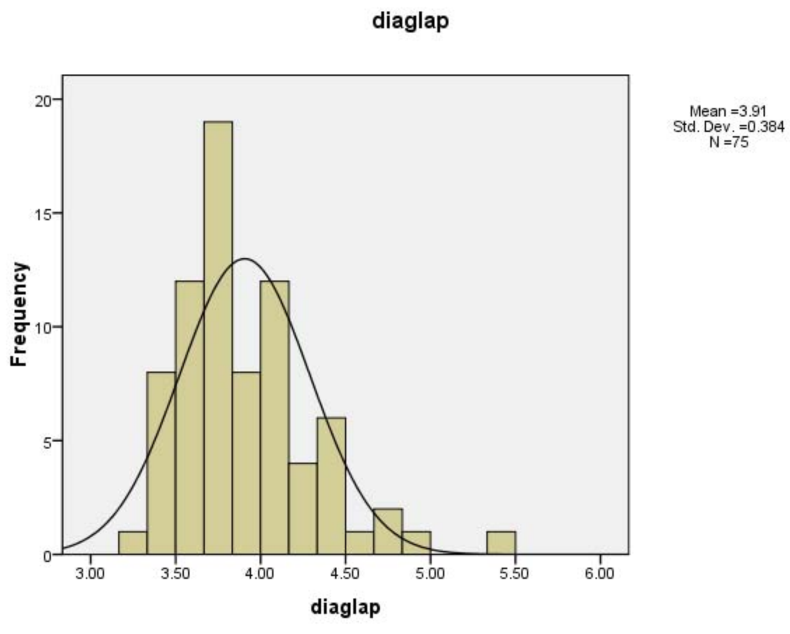

Figure 44 Histogram of Diagnostische laparoscopie, incl. event.proefexcisie

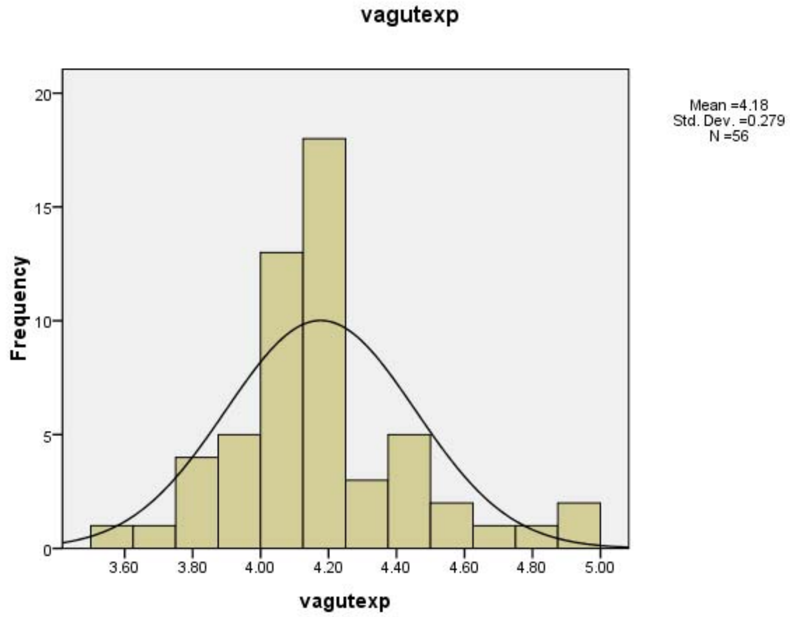

Figure 45 Histogram of Vaginale uterus extirpatie

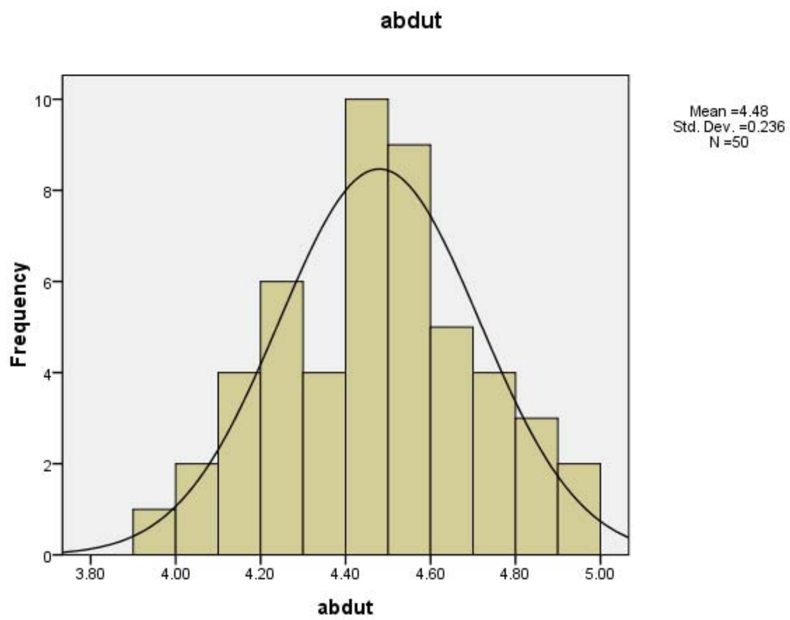

Figure 46 Histogram of Abdominale uterus extirpatie

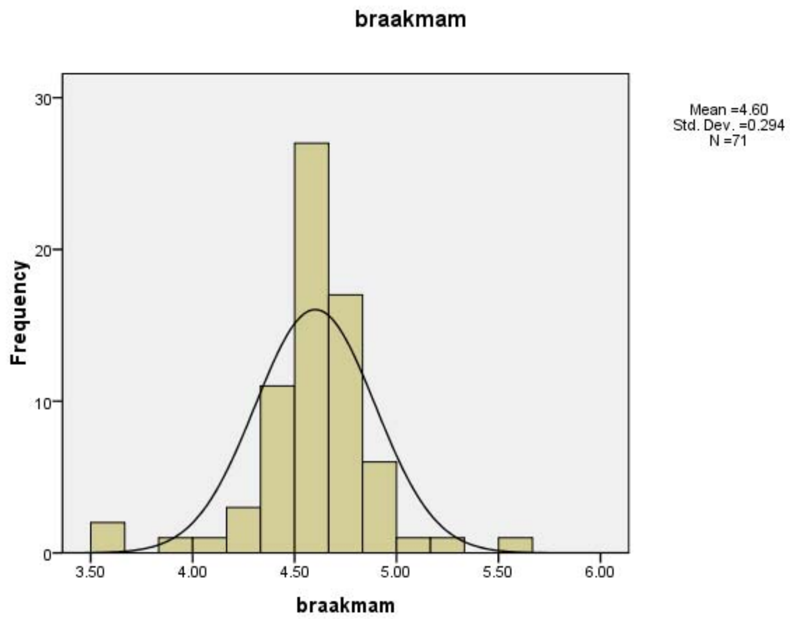

Figure 47 Histogram of Mammareductie plastiek/reconstructive by Braak

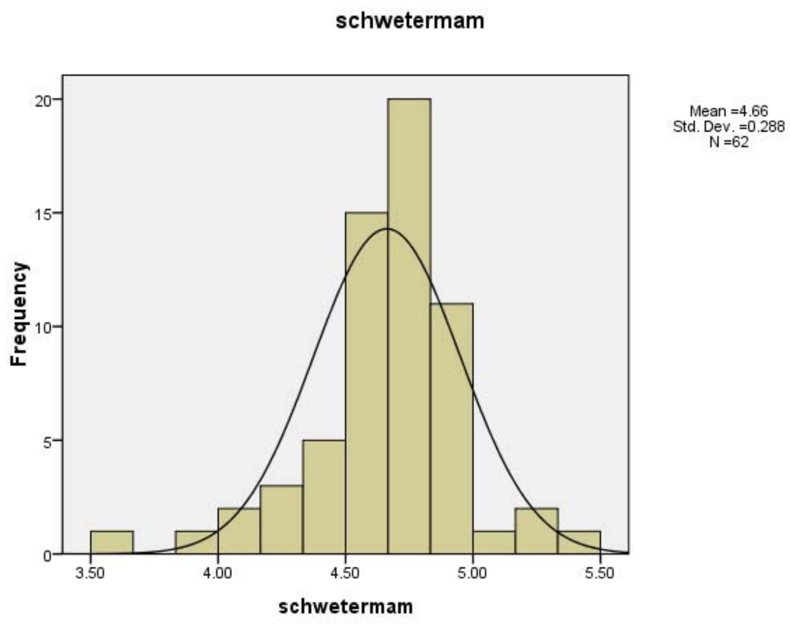

Figure 48 Histogram of Mammareductie plastiek/reconstructive by Schweter

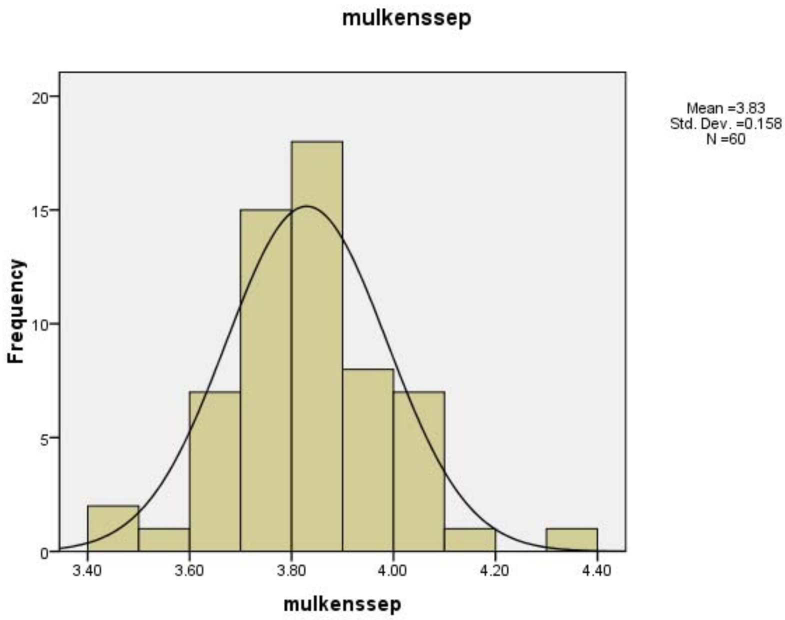

Figure 49 Histogram of Septum corrective by Mulkens

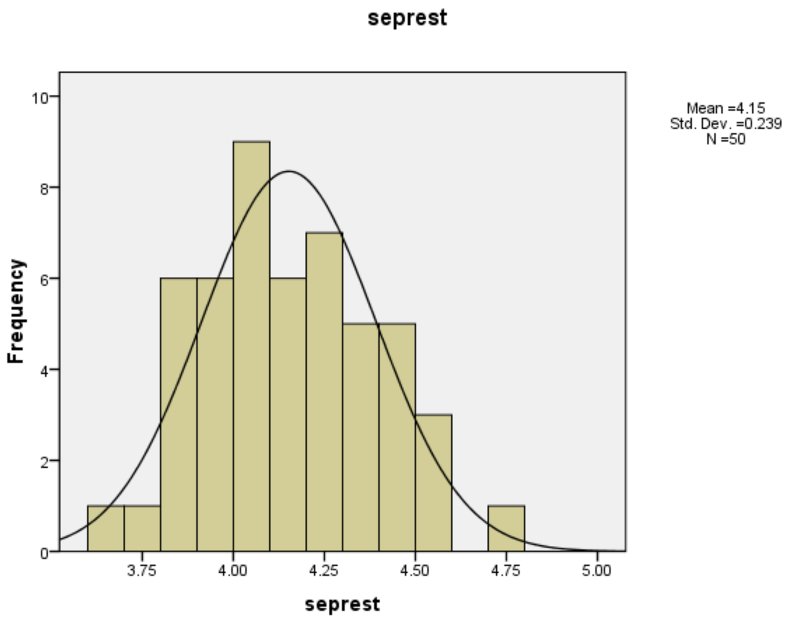

Figure 50 Histogram of Septum corrective rest

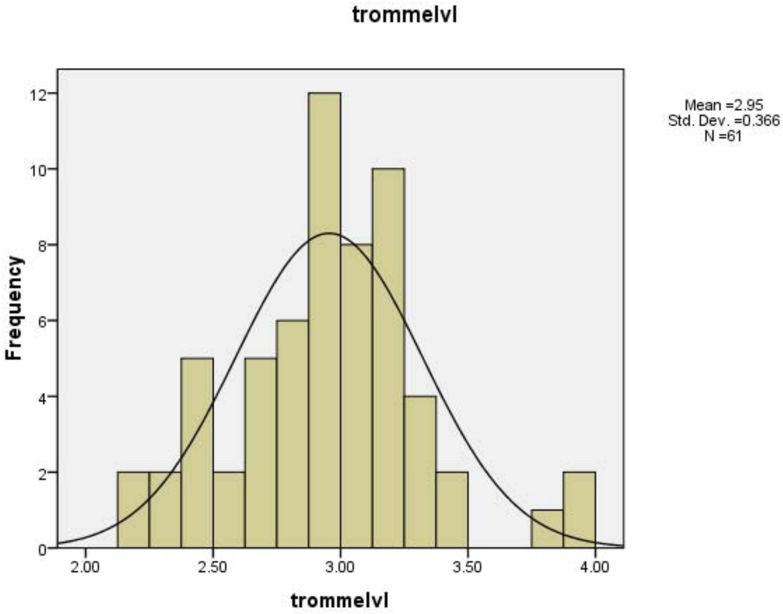

Figure 51 Histogram of Trommelvliesbuis, tbb

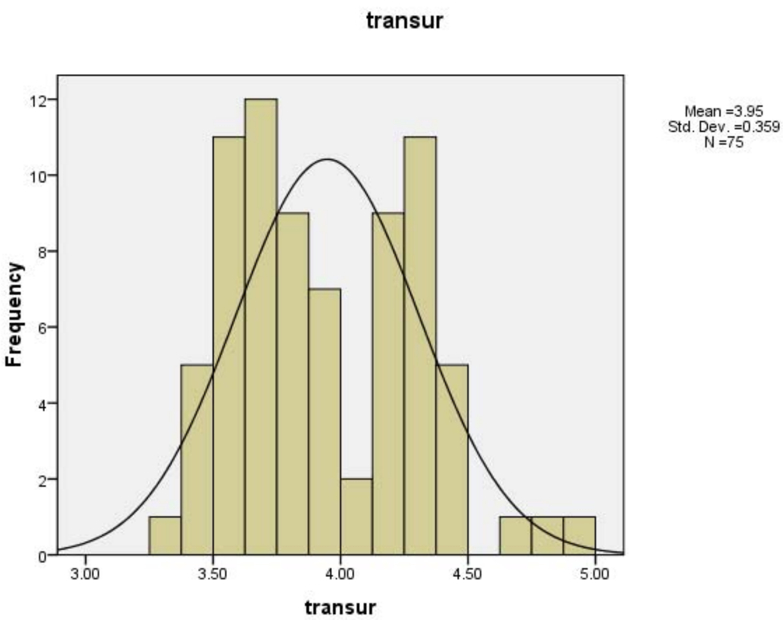

Figure 52 Histogram of Transurethrale prostaatresectie.TUR-P. / TUMT

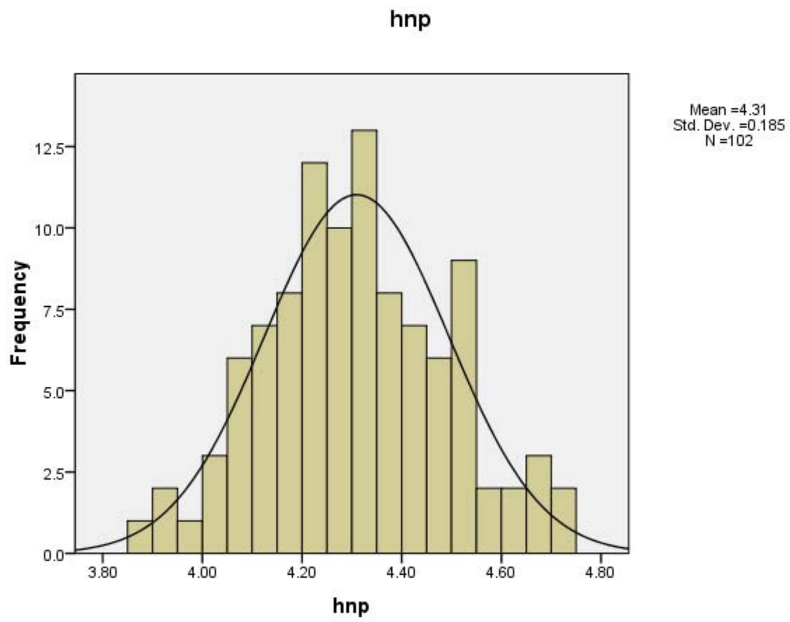

Figure 53 Histogram of HNP, Hernia lumbalis

