MASTER THESIS

OPTIMIZATION OF THE OPERATING ROOM SESSION PLANNING WITHIN DR. HORACIO E. ODUBER HOSPITAL

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Dr. Horacio E. Oduber HOSPITAL

UNIVERSITY OF TWENTE.

Management summary

Motivation & research objective

According to Andringa (2018) the OR session planning within Dr. Horacio E. Oduber hospital (HOH) is suboptimal. A consequence is that there is a peak in bed demand on certain days in the surgical nursing wards. A data analysis, which is part of this research, shows for both surgical nursing wards (surgical 3 and B4) a peak in bed demand at the beginning of the week and an off-peak load during the weekend. This research was carried out within the specialism general surgery to analyze whether it is possible to optimize the OR session planning such that there is a better distribution of bed occupation during the week. We thereby arrive at the following research objective:

To derive recommendations for optimizing the OR session planning within HOH such that the peaks in bed demand in the surgical nursing wards can be decreased.

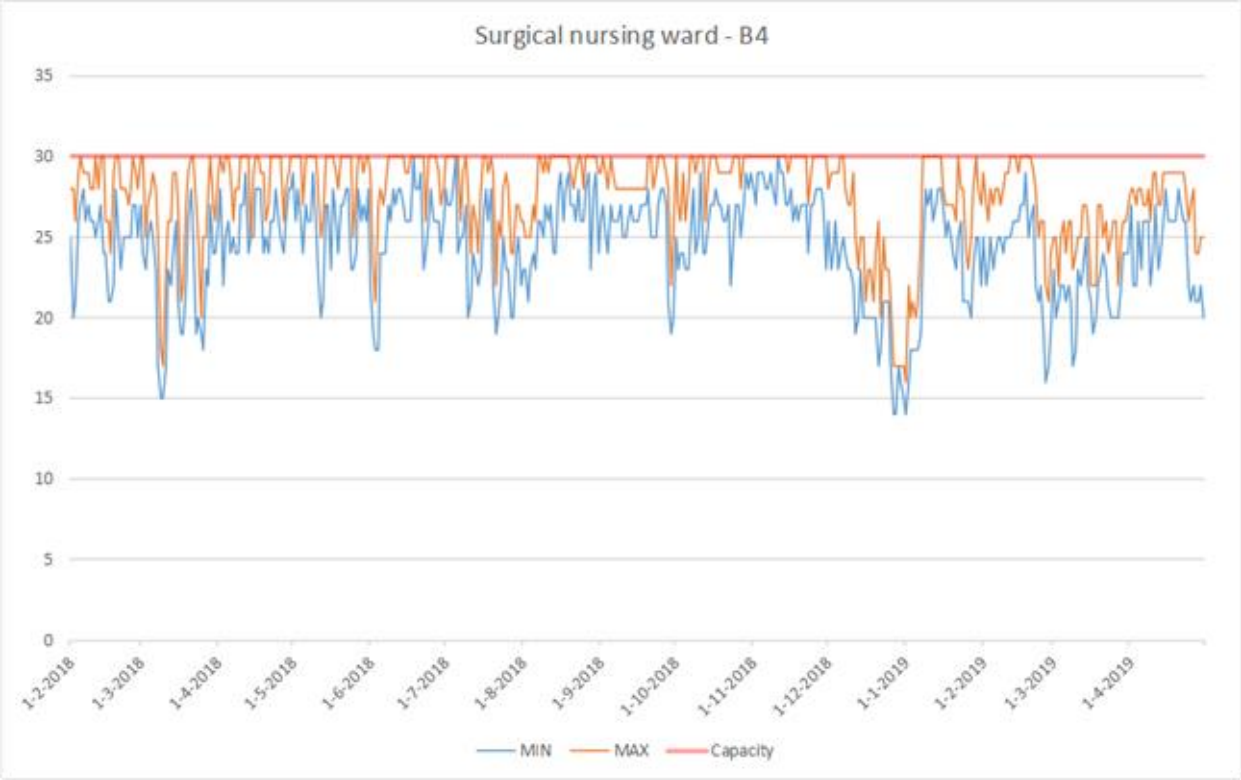
Research method

To write this research, the 'Managerial Problem-Solving approach' was used. Summary figure 1 gives an overview of the bed occupancy for ward B4. The current OR scheduling of HOH is explained using concepts known from the literature. A literature review is also being conducted to search for intervention options for HOH regarding the OR session planning. The Master Surgery Schedule (MSS) has been chosen to optimize the OR session planning. A Master Surgery Scheduling (MSS) allocates surgeons and surgical specialties to a specific OR time block, a day and a room, for a weekly planning horizon. In this research it was decided to exchange with specialists within the specialism general surgery.