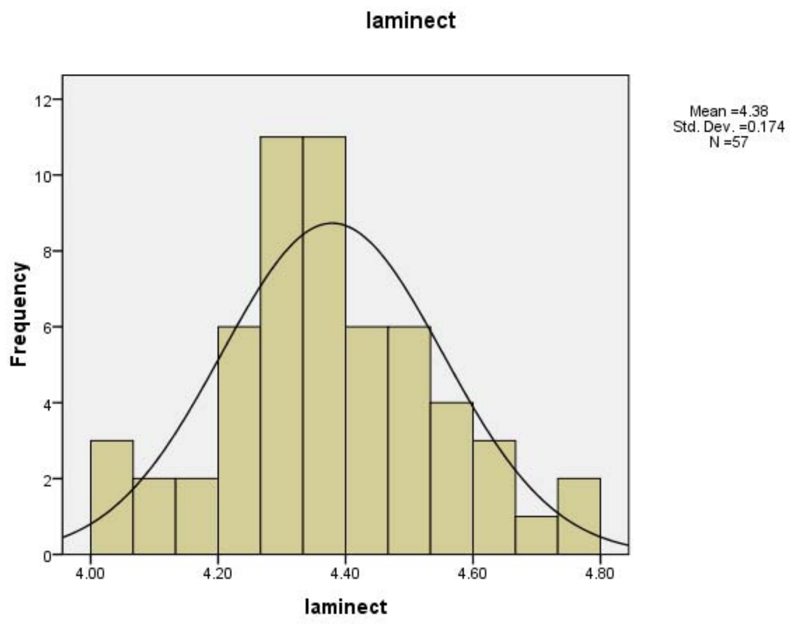

Figure 54 Histogram of Laminectomie. extraduraal

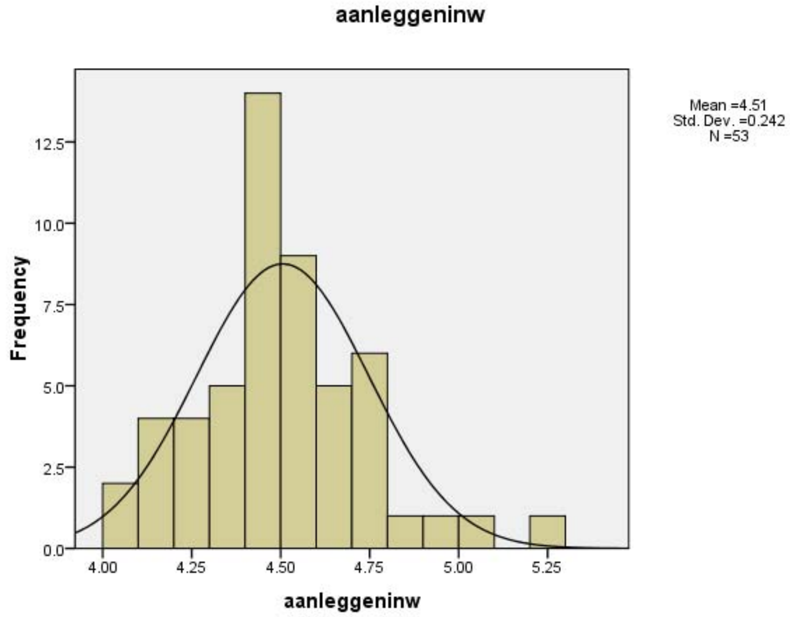

Figure 55 Histogram of Aanleggen inwendige arterioveneuze shunt, cimino

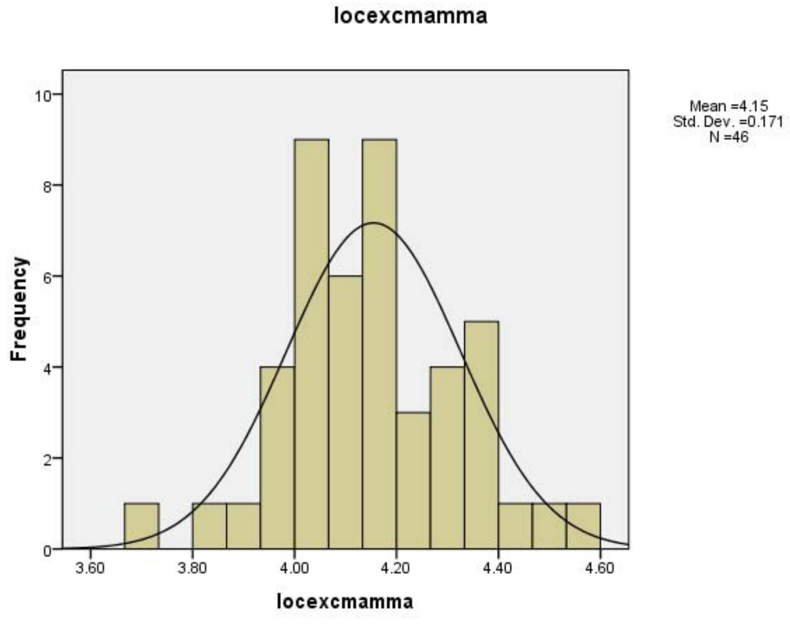

Figure 56 Histogram of Loc. excisie mammatumor + SWK

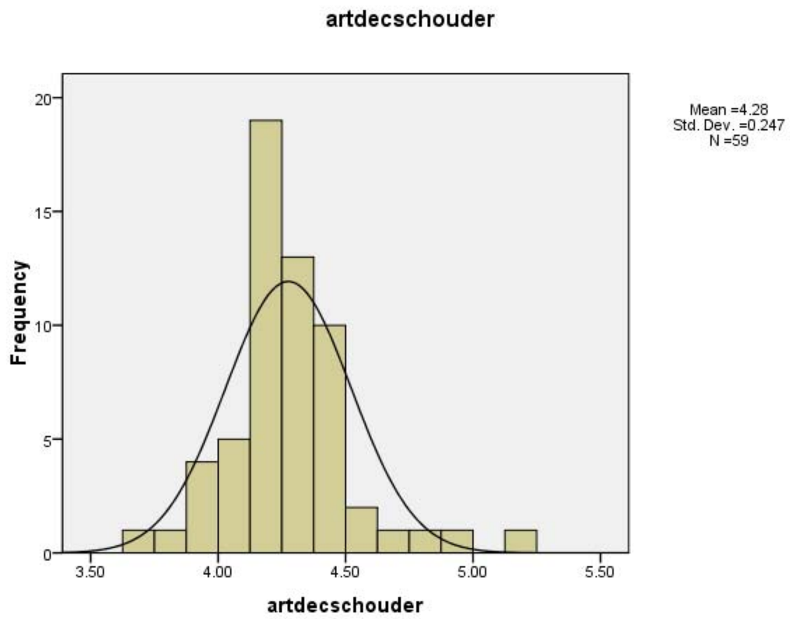

Figure 57 Histogram of Arthroscopische decompressie schouder

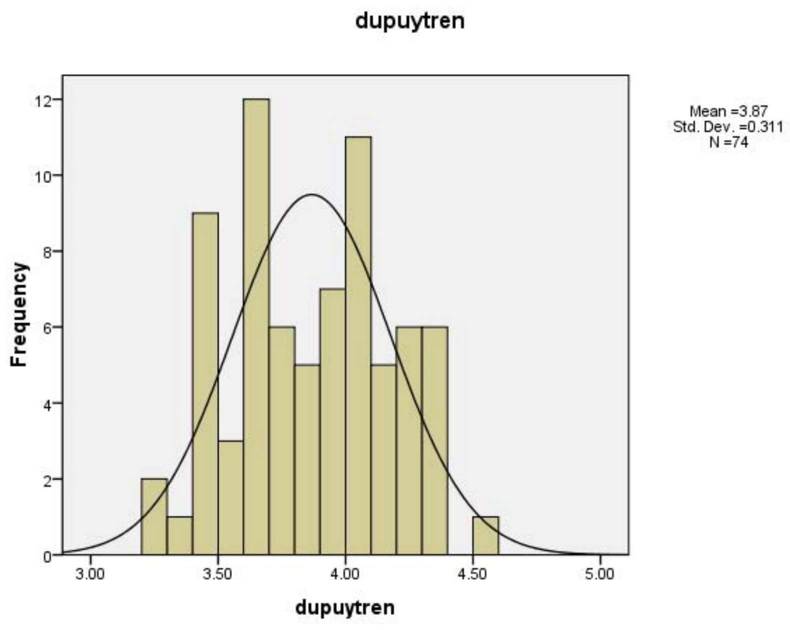

Figure 58 Histogram of Dupuytren met 2 of meer stralen

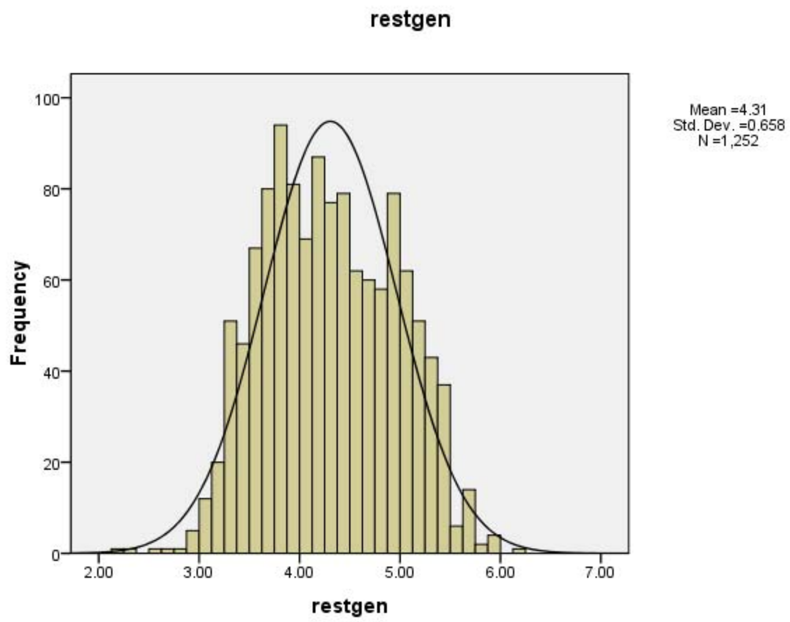

Figure 59 Histogram of General surgery rest

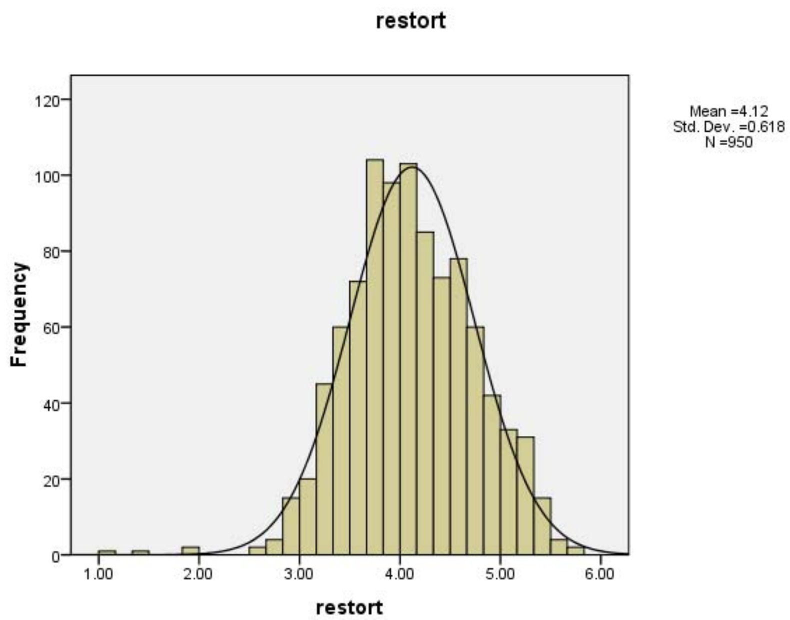

Figure 60 Histogram of Orthopedics rest

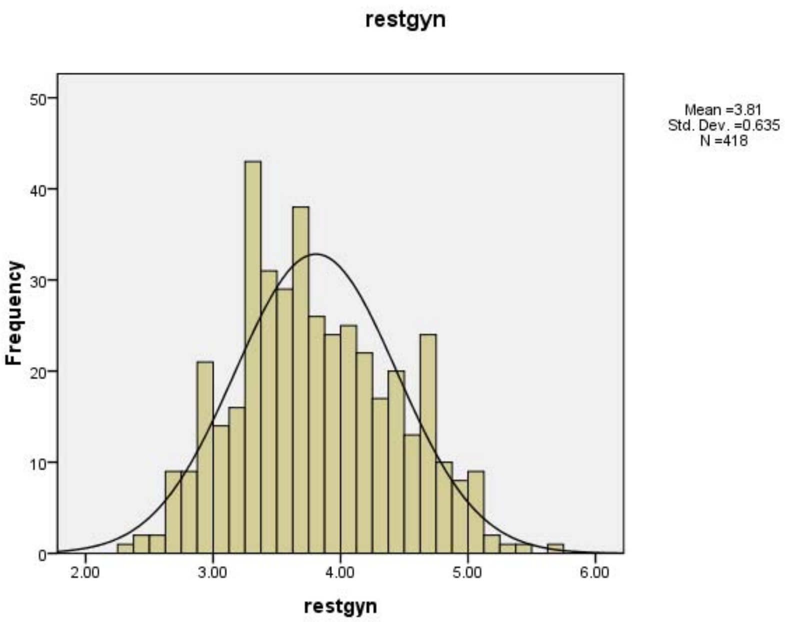

Figure 61 Histogram of Gynecology rest

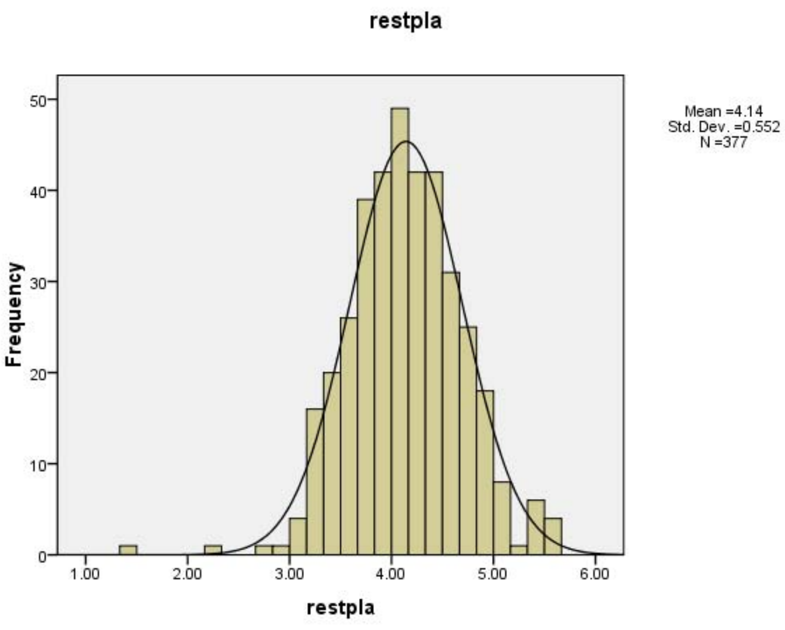

Figure 62 Histogram of Plastic surgery rest

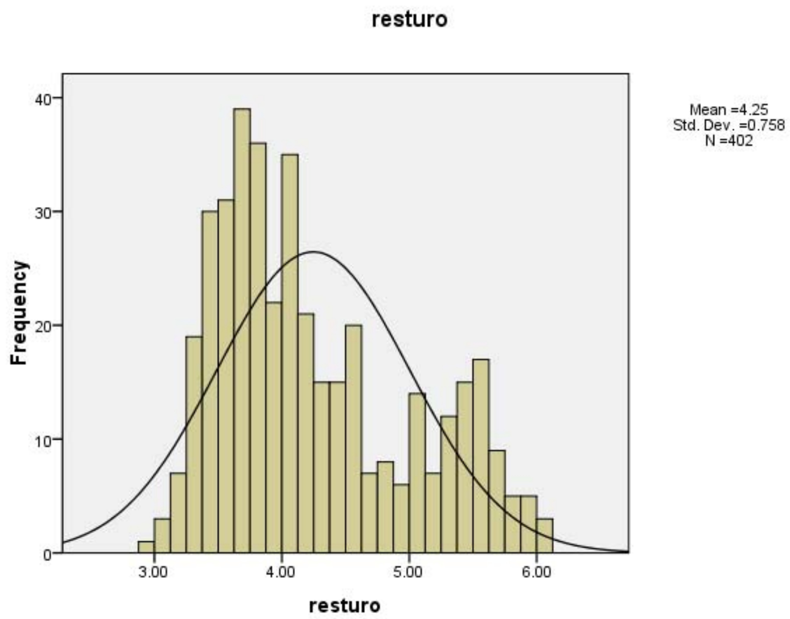

Figure 63 Histogram of Urology rest

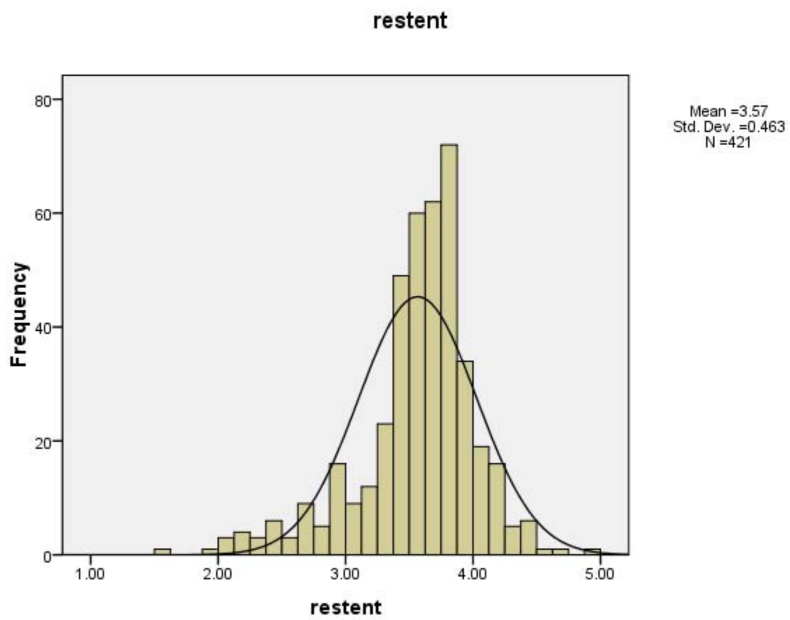

Figure 64 Histogram of ENT rest

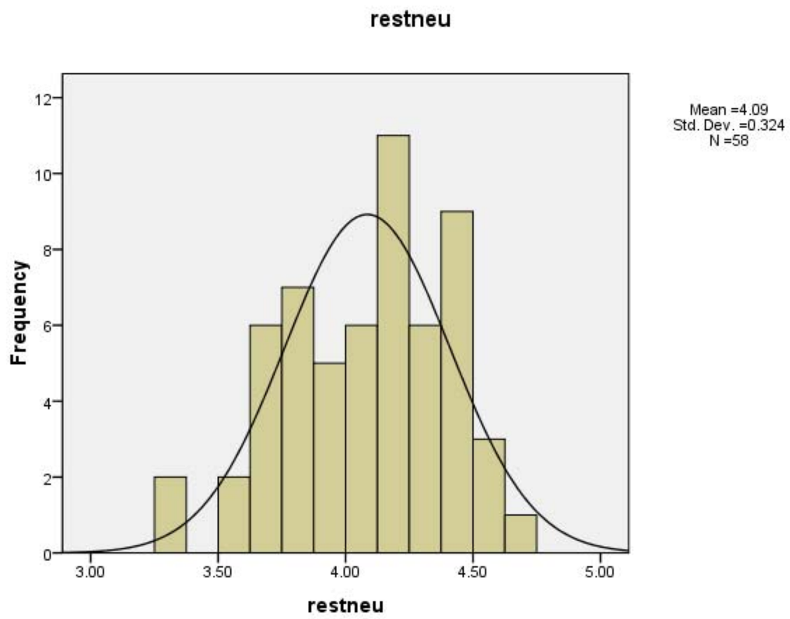

Figure 65 Histogram of Neurosurgery rest

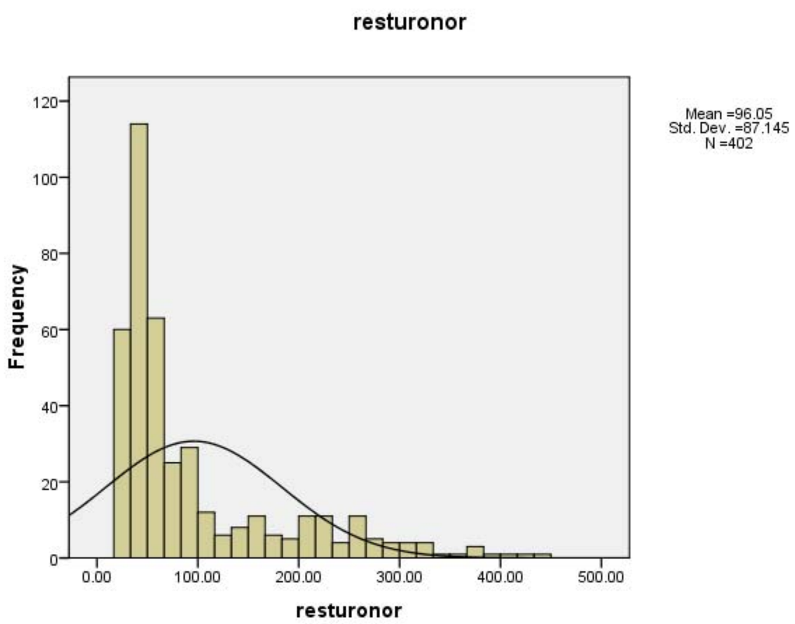

Figure 66 Histogram of Urology rest compared to normal distribution

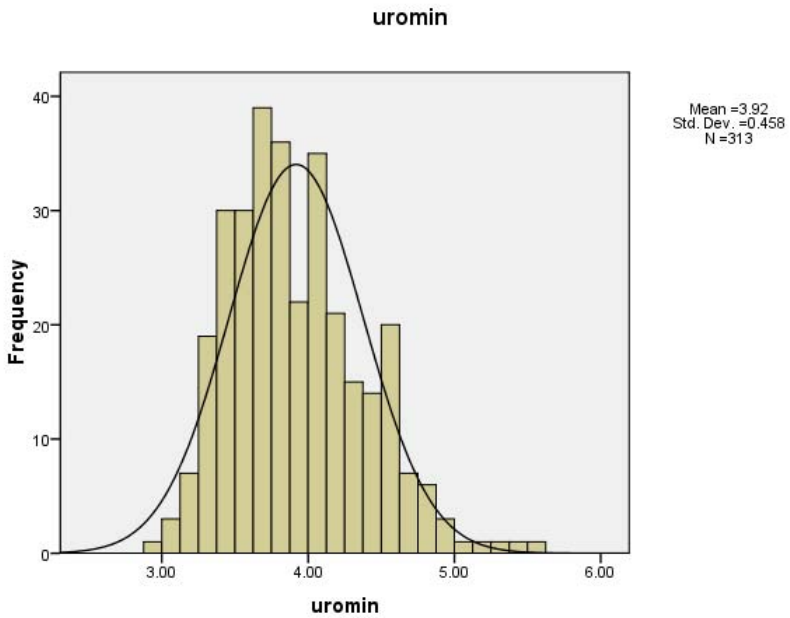

Figure 67 Histogram of Urology short duration

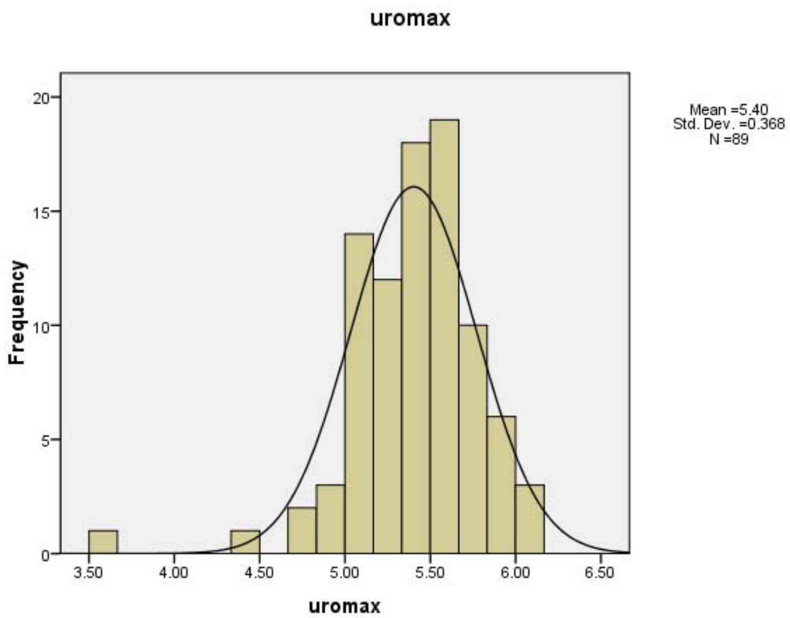

Figure 68 Histogram of Urology long duration

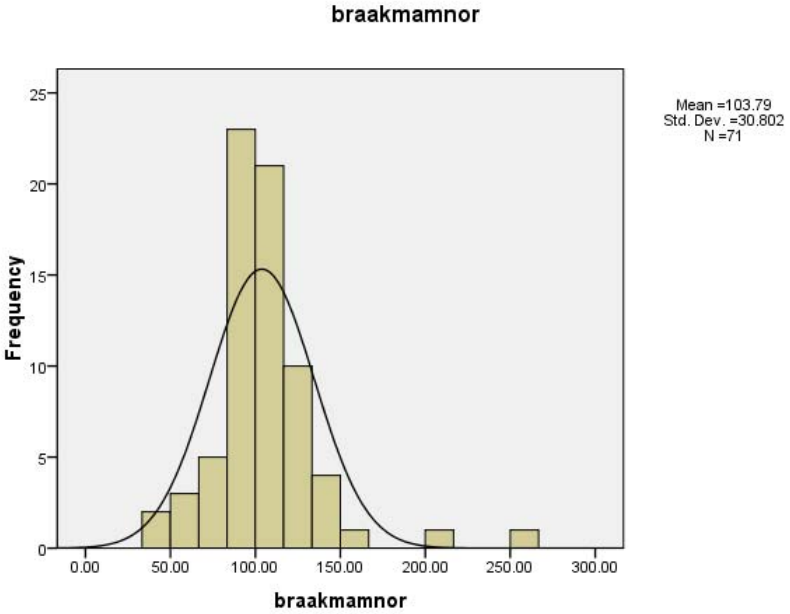

Figure 69 Histogram of Mammareductie plastiek/reconstructive by Braak compared to normal distribution

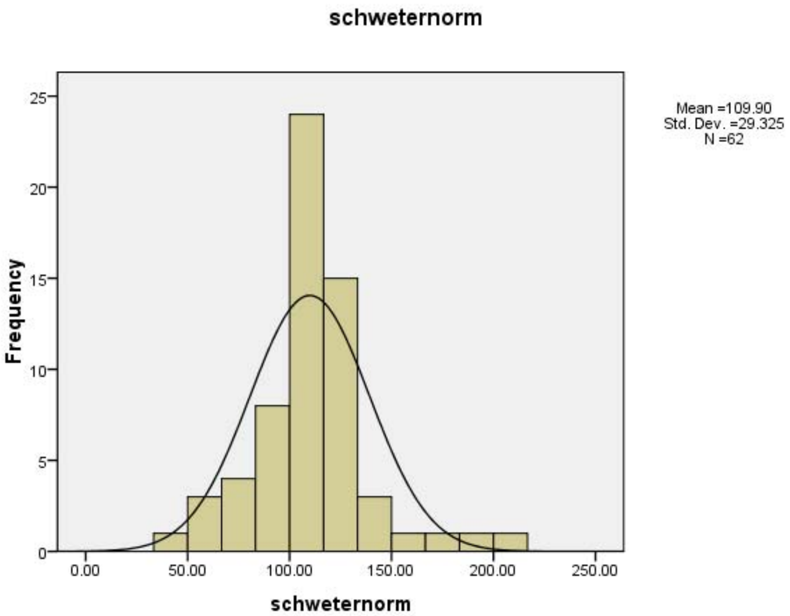

Figure 70 Histogram of Mammareductie plastiek/reconstructive by Schweter compared to normal distribution

D2 Q-Q plots

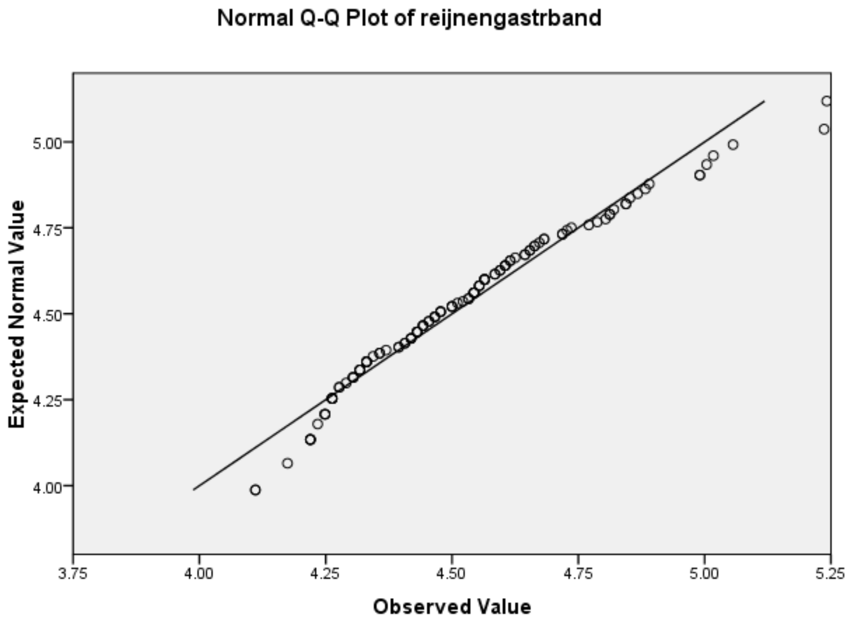

Figure 71 Q-Q plot of the logarithm of the surgery duration (Maagband, Gastric Banding Endoscopisch by Reijnen)

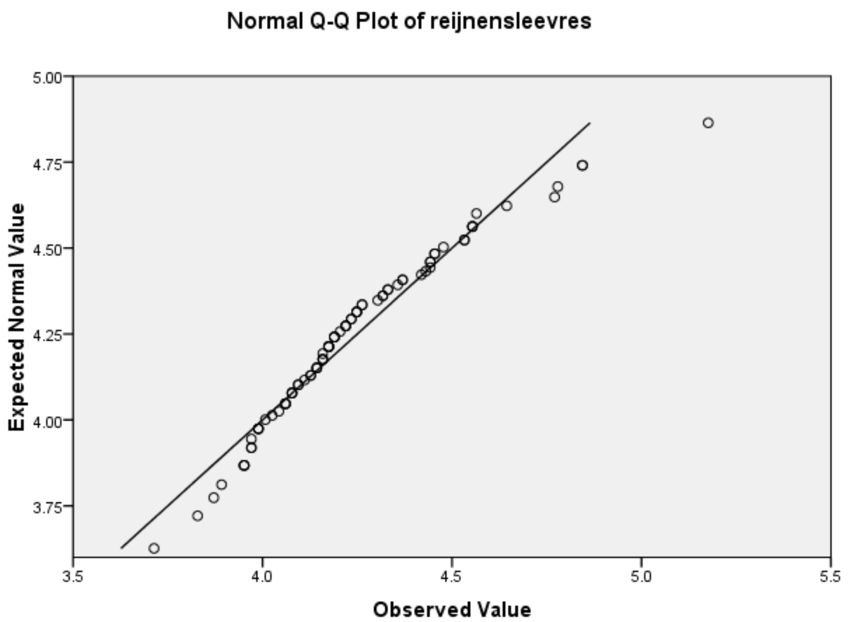

Figure 72 Q-Q plot of the logarithm of the surgery duration (Sleeve resectie / Gastric Sleeve.by Reijnen)