This research uses the Patient Flow Forecasting (PFF). This tool, developed by Rhythm, makes a forecast of the bed demand. For every block, the tool will count how many times (e.g. over the period 1st of February 2018 until April 30, 2019) *k* patients were operated $k \in \{0,1, \dots\}$. With this, we can determine an empirical discrete distribution. The same will be conducted for the length of stay of these patients. Since empirical discrete distributions cannot be added up, convolutions will be used.

Within HOH, the specialists have a fixed day to perform surgeries. In many cases this planning is not adhered to. Therefore, two separate datasets have been created and the analysis is conducted for the realization and the plan of HOH. The realization is what happened in practice, for the plan we assume that the planned sessions for specialist X are conducted by specialist X.

For the analysis of the realization, three datasets have been made of the 1st of February 2018 until April 30, 2019. Ultimately dataset R-3 is used for the analysis of the current situation, this dataset included all surgeries which were only conducted in the morning sessions and the afternoon sessions and which were planned for general surgery. With this final dataset the exchanges between specialists can be made. The dataset for the plan of HOH consists of one dataset (P-1), where the exchanges between specialists can be made. In P-1 the data of 1st of February 2019 until April 30, 2019 is used. In this dataset the plan is made for the specialism general surgery which includes all surgeries conducted in the morning sessions and afternoon sessions, and which were planned for general surgery.



Summary figure 1 Overview of the bed occupancy for ward B4 (n=2,290, OR system HOH, 2018-2019)

Results

For both categories (realization and plan), the current situation is shown with three intervention options. The various options have been loaded into PFF and they are compared to the current situation. This research focused on the best intervention option. The three intervention options are listed below, these options are the same for the realization and the plan:

Option 1: General surgery E (Monday) exchange with General surgery C (Thursday).

Option 2: General surgery A (Monday) exchange with General surgery C (Thursday).

Option 3: Move General surgery A from Monday to Friday

Realization

The data which is used for the analysis of the realization is very small and cannot be optimally exchanged with specialists. Looking at the current situation and the three intervention options that were analyzed, the current situation will not be optimized. There is still an off-peak load during the weekends. The differences in beds between the peaks and off-peak loads for those options are three, four, and five beds. To compare the current situation and the three intervention options, the 5% and 95% quantiles (respectively the Lower Control Limit (LCL) and the Upper Control Limit (UCL)) of the distribution of the bed occupancy for the current situation and the intervention options are calculated.

Intervention option 3 is the best option compared to intervention option 1 and intervention option 2 since this option is the only option that shows a smaller bandwidth compared to the current situation. There is not enough difference between the current situation and intervention option 3 to apply this intervention in practice. Summary table 1 gives an overview of the differences in bed occupancy between the peaks and off-peak loads, LCL, UCL, and the bandwidth of the distribution of the bed occupancy of all options.

Summary table 1 Overview of the differences in bed occupancy, LCL, UCL, and the bandwidth of the distribution of the bed occupancy of all options

	Differences in bed occupancy	LCL	UCL	Bandwidth
Current situation	3 and 4	4.39	10.95	6.56
Intervention option 1	3, 4, and 5	3.84	10.48	6.64
Intervention option 2	3 and 4	4.14	11.10	6.96
Intervention option 3	3, 4, and 5	4.56	10.88	6.32

Plan

This research has shown that the surgeries that are planned for general surgery are not always performed within general surgery. In this case we assume that the planned sessions for specialist X are conducted by specialist X. MSS intervention option 3 has the best distribution of beds, especially during the week. There is still an off-peak load during the weekends. The differences in bed occupancy between the peak and off-peak load for MSS intervention option 3 is five and six beds. The differences in bed occupancy between the peak and off-peak load for the MSS current situation, MSS intervention option 2, and MSS intervention option 3 is seven, eight, and nine beds. To compare the MSS current situation and the three MSS intervention options, the 5% and 95% quantiles (respectively the Lower Control Limit (LCL) and the Upper Control Limit (UCL)) of the distribution of the bed occupancy for the MSS current situation and the MSS intervention options are calculated.