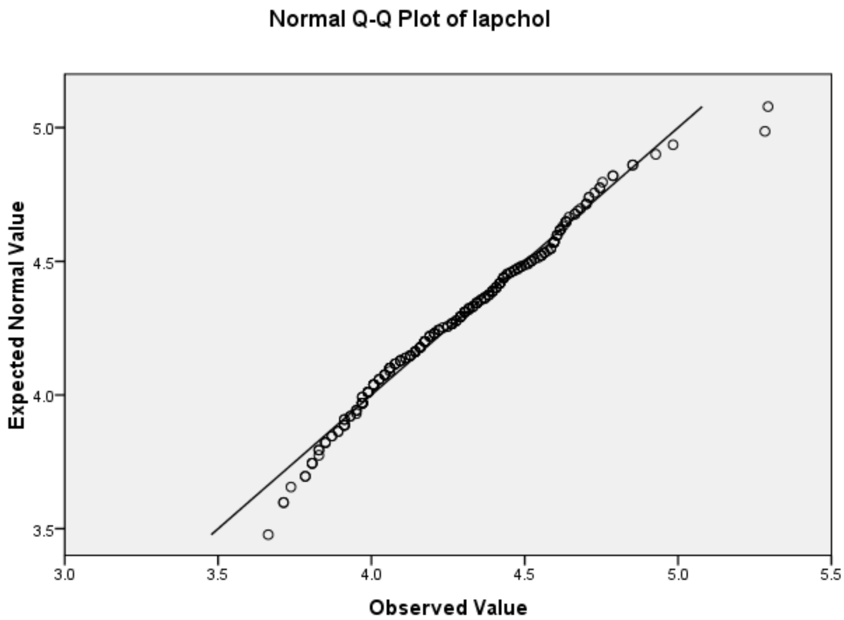

Figure 73 Q-Q plot of the logarithm of the surgery duration (Lap. chol. /Cholecystectomie per laparoscoop)

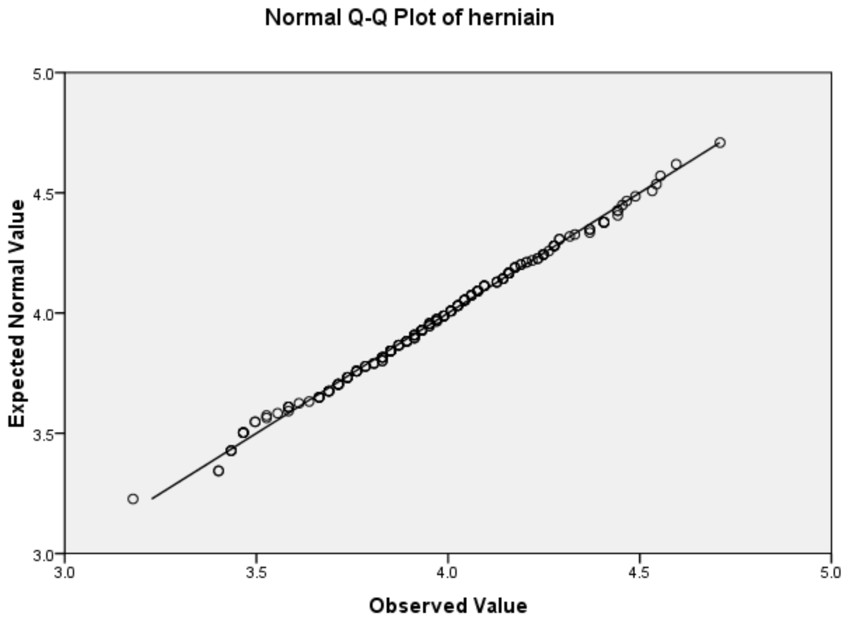

Figure 74 Q-Q plot of the logarithm of the surgery duration (Hernia inguinalis, liesbreuk)

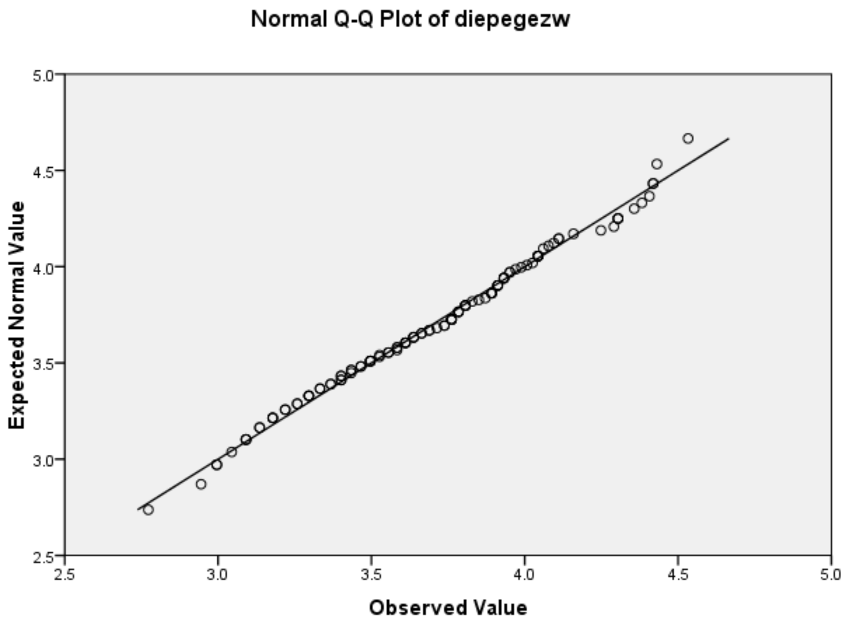

Figure 75 Q-Q plot of the logarithm of the surgery duration (Diepe gezwellen verwijderen huid en sub-cutis)

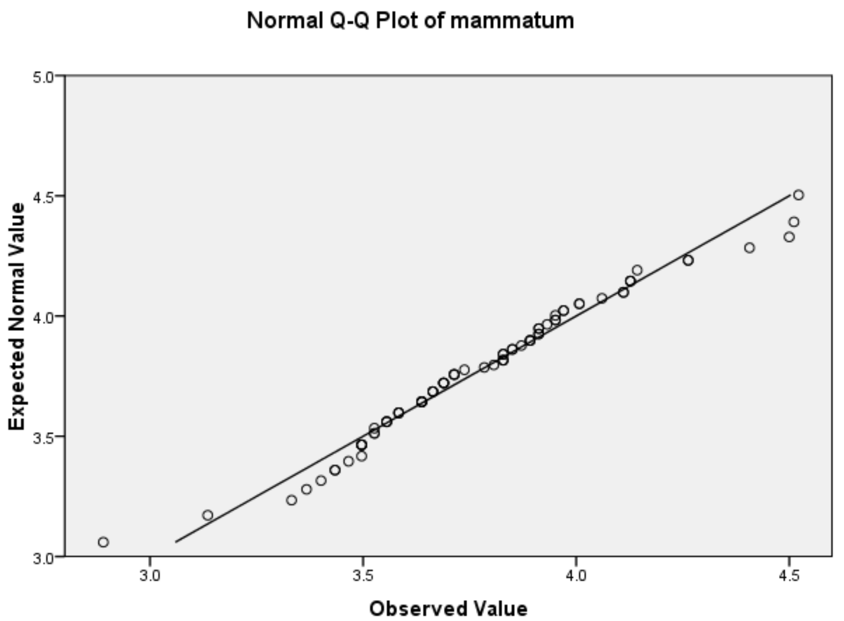

Figure 76 Q-Q plot of the logarithm of the surgery duration (Loc. exc. mammatumor / mamma sparende ok)

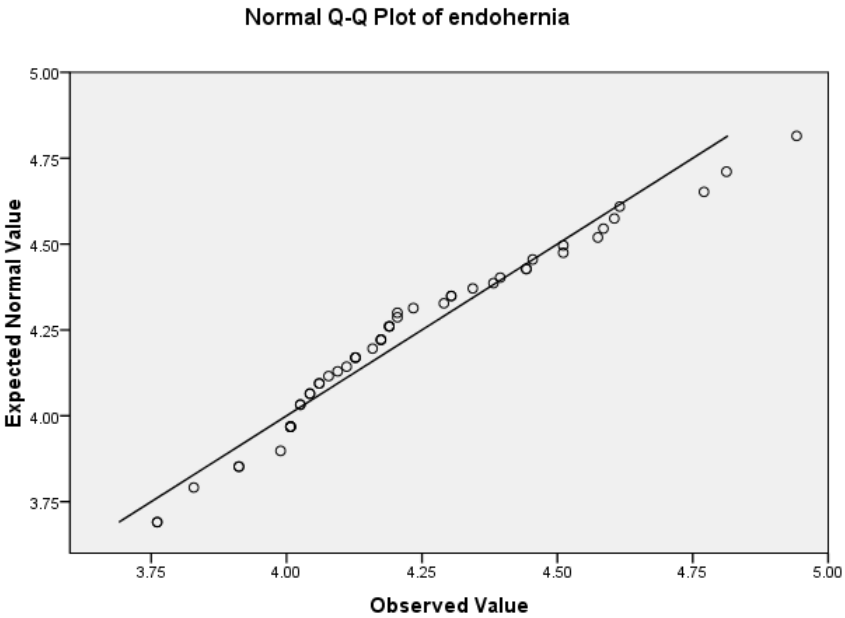

Figure 77 Q-Q plot of the logarithm of the surgery duration (Endosopische operatie hernia inguinalis/ TEP)

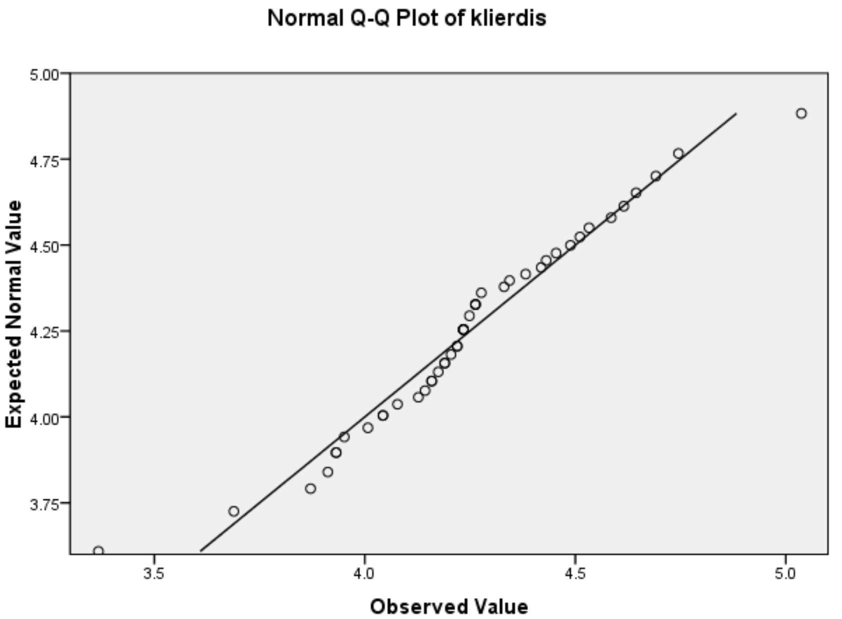

Figure 78 Q-Q plot of the logarithm of the surgery duration (Klierdissectie, axillair (okselklierdissectie))

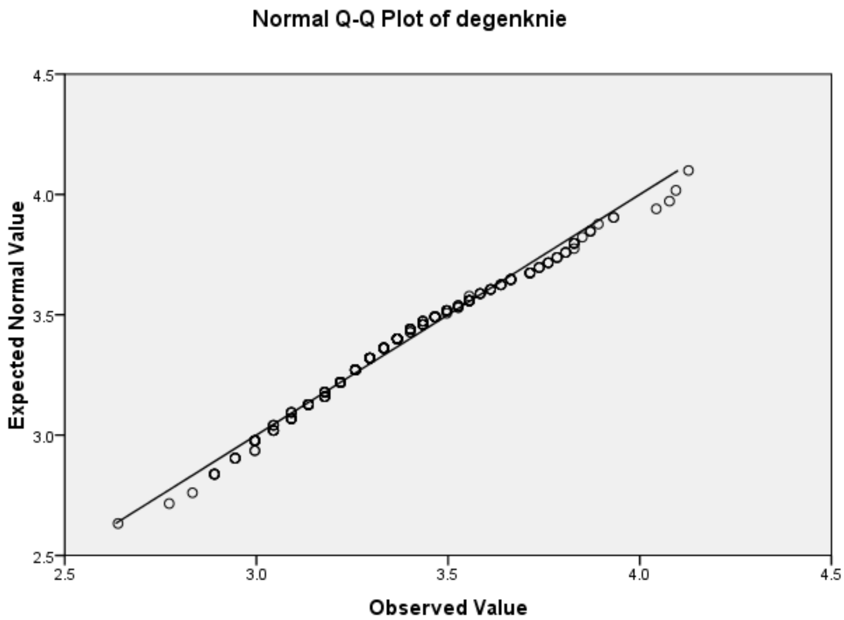

Figure 79 Q-Q plot of the logarithm of the surgery duration (Arthroscopie van de knie by Degen)

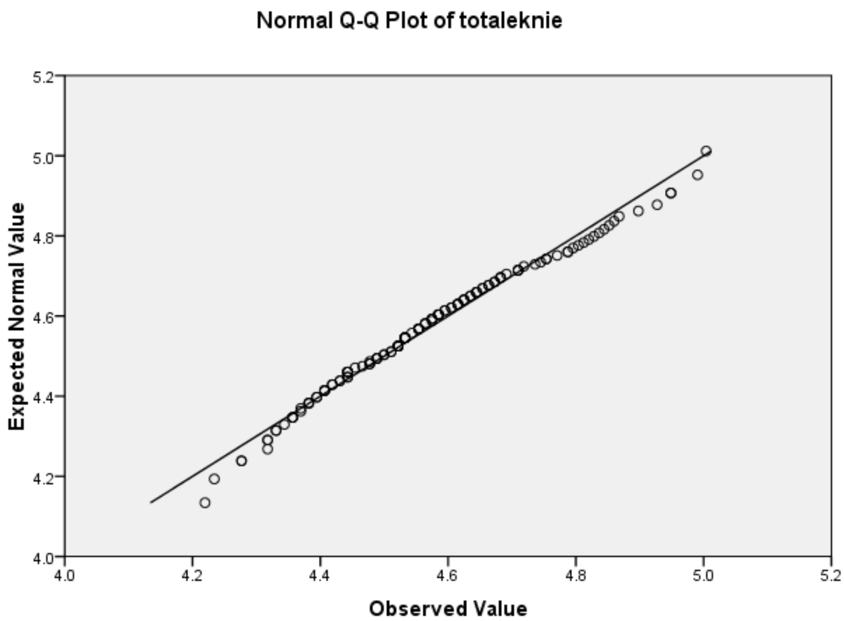

Figure 80 Q-Q plot of the logarithm of the surgery duration (Totale knieprothese)

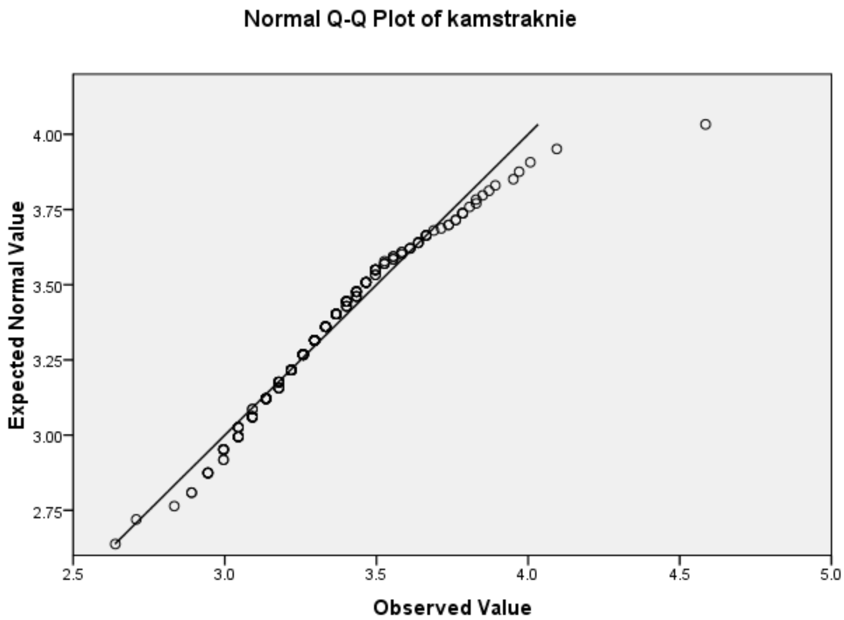

Figure 81 Q-Q plot of the logarithm of the surgery duration (Arthroscopie van de knie by Kamstra)