MSS intervention option 3 is the best option compared to MSS intervention option 1 and MSS intervention option 2 since this option is the only option that shows a smaller bandwidth compared to the MSS current situation. There is a difference of two beds between MSS intervention option 3 and MSS current situation. Summary table 2 gives an overview of the differences in bed occupancy between the peaks and off-peak loads, LCL, UCL, and the bandwidth of the distribution of the bed occupancy of all MSS options.

Summary table 2 Overview of the differences in bed occupancy, LCL, UCL, and the bandwidth of the distribution of the bed occupancy of all MSS options

	Differences in bed occupancy	LCL	UCL	Bandwidth
MSS current situation	7 and 8	13.97	23.29	9.32
MSS intervention option 1	8 and 9	14.02	23.22	9.20
MSS intervention option 2	7 and 8	14.14	23.26	9.12
MSS intervention option 3	5 and 6	14.95	22.31	7.36

MSS intervention option 3 has been worked out in an MSS (see Summary figure 2). This is the best intervention option for the specialism general surgery within HOH.

		OR 1	OR 2	OR 3	OR 4	OR 5	OR 6
Monday	7:30-11:00			General surgery F	General surgery E		
Monday	11:00-14:30			General surgery F	General surgery E		
Tuesday	7:30-11:00	General surgery D					
Tuesday	11:00-14:30	General surgery D					
Wednesday	7:30-11:00				General surgery B		
Wednesday	11:00-14:30				General surgery B		
Thursday	7:30-11:00			General surgery C			
Thursday	11:00-14:30			General surgery C			
Friday	7:30-11:00	General surgery A					
Friday	11:00-14:30	General surgery A					Observer general surgery A

		OR 1	OR 2	OR 3	OR 4	OR 5	OR 6
Monday	7:30-11:00			General surgery F	General surgery E		
Monday	11:00-14:30			General surgery F	General surgery E		
Tuesday	7:30-11:00	General surgery D					
Tuesday	11:00-14:30	General surgery D					
Wednesday	7:30-11:00				General surgery B		
Wednesday	11:00-14:30				General surgery B		
Thursday	7:30-11:00			General surgery C			
Thursday	11:00-14:30			General surgery C			
Friday	7:30-11:00	General surgery A					General surgery D
Friday	11:00-14:30	General surgery A					General surgery B

Summary figure 2 Best intervention option MSS for the specialism general surgery within HOH

A step-by-step plan is created when HOH wants to exchange specialists of the aforementioned options. We suggest a step-by-step plan that contains the following main steps:

1. The OR committee should create a roadmap
2. Involve specialists and OR personnel
3. Implementation OR session planning
4. Evaluate the changes

Further research

Master Surgery Schedule: Our main recommendation is to implement an MSS. Currently, HOH does not use an MSS. To create more insight and order, an MSS would improve the OR session planning for the specialism general surgery. For optimizing this OR session planning, HOH should use and implement MSS option 3.

Master Surgery Schedule implementing within HOH: This research has shown that general surgery deviates a lot from the OR session planning. Before HOH wants to implement a change, it will first have to be examined why people deviate so much and if it is worth implementing an MSS within HOH.

Master Surgery Schedule all specialists: Furthermore, it would be optimal if specialists from all specialisms are examined and that for the best option an MSS would create. This research has only focused at the specialism general surgery, but a change in another specialism may also give a better outcome in the demand for beds.