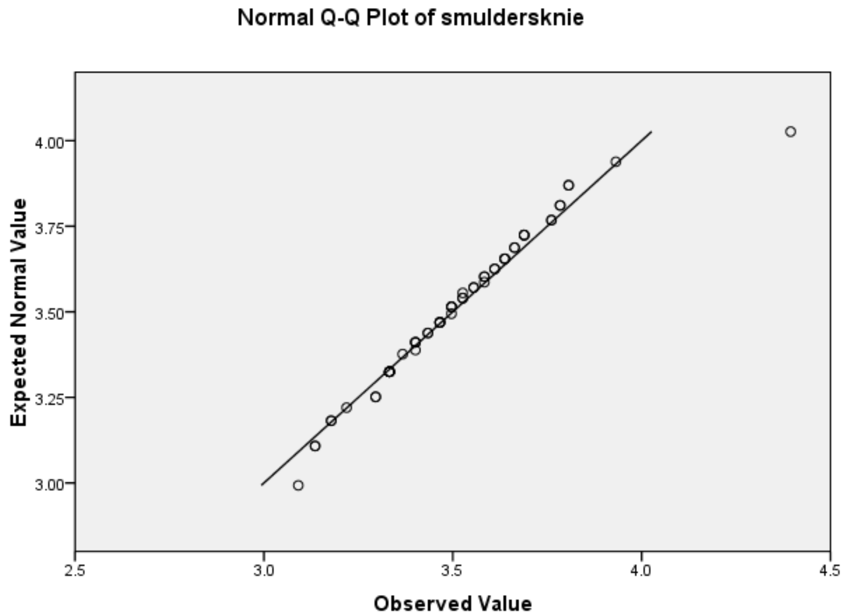

Figure 82 Q-Q plot of the logarithm of the surgery duration (Arthroscopie van de knie by Smulders)

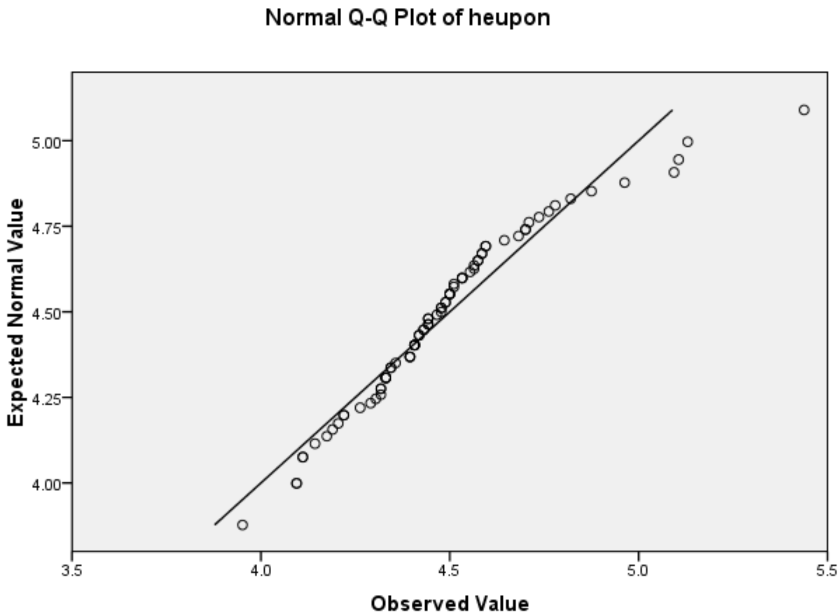

Figure 83 Q-Q plot of the logarithm of the surgery duration (Totale heup, ongecementeerd)

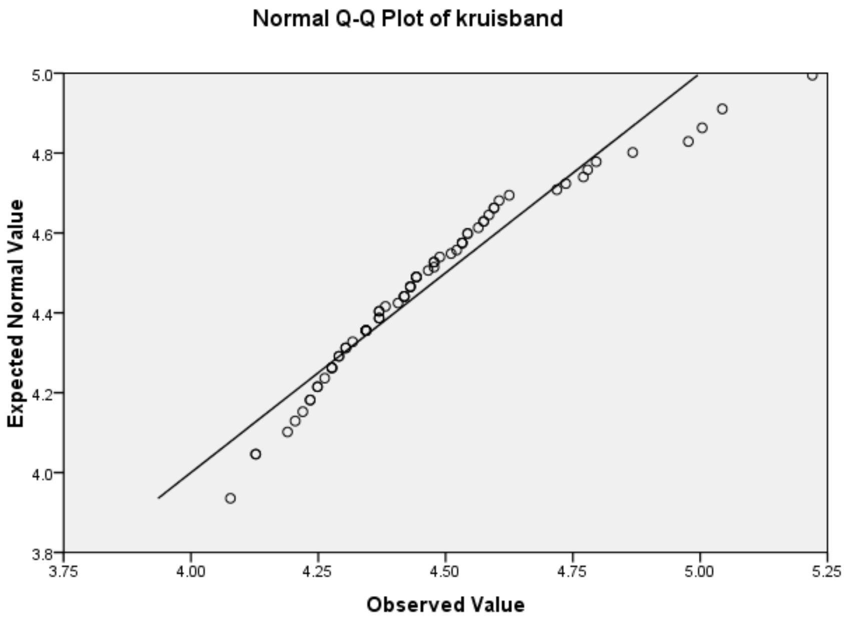

Figure 84 Q-Q plot of the logarithm of the surgery duration (Voorste kruisbandplastiek)

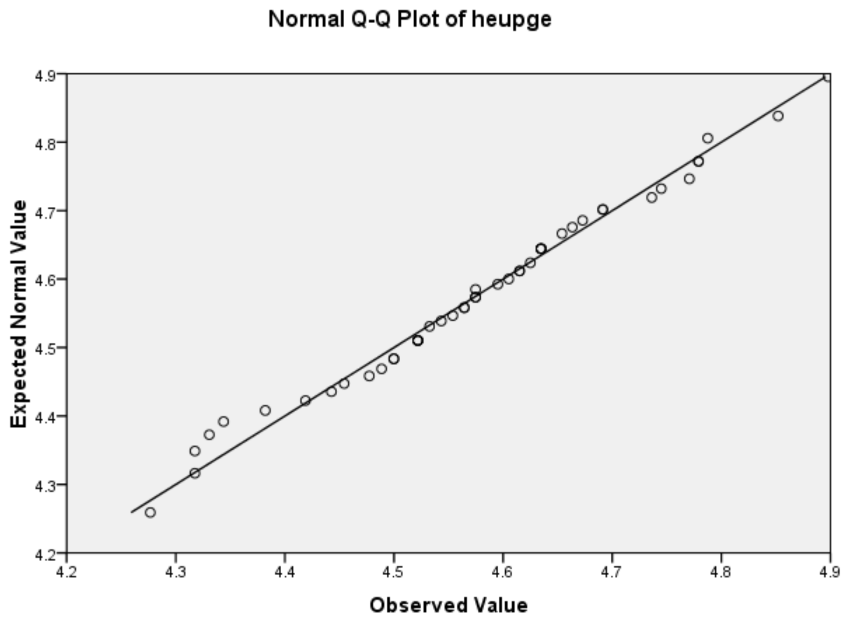

Figure 85 Q-Q plot of the logarithm of the surgery duration (Totale heup gecementeerd)

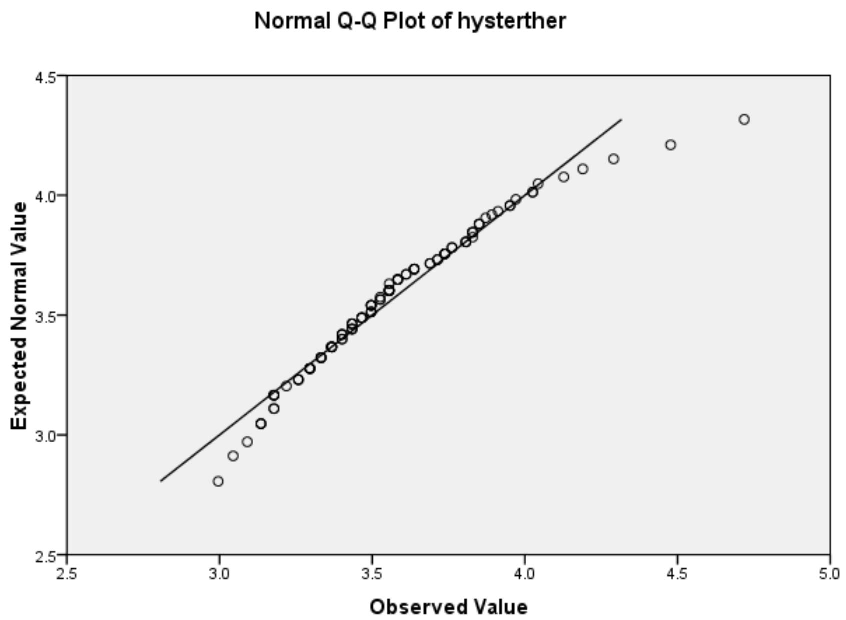

Figure 86 Q-Q plot of the logarithm of the surgery duration (Therapeutische hysteroscopie, klein)

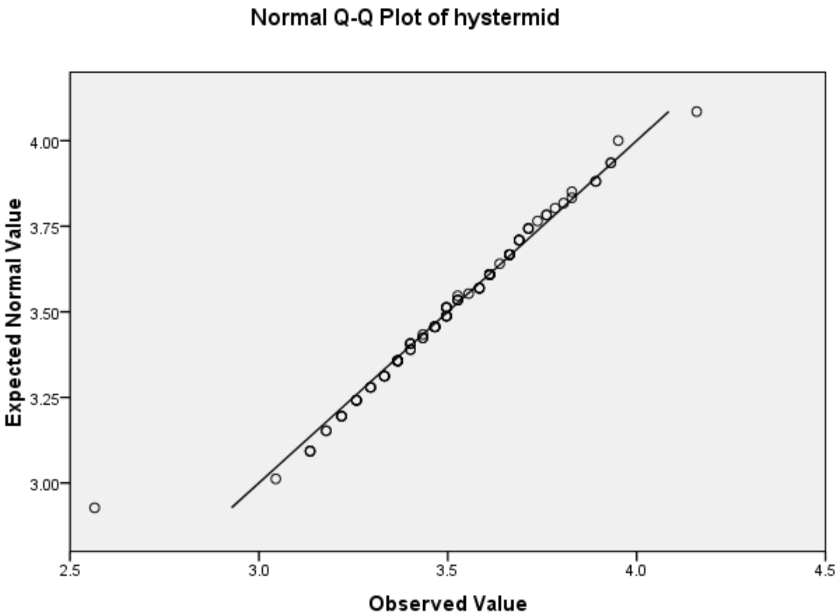

Figure 87 Q-Q plot of the logarithm of the surgery duration (Hysteroscopie + resectie , middel)

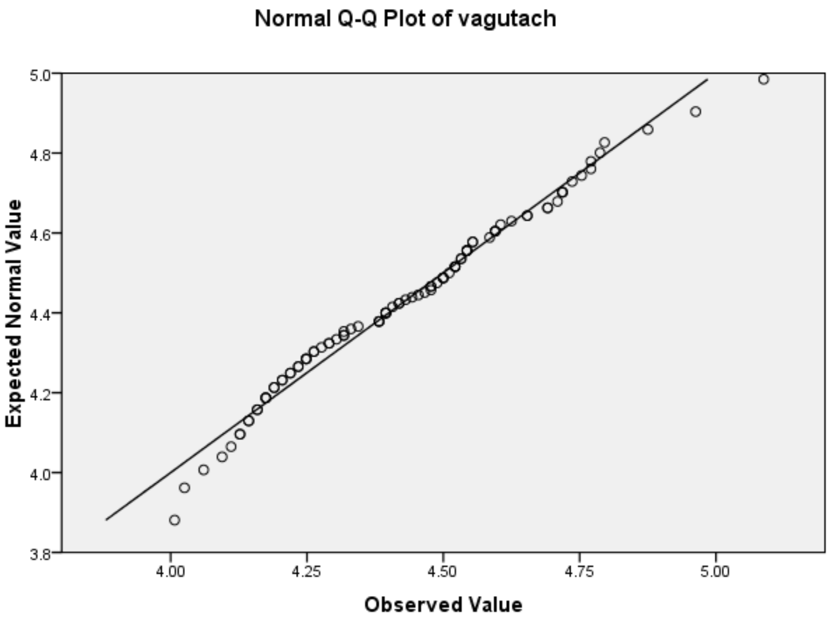

Figure 88 Q-Q plot of the logarithm of the surgery duration (Vag. ut. + voor-+achterwandplastiek)

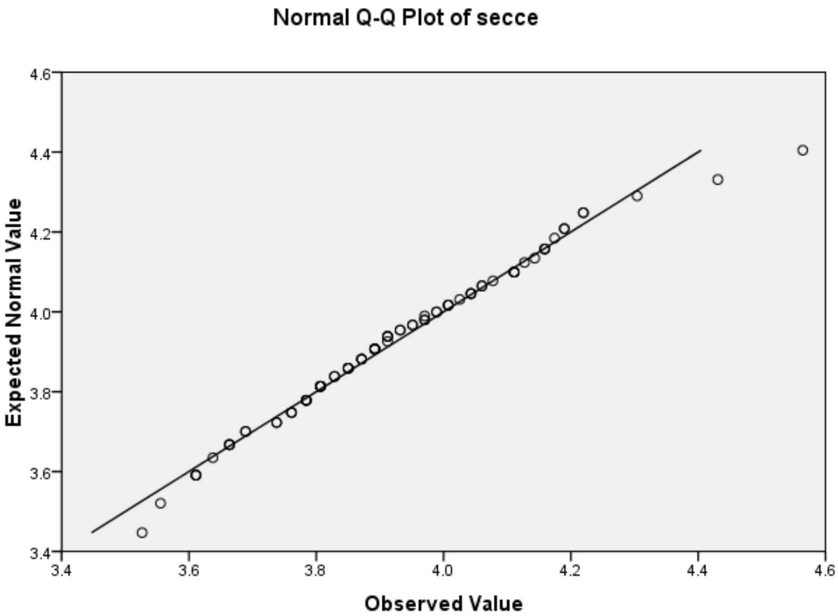

Figure 89 Q-Q plot of the logarithm of the surgery duration (Sectio caesarea zonder voorbehandeling)

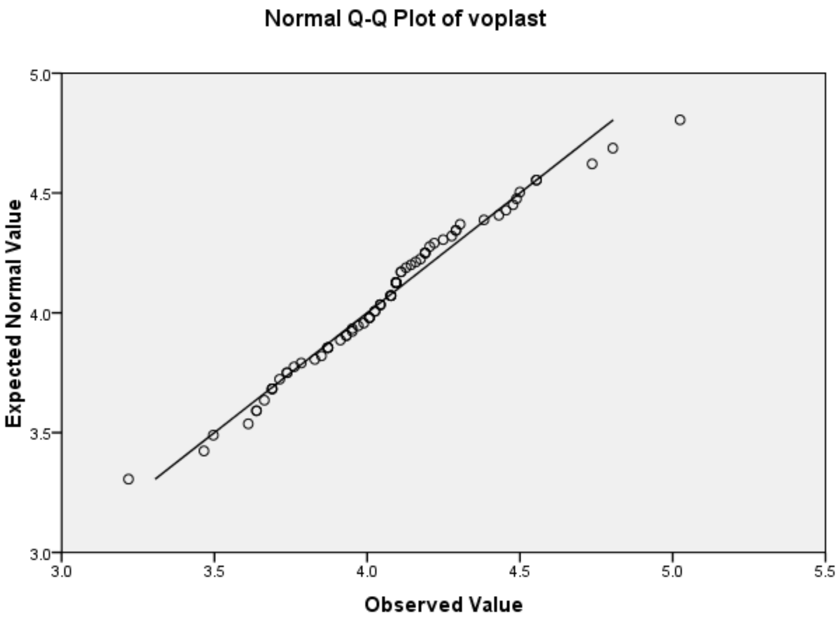

Figure 90 Q-Q plot of the logarithm of the surgery duration (Voor en achterwand plastiek)