Managementsamenvatting (Dutch)

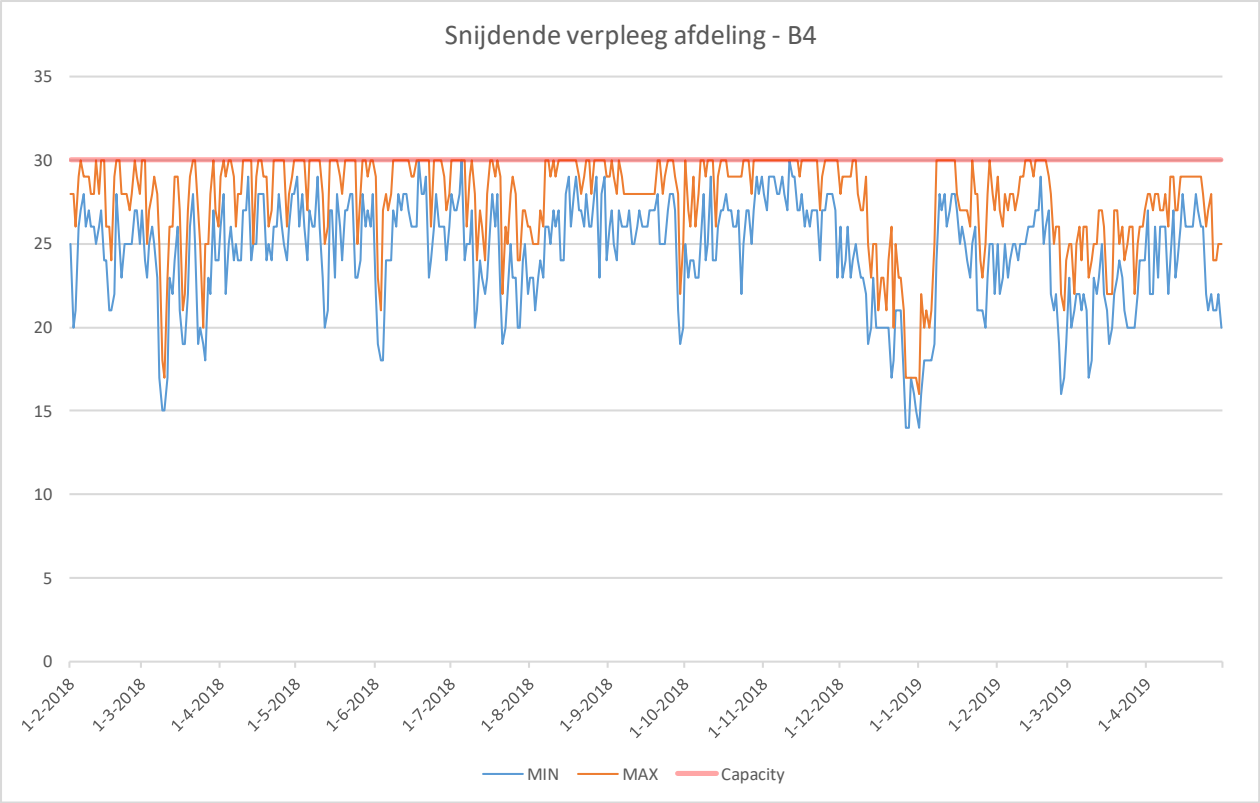
Aanleiding & doel van het onderzoek

Naar aanleiding van het onderzoek van Andringa (2018) is naar voren gekomen dat de OK-sessie planning niet optimaal is. Een gevolg van de suboptimale OK-sessie planning binnen het Dr. Horacio E. Oduber hospital (HOH) is dat er op bepaalde dagen een piek in de vraag naar bedden is op de snijdende verpleegafdeling. Een data-analyse, die onderdeel uitmaakt van dit onderzoek, toont aan dat er voor beide snijdende afdelingen (snijdend 3 en B4) een piek in beddenvraag is aan het begin van de week en een dal-bezetting van de bedden in het weekend. Er is een onderzoek uitgevoerd binnen het specialisme algemene chirurgie om te analyseren of het mogelijk is om de OK-sessie planning te optimaliseren zodat er een betere spreiding is van de bedden gedurende de week. Daarbij komen we bij het volgende onderzoeksdoel uit:

Een aanbeveling geven voor het optimaliseren van de OK-sessie planning binnen HOH, zodat de piek in beddenvraag op de snijdende verpleegafdelingen wordt verminderd.

Onderzoeksmethode

Voor het schrijven van dit onderzoek is gebruik gemaakt van het Algemene Bedrijfskundige Probleemaanpak. Samenvatting figuur 1 geeft een overzicht van de bedbezetting voor afdeling B4. De huidige organisatie van de OK-planning van HOH wordt uitgelegd met behulp van concepten die bekend zijn uit de literatuur. Verder wordt er een literatuurstudie uitgevoerd om te zoeken naar mogelijke interventies die te gebruiken zijn voor het optimaliseren van de OK-sessie planning. Voor het optimaliseren van de OK- sessie planning voor dit onderzoek is er gekozen voor een Master Surgery Schedule (MSS). Een MSS wijst specialismen of specialisten toe voor een specifiek OK-tijdblok, een dag en een kamer, voor een wekelijkse planningshorizon. In dit onderzoek is er gekozen om te wisselen met specialisten binnen het specialisme algemene chirurgie.



Samenvatting figuur 1 Overzicht van de bedbezetting voor afdeling B4 (n=2290, OR system HOH, 2018-2019)

Voor dit onderzoek is gebruik gemaakt van de Patient Flow Forecasting (PFF). Deze tool is ontwikkeld door Rhythm en kan de beddenvraag voorspellen. Voor elk blok telt PFF hoe vaak k patiënten werden geopereerd $k \in \{0,1, \dots\}$. Hiermee kan een empirische discrete kansverdeling bepaald worden. Hetzelfde zal worden uitgevoerd voor de ligduur van deze patiënten. Aangezien kansverdelingen niet bij elkaar opgeteld kunnen worden, wordt er gebruik gemaakt van convoluties.

Specialisten die werkzaam zijn bij het HOH hebben een vaste dag om operaties uit te voeren. In veel gevallen wordt er niet aan deze planning gehouden. Daarom zijn er twee verschillende datasets gemaakt en wordt de analyse uitgevoerd voor de realisatie en het plan van HOH. De realisatie is gebaseerd op wat er in de praktijk is uitgevoerd, bij het plan nemen we aan dat de geplande sessies voor specialist X ook worden uitgevoerd door specialist X.

Voor de analyse van de realisatie zijn er drie datasets gemaakt van 1 februari 2018 tot en met 30 april 2019. Uiteindelijk is dataset R-3 gebruikt voor de analyse van de huidige situatie.

Dataset R-3 omvat alle operaties die in de ochtend- en middagsessie zijn uitgevoerd door algemene chirurgie en gepland waren voor algemene chirurgie. Uiteindelijk kan er met deze dataset gewisseld worden tussen de specialisten. De dataset voor het plan bestaat uit één dataset (P-1), hierin kunnen de wisselingen uitgevoerd worden tussen de specialisten. In P-1 worden de gegevens van 1 februari 2019 tot en met 30 april 2019 gebruikt. Deze dataset omvat alle operaties die in de ochtend- en middagsessie zijn uitgevoerd door algemene chirurgie en gepland waren voor algemene chirurgie.

Resultaten

Voor beide categorieën (realisatie en plan) wordt de huidige situatie weergegeven met drie interventie opties. De verschillende opties zijn ingeladen in PFF en vergeleken met de huidige situatie. Dit onderzoek richt zich op de beste interventie optie. De drie interventie opties staan hieronder vermeld, deze opties zijn hetzelfde voor de realisatie en het plan:

Optie 1: Wisseling van Algemene chirurgie E (maandag) met Algemene chirurgie C (donderdag)

Optie 2: Wisseling van Algemene chirurgie A (maandag) met Algemene chirurgie C (donderdag)

Optie 3: Verplaatsing van Algemene chirurgie A van maandag naar vrijdag

Realisatie

Er zijn uiteindelijk weinig gegevens gebruikt voor de analyse van de realisatie, hierdoor kan er niet optimaal gewisseld worden met specialisten. Kijkend naar de huidige situatie en de drie interventie opties, zal de huidige situatie niet geoptimaliseerd kunnen worden. Er is nog steeds een dal-bezetting van de bedden in het weekend. De verschillen in bedden tussen de pieken en de dal-bezetting voor de opties zijn drie, vier en vijf bedden. Om de huidige situatie en de drie interventie opties te vergelijken, zijn de 5% en 95% kwantielen (respectievelijk de onderste controlelimiet (LCL) en de bovenste controlelimiet (UCL)) van de verdeling van de bedbezetting voor de huidige situatie en de interventie opties berekend.