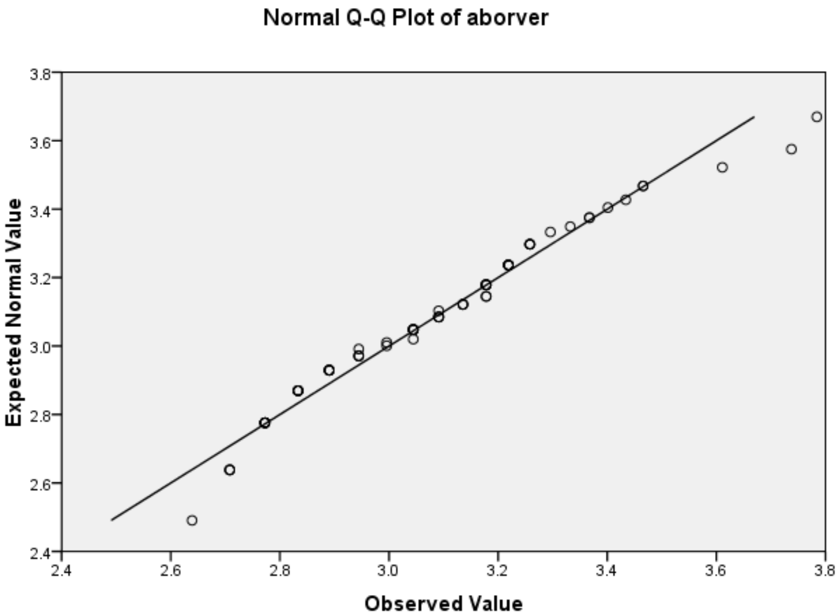

Figure 91 Q-Q plot of the logarithm of the surgery duration (Abortus verwijdering./ Missed abortion)

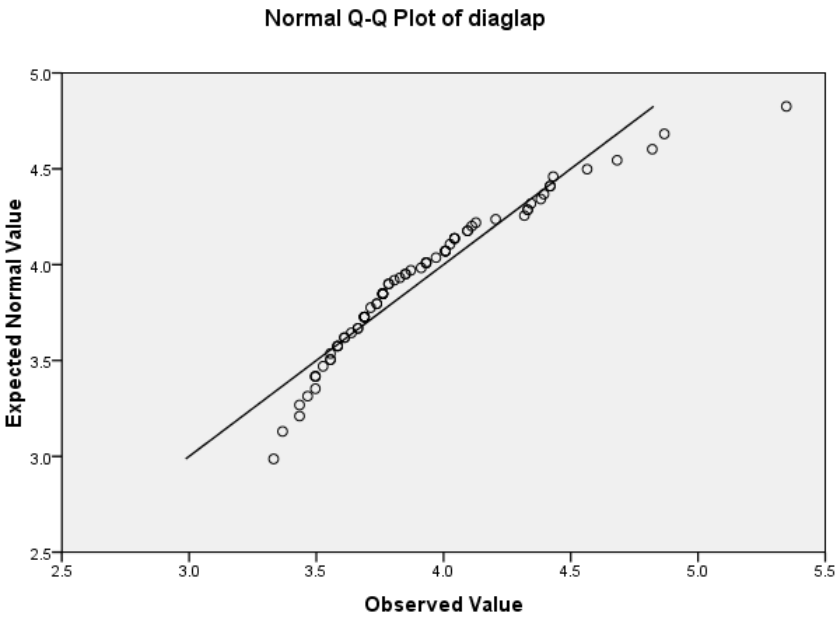

Figure 92 Q-Q plot of the logarithm of the surgery duration (Diagnostische laparoscopie, incl. event.proefexcisie)

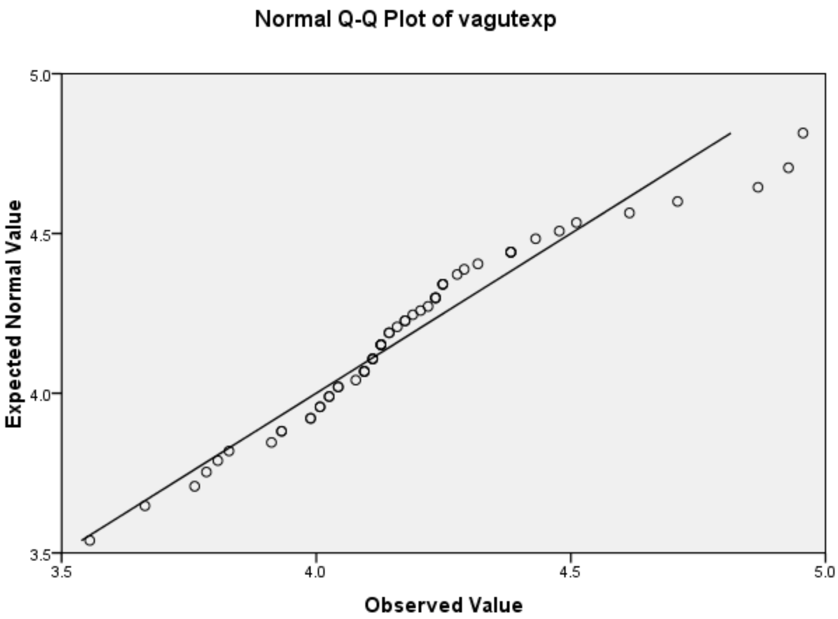

Figure 93 Q-Q plot of the logarithm of the surgery duration (Vaginale uterus extirpatie)

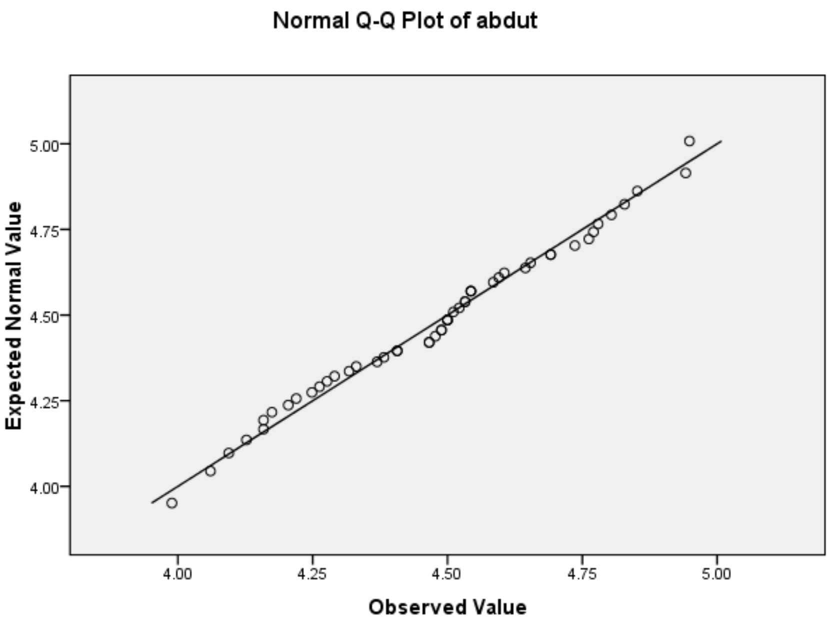

Figure 94 Q-Q plot of the logarithm of the surgery duration (Abdominale uterus extirpatie)

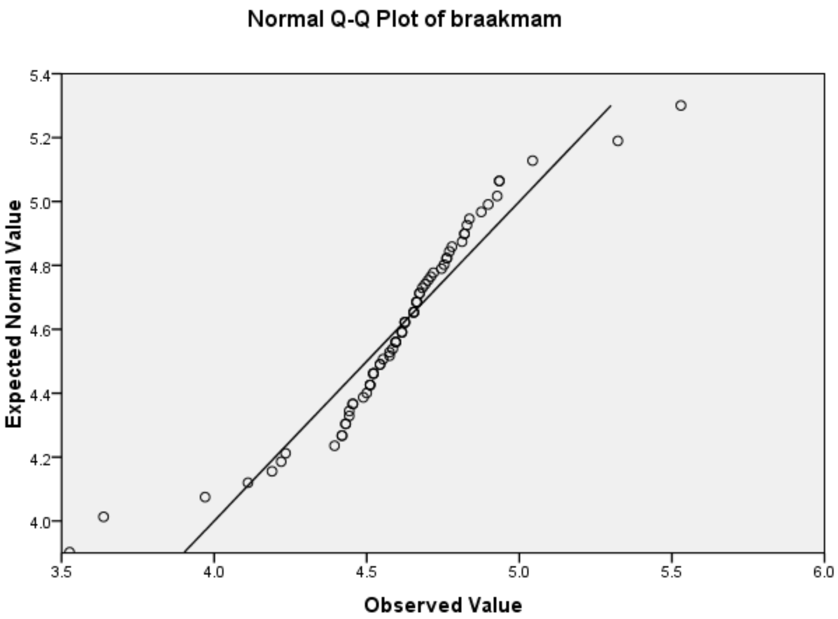

Figure 95 Q-Q plot of the logarithm of the surgery duration (Mammareductie plastiek/reconstructive by Braak)

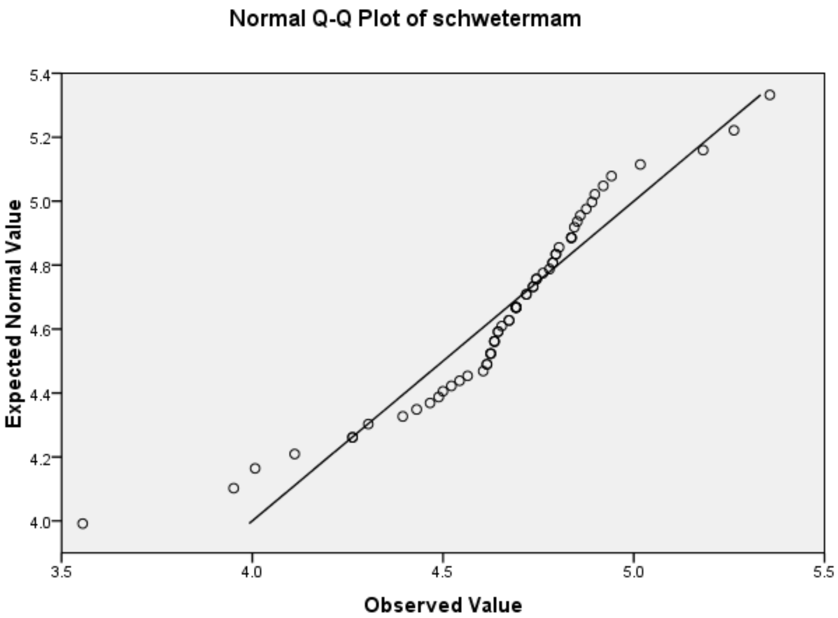

Figure 96 Q-Q plot of the logarithm of the surgery duration (Mammareductie plastiek/reconstructive by Schweter)

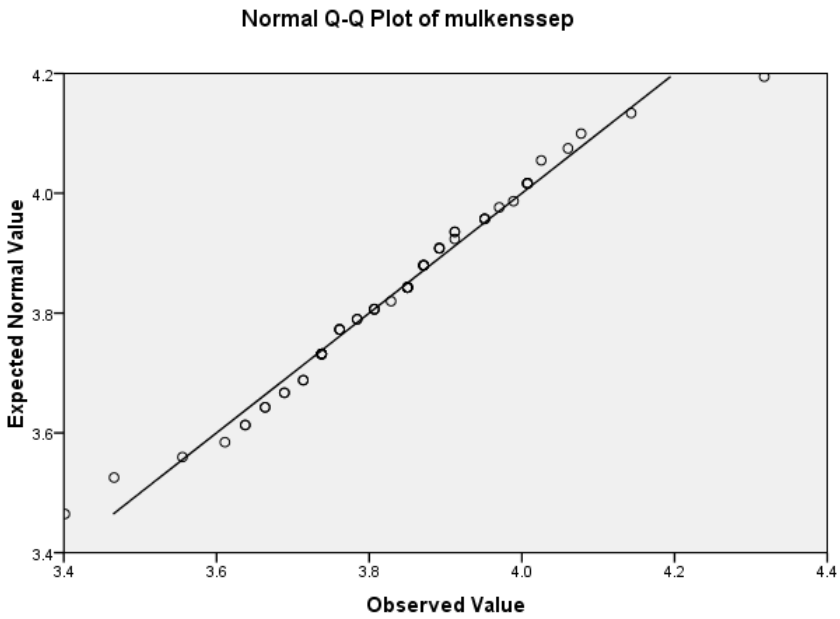

Figure 97 Q-Q plot of the logarithm of the surgery duration (Septum corrective by Mulkens)

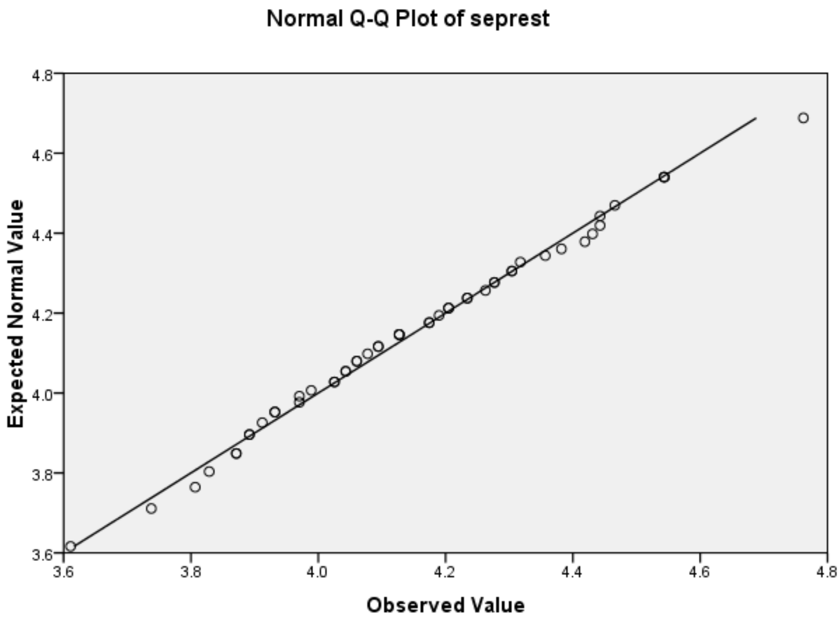

Figure 98 Q-Q plot of the logarithm of the surgery duration (Septum corrective rest)

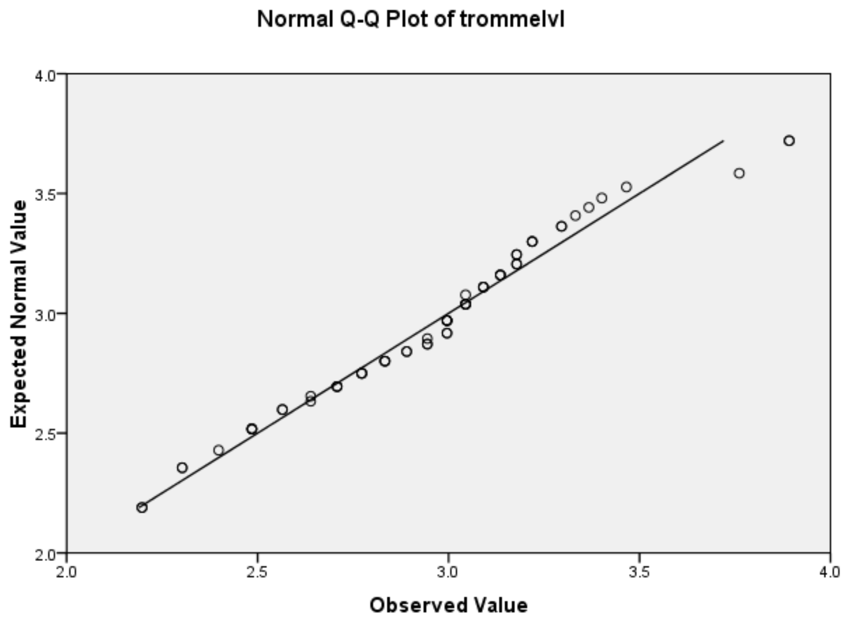

Figure 99 Q-Q plot of the logarithm of the surgery duration (Trommelvliesbuis, tbb)

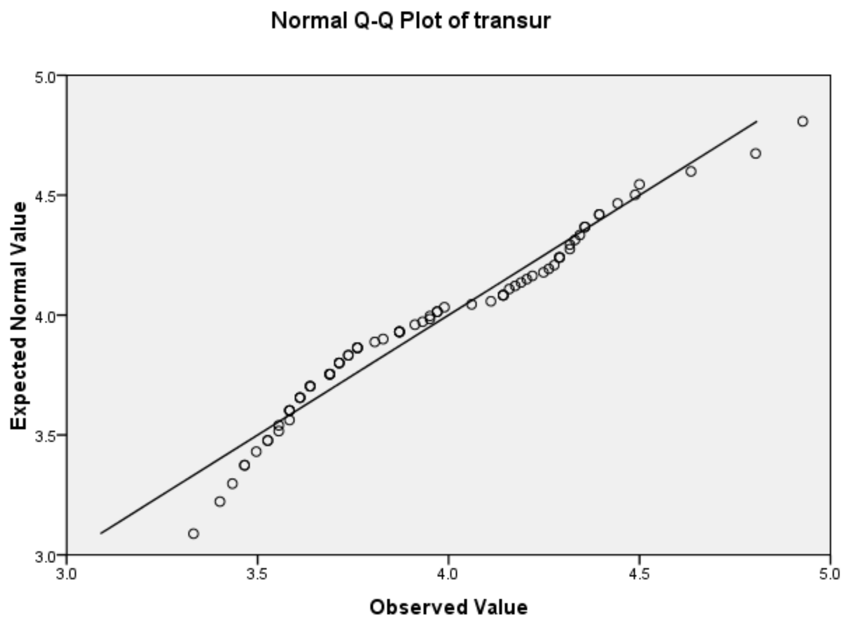

Figure 100 Q-Q plot of the logarithm of the surgery duration (Transurethrale prostaatresectie.TUR-P. / TUMT)

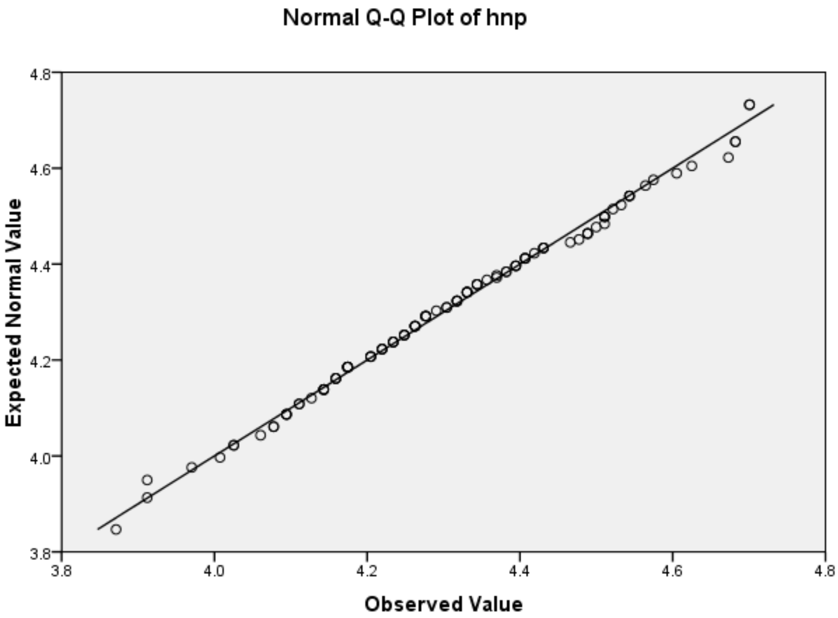

Figure 101 Q-Q plot of the logarithm of the surgery duration (HNP, Hernia lumbalis)

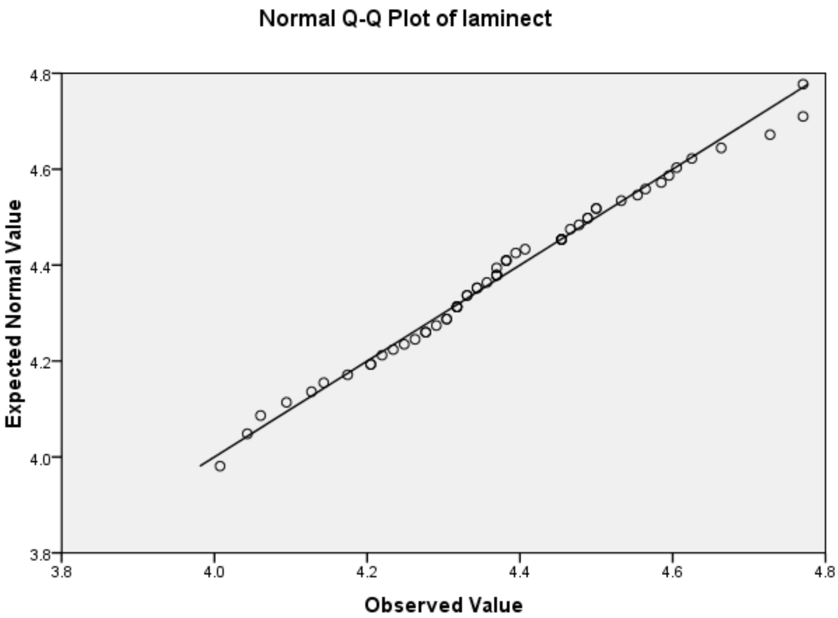

Figure 102 Q-Q plot of the logarithm of the surgery duration (Laminectomie. extraduraal)

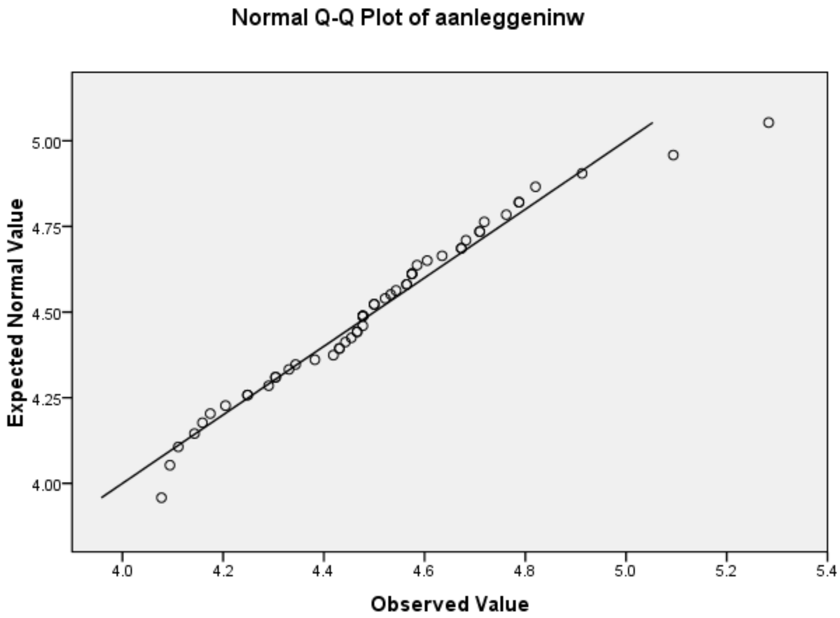

Figure 103 Q-Q plot of the logarithm of the surgery duration (Aanleggen inwendige arterioveneuze shunt, cimino)

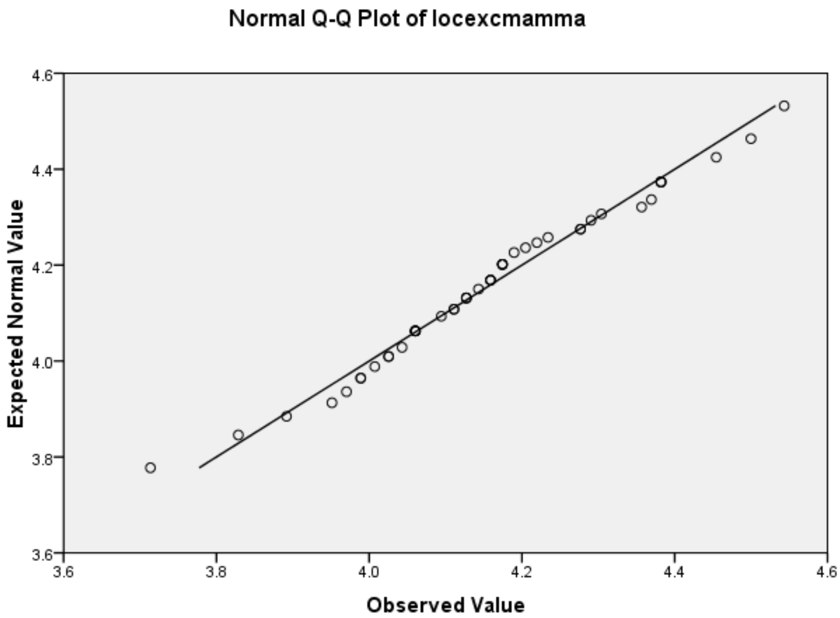

Figure 104 Q-Q plot of the logarithm of the surgery duration (Loc. excisie mammatumor + SWK)

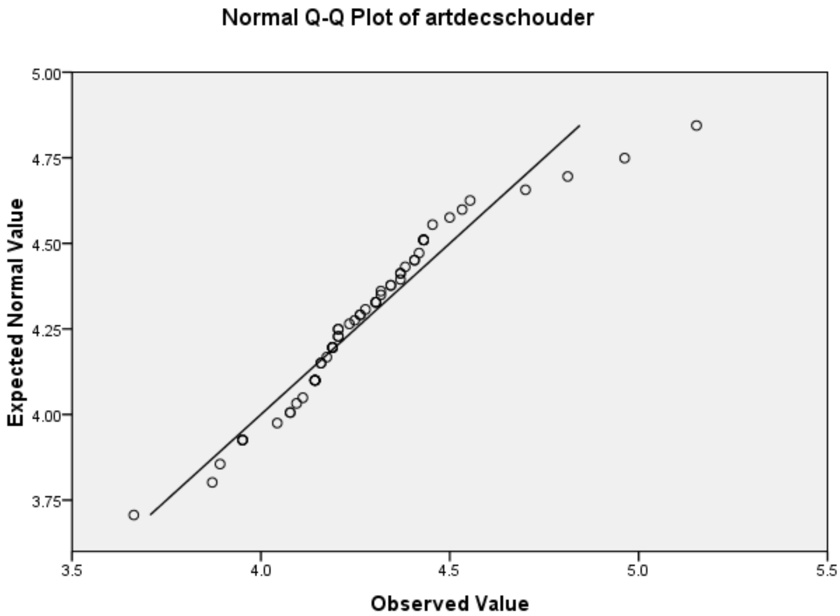

Figure 105 Q-Q plot of the logarithm of the surgery duration (Arthroscopische decompressie schouder)

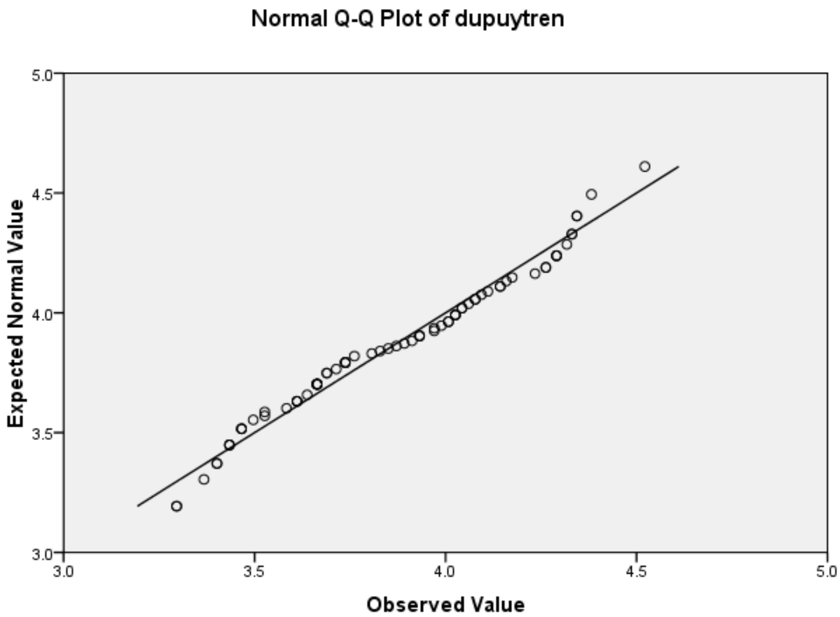

Figure 106 Q-Q plot of the logarithm of the surgery duration (Dupuytren met 2 of meer stralen)

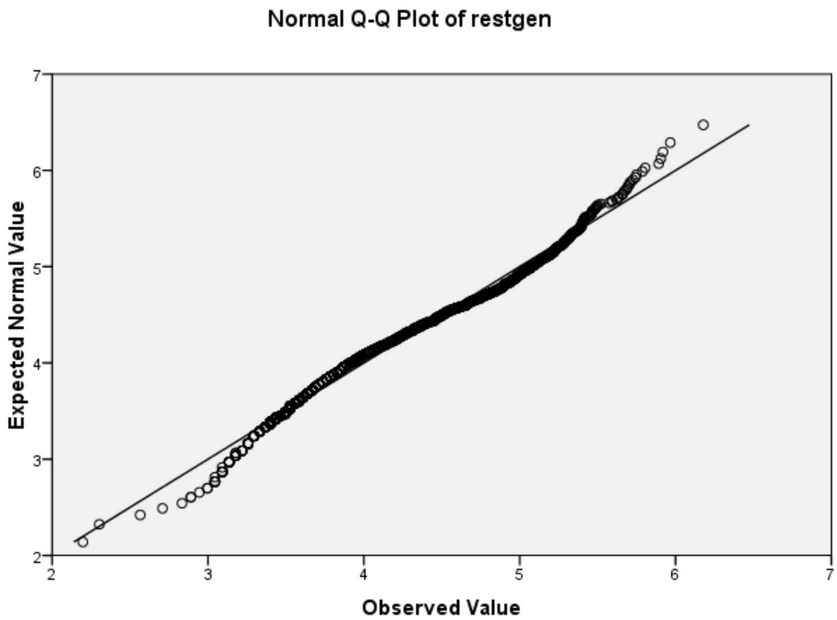

Figure 107 Q-Q plot of the logarithm of the surgery duration (General surgery rest)

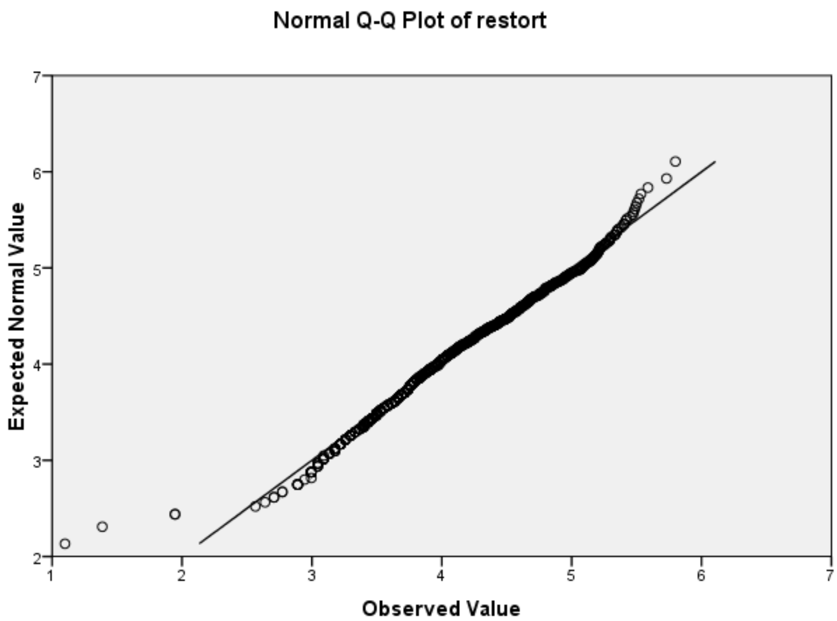

Figure 108 Q-Q plot of the logarithm of the surgery duration (Orthopedics rest)