Interventie optie 3 is de beste optie vergeleken met interventie optie 1 en interventie optie 2, omdat deze optie de enige optie is die een smallere bandbreedte heeft dan de huidige situatie.

Er is onvoldoende verschil tussen de huidige situatie en interventie optie 3 om deze interventie toe te passen in de praktijk. Samenvatting tabel 1 geeft een overzicht van de verschillen in bedbezetting tussen de pieken en dal-bezetting, LCL, UCL en de bandbreedte van de bedbezetting van alle opties.

Samenvatting tabel 1 Overzicht van de verschillen in bedbezetting, LCL, UCL en de bandbreedte van alle opties

	Verschil in bedbezetting	**LCL**	**UCL**	**Bandbreedte**
Huidige situatie	3 en 4	4,39	10,95	6,56
Interventie optie1	3, 4 en 5	3,84	10,48	6,64
Interventie optie 2	3 en 4	4,14	11,10	6,96
Interventie optie 3	3, 4 en 5	4,56	10,88	6,32

Plan

Dit onderzoek heeft aangetoond dat de operaties die gepland staan voor algemene chirurgie niet altijd worden uitgevoerd door algemene chirurgie. In dit geval nemen we aan dat de geplande sessies voor specialist X uitgevoerd worden door specialist X. MSS-interventie optie 3 heeft de beste verdeling van de bedden, vooral gedurende de week. Er is nog steeds een dal-bezetting tijdens het weekend. Het verschil in bedden tussen de piek en dal-bezetting voor MSS-interventie optie 3 is vijf en zes bedden. Het verschil in bedden tussen de piek en dal-bezetting voor MSS huidige situatie, MSS-interventie optie 1 en MSS-interventie optie 2 is zeven en acht bedden. Om de huidige situatie en de drie interventie opties te vergelijken, zijn de 5% en 95% kwantielen (respectievelijk de onderste controlelimiet (LCL) en de bovenste controlelimiet (UCL)) van de verdeling van de bedbezetting voor de huidige situatie en de interventie opties berekend.

MSS-interventie optie 3 is de beste optie vergeleken met interventie optie 1 en interventie optie 2, omdat deze optie de enige optie is die een smallere bandbreedte heeft dan de huidige situatie. Er is een verschil van 2 bedden tussen deze twee opties. Samenvatting tabel 2 geeft een overzicht van de verschillen in bedbezetting tussen de pieken en dal-bezetting, LCL, UCL en de bandbreedte van de bedbezetting van alle MSS-opties.

Samenvatting tabel 2 Overzicht van de verschillen in bedbezetting, LCL, UCL en de bandbreedte van alle MSS-opties

	Verschil in bedbezetting	**LCL**	**UCL**	**Bandbreedte**
MSS huidige situatie	7 en 8	13,97	23,29	9,32
MSS-interventie optie 1	8 en 9	14,02	23,22	9,20
MSS-interventie optie 2	7 en 8	14,14	23,26	9,12
MSS-interventie optie 3	5 en 6	14,95	22,31	7,36

MSS-interventie optie 3 is uitgewerkt in een MSS (zie Samenvatting figuur 2). Dit is de beste interventie optie voor het specialisme algemene chirurgie binnen HOH.

		OR 1	OR 2	OR 3	OR 4	OR 5	OR 6
Monday	7:30-11:00			General surgery F	General surgery E		
Monday	11:00-14:30			General surgery F	General surgery E		
Tuesday	7:30-11:00	General surgery D					
Tuesday	11:00-14:30	General surgery D					
Wednesday	7:30-11:00				General surgery B		
Wednesday	11:00-14:30				General surgery B		
Thursday	7:30-11:00			General surgery C			
Thursday	11:00-14:30			General surgery C			
Friday	7:30-11:00	General surgery A					
Friday	11:00-14:30	General surgery A					Observer general surgery A

		OR 1	OR 2	OR 3	OR 4	OR 5	OR 6
Monday	7:30-11:00			General surgery F	General surgery E		
Monday	11:00-14:30			General surgery F	General surgery E		
Tuesday	7:30-11:00	General surgery D					
Tuesday	11:00-14:30	General surgery D					
Wednesday	7:30-11:00				General surgery B		
Wednesday	11:00-14:30				General surgery B		
Thursday	7:30-11:00			General surgery C			
Thursday	11:00-14:30			General surgery C			
Friday	7:30-11:00	General surgery A					General surgery D
Friday	11:00-14:30	General surgery A					General surgery B

Samenvatting figuur 2 Beste interventie optie MSS voor het specialisme algemene chirurgie binnen HOH

Er is een stappenplan geschreven voor HOH wanneer zij bovengenoemde opties willen implementeren binnen het ziekenhuis. Onze stappenplan bevat de volgende hoofdstappen:

1. De OK-commissie zou een stappenplan moeten opstellen
2. Specialisten en OK-personeel betrekken bij het plan
3. Implementeren van de OK-sessie planning
4. Evalueren van de veranderingen

Vervolgonderzoek

Master Surgery Schedule: Onze belangrijkste aanbeveling is om een MSS te implementeren. Momenteel gebruikt HOH geen MSS. Om meer orde en inzicht te creëren zou een MSS de OK-sessie planning voor algemene chirurgie kunnen verbeteren. Voor het optimaliseren van de OK-sessie planning zou het HOH MSS-interventie optie 3 kunnen gebruiken en implementeren.

Master Surgery Schedule implementeren binnen HOH: Dit onderzoek heeft aangetoond dat algemene chirurgie veel afwijkt van de OK-sessie planning. Voordat HOH een wijziging wil implementeren zal er eerst onderzocht moeten worden waarom de specialisten van algemene chirurgie zoveel afwijken en of het de moeite waard is om een MSS binnen HOH te implementeren.

Master Surgery Schedule van alle specialisten: Daarnaast zou het optimaal zijn als alle specialisten van alle specialismen worden onderzocht en dat daar een beste MSS voor gecreëerd zou worden. Dit onderzoek heeft zich namelijk alleen gericht op het specialisme algemene chirurgie, maar een wisseling bij een andere specialist/specialisme kan ook van invloed zijn op de beddenvraag.

Preface

In front of you lies my master thesis. This thesis is my final step in finishing my master Health Sciences within the track “Optimization of Healthcare Processes” at the University of Twente.

After working for 5 years as a podiatrist, I quitted my job in June 2017. Thereafter, I started in September with the pre-master Gezondheidswetenschappen at the University of Twente. It was a great period in which I have learned a lot and met many nice people. For now, I am glad that 2 years after quitting my job I can finally present you the results of my master thesis.

I want to thank the dr. Horacio E. Oduber Hospitaal (HOH) for giving me the opportunity to perform my master thesis at Aruba and providing me with an inside look in the hospital. I would like to give a special thanks to my supervisor Stefan Lucas from HOH. Stefan helped me during the skype meetings and thereafter. I would also give a special thanks to Ricardo Dekker, he helped me a lot with the data I needed for this research. I loved the period in Aruba, and it was a great experience, which I would not want to have missed.

Furthermore, I want to thank my first supervisor from the University of Twente, Erwin Hans, for his guidance and enthusiasm. The meetings at school and calls via Skype were always supportive and valuable. I also want to thank my second supervisor from the University of Twente, Karin Groothuis, for her advice during this research. And last, but not least, I would like to thank Stephan Bras for his feedback and support from Rhythm during the weekly Skype sessions.

I hope you enjoy your reading!