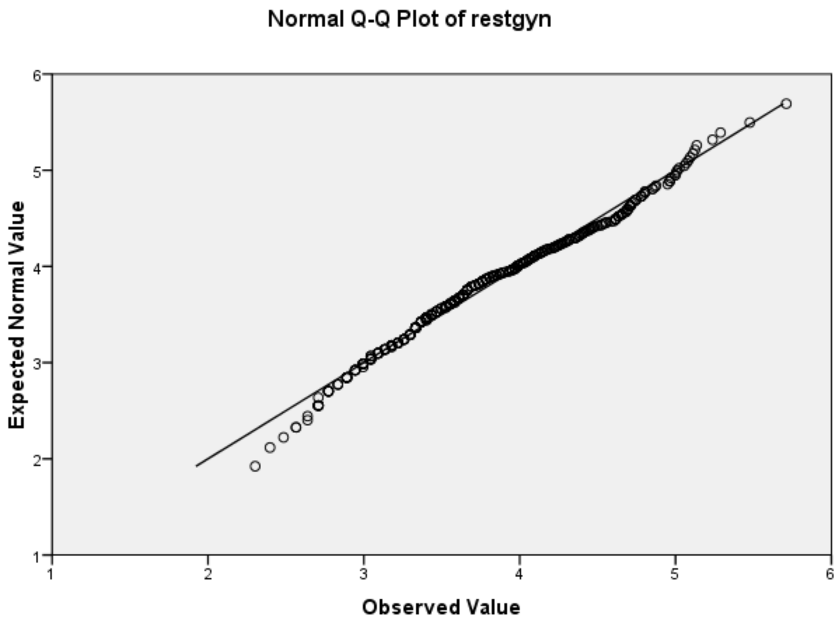

Figure 109 Q-Q plot of the logarithm of the surgery duration (Gynecology rest)

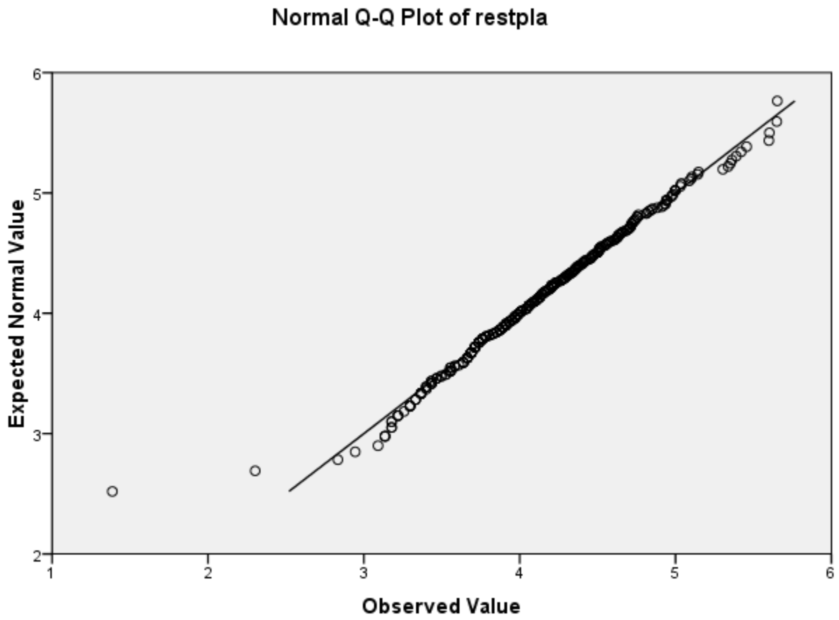

Figure 110 Q-Q plot of the logarithm of the surgery duration (Plastic surgery rest)

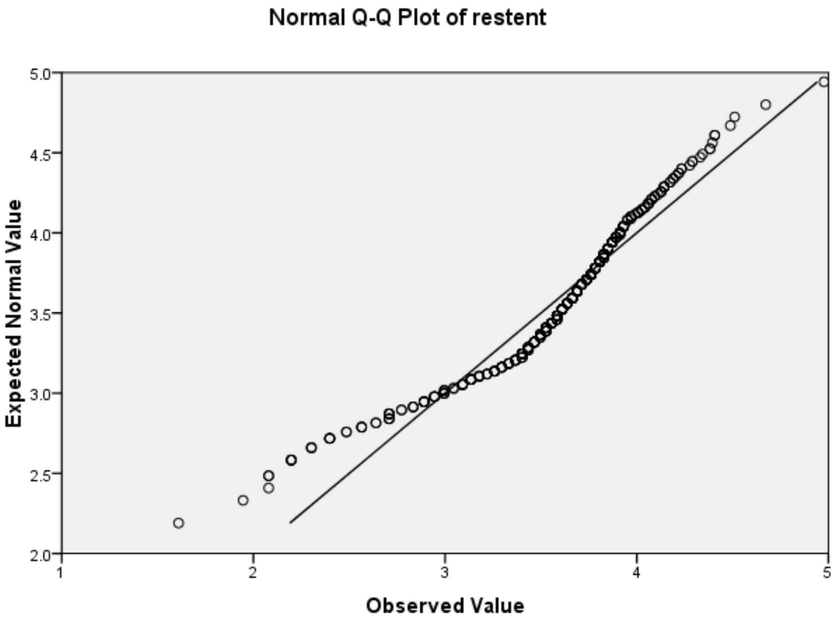

Figure 111 Q-Q plot of the logarithm of the surgery duration (ENT rest)

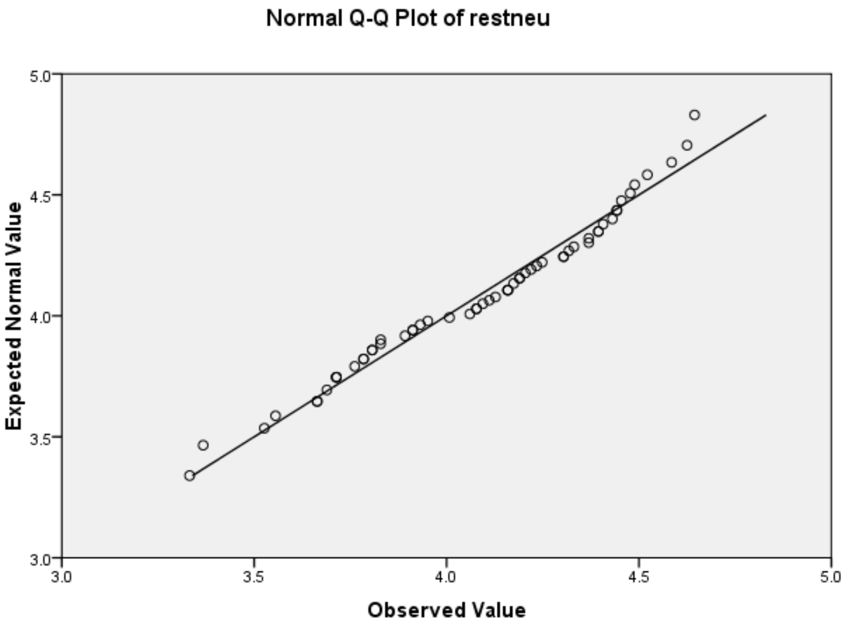

Figure 112 Q-Q plot of the logarithm of the surgery duration (Neurosurgery rest)

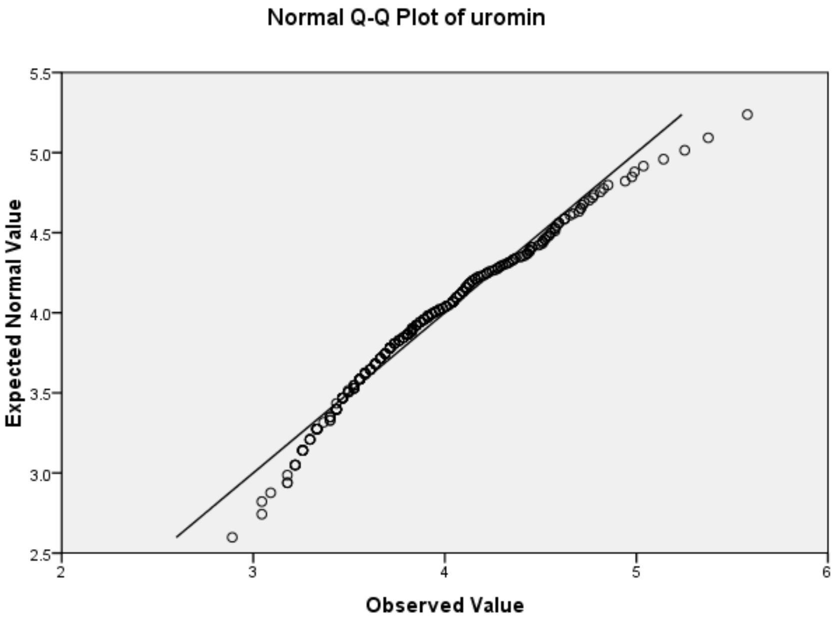

Figure 113 Q-Q plot of the logarithm of the surgery duration (Urology short duration)

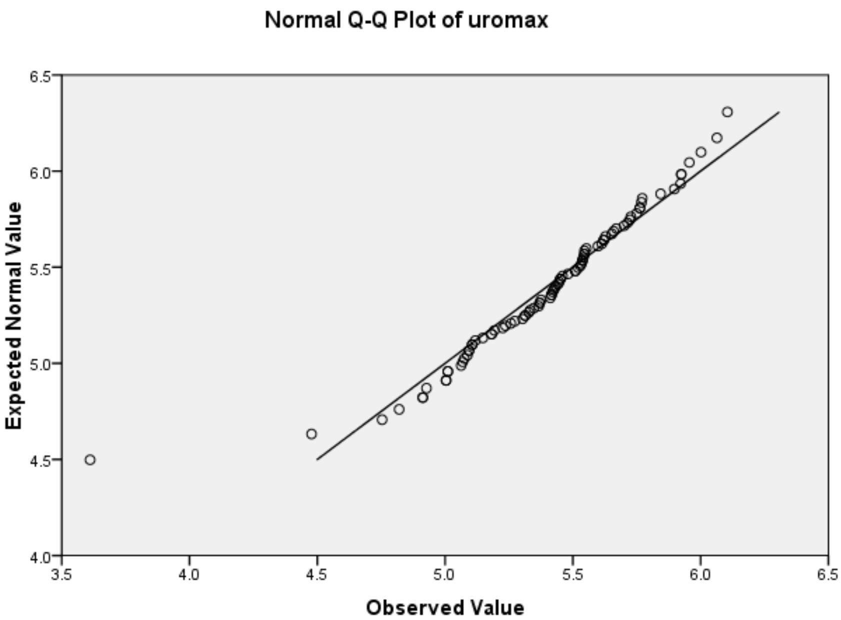

Figure 114 Q-Q plot of the logarithm of the surgery duration (Urology long duration)

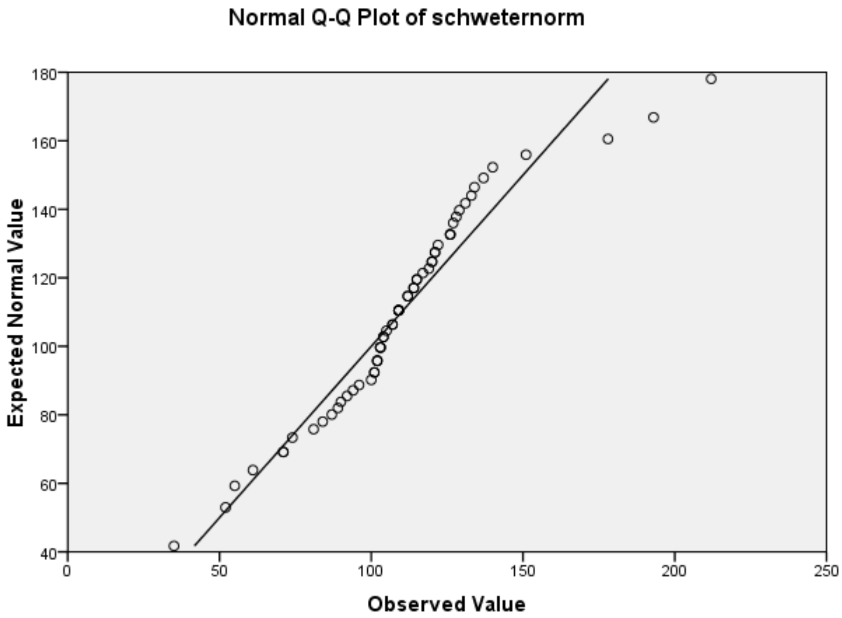

Figure 115 Q-Q plot of the of the surgery duration (Mammareductie plastiek/reconstructive by Schweter)

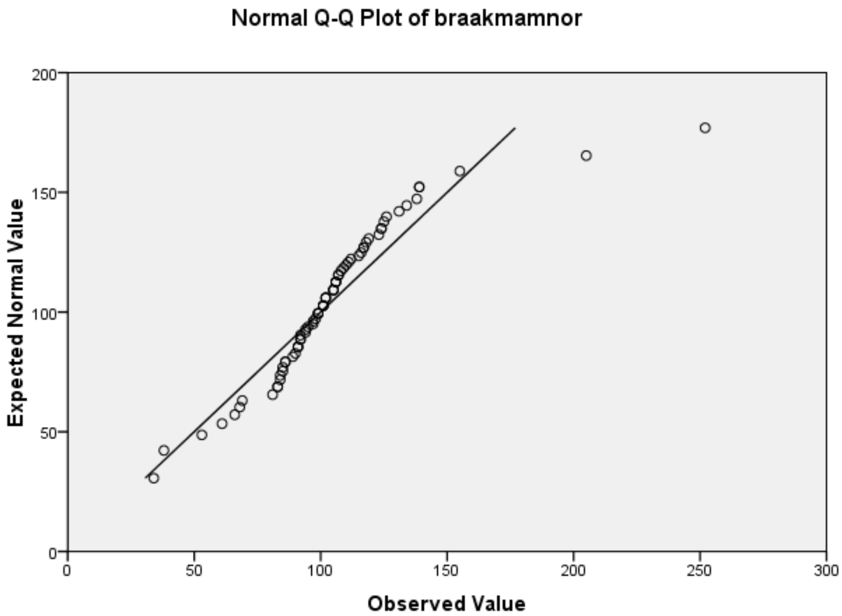

Figure 116 Q-Q plot of the of the surgery duration (Mammareductie plastiek/reconstructive by Braak)

D3 Kolmogorov- Smirnov test and distribution characteristics

Table 46 Results of the Kolmogorov- Smirnov test

	Sigma	Distribution type	Mean	Standard deviation	# of surgeries
reijnengastrband	0.50	lognormal	4.53	0.23	116
reijnensleevres	0.18	lognormal	4.25	0.26	80
lapchol	0.41	lognormal	4.28	0.29	247
herniain	0.91	lognormal	3.97	0.27	201
diepegezw	0.74	lognormal	3.70	0.38	118
mammatum	0.77	lognormal	3.78	0.30	76
endohernia	0.18	lognormal	4.22	0.26	51
klierdis	0.49	lognormal	4.25	0.29	45
degenknie	0.02	lognormal	3.37	0.26	274
totaleknie	0.77	lognormal	4.57	0.17	126
kamstraknie	0.06	lognormal	3.34	0.25	232
smuldersknie	0.92	lognormal	3.51	0.23	56
heupon	0.10	lognormal	4.48	0.25	79
kruisband	0.40	lognormal	4.47	0.22	69
heupge	0.97	lognormal	4.58	0.14	47
hysterther	0.19	lognormal	3.56	0.30	109
hystermid	0.96	lognormal	3.51	0.23	94
vagutach	0.79	lognormal	4.43	0.22	93
secce	0.81	lognormal	3.93	0.20	79
voplast	0.62	lognormal	4.06	0.31	73
aborver	0.71	lognormal	3.08	0.25	68
diaglap	0.15	lognormal	3.91	0.38	75
vagutexp	0.17	lognormal	4.18	0.28	56
abdut	0.74	lognormal	4.48	0.24	50
braakmamnor	0.14	normal	103.79	30.80	71
schwetermamnor	0.28	normal	109.90	29.33	62
mulkenssep	0.84	lognormal	3.83	0.16	60
seprest	0.99	lognormal	4.15	0.24	50
trommelvl	0.55	lognormal	2.95	0.37	61
transur	0.19	lognormal	3.95	0.36	75
hnp	0.95	lognormal	4.31	0.18	102
laminect	0.75	lognormal	4.38	0.17	57
aanleggeninw	0.80	lognormal	4.51	0.24	53
locexcmamma	0.68	lognormal	4.15	0.17	46
artdecschouder	0.28	lognormal	4.28	0.25	59
dupuytren	0.54	lognormal	3.87	0.31	74
restgen	0.00	lognormal	4.31	0.66	1252
restort	0.18	lognormal	4.12	0.62	950
restgyn	0.02	lognormal	3.81	0.63	418
restpla	0.90	lognormal	4.14	0.55	377
restent	0.00	lognormal	3.57	0.46	421
restneu	0.73	lognormal	4.09	0.32	58
uromax	0.58	lognormal	5.40	0.37	89
uromin	0.07	lognormal	3.92	0.46	313