Anneloes Herink

Enschede, July 2019

Table of Contents

List of Abbreviations

AZV (Algemene Ziektekosten Verzekering)	Basic insurance (health insurance)
Closed bed	A bed that is physically there but there are no personnel scheduled to support it
CSSD (Central Sterile Supply Department)	Sterile department
Designated ward	The intended ward for a patient
Elective patient	Scheduled patient requiring non-urgent care
ED (Emergency Department)	A medical treatment facility specializing in emergency medicine
Emergency patient	Unscheduled patient requiring urgent care
Electronic Medical Record (EMR)	A software application in which medical record data of the patient is stored in digital form and made available
FCFS (First Come First Serve) policy	The first patient will be served first
FIN (Financial Identification Number)	A patient gets a unique number for every hospitalization at the hospital
HOH	Dr. Horacio E. Oduber Hospital
Inpatient	A patient admitted to one of the wards in the hospital
Intake	The moment a patient arrives at the hospital on the day of the treatment/surgery
LEPT (Longest Expected Processing Times)	The scheduling algorithm in which the longest expected duration is scheduled first

LOS (Length of Stay)	The amount of time (days/hours) a patient occupies a bed
MRN (Medical Record Number)	Every patient has a unique MRN
MRSA (Methicillin-Resistant Staphylococcus Aureus)	A bacterium
MSS (Master Surgery Schedule)	The schedule assigning blocks in a specific OR to a specific specialty
Opened bed	A bed for which supporting personnel is scheduled on wards
OR (Operating Room)	The room equipped for performing surgeries. The medical equipment available differs per OR
OR schedule	The schedule assigning patients, specialists, staff, and equipment to an operating room
Outpatient	A patient that is not admitted to one of the wards in the hospital
PACU (Post Anesthesia Care Unit)	A unit designed to provide care for patients recovering from general anesthesia, regional anesthesia, or local anesthesia
PFF (Patient Flow Forecasting)	A tool which is used for the analysis, created by Rhythm
POS (Pre-Operative Screening)	Screening for patients before they are getting scheduled for surgery
SA (Simulated Annealing)	An effective local search to optimize the OR schedule

SEPT (Shortest Expected Processing Time)	The scheduling algorithm in which the shortest expected duration is scheduled first
Ward	A facility inside a hospital that is dedicated to the care of inpatients of a specific medical specialty

1 Introduction

This research is conducted at the Horacio E. Oduber Hospital in Aruba to derive recommendations for optimizing the OR session planning such that the peaks in bed demand at the surgical nursing wards can be decreased. This chapter describes the research context (Section 1.1), problem description (Section 1.2), research objective (Section 1.3), scope (Section 1.4), and the research questions (Section 1.5).

1.1 Research context: Dr. Horacio E. Oduber Hospital

In 1977, the Dr. Horacio E. Oduber Hospital (HOH) was founded in Aruba. Aruba is an island in the Caribbean Sea, and it is part of the kingdom of the Netherlands. It has over 116,000 citizens and a surface of 180 square kilometers (CIA, 2018). The HOH is the only hospital on this island. There are more than 900 employees and about 70 medical specialists working in this hospital. Every year, approximately 10,000 patients are admitted in the hospital. Furthermore, the hospital has a capacity of six operating rooms (ORs), 172 nursing beds, and offers all major medical specialties such as Gynecology, Urology, and General Surgery. In the year 2014, HOH started the project 'Hunto Miho', which means 'better together'. With this project HOH wants to realize their ambition to become one of the best hospitals in the region (HOH, 2019).

1.2 Problem description

According to Andringa (2018) the OR session planning of HOH is suboptimal, i.e., the available OR capacity could be allocated better. Therefore, HOH can benefit from further research on optimizing the OR session planning. According to the managers of HOH the current OR session planning is full. When the hospital wants to hire more specialists, it is impossible for the specialists to get more OR time. HOH faces also large peaks in bed demand on certain days in the surgical nursing wards. This may be caused by the perceived suboptimal OR session planning. Peaks in bed demand may cause overflowing of these wards, which affects both the quality of care and the efficiency of the hospital. Therefore, it is very important to optimize the OR session planning to decrease the large peaks in bed demand.

1.3 Research objective

The objective of this research is:

To derive recommendations for optimizing the OR session planning within HOH such that the peaks in bed demand in the surgical nursing wards can be decreased.

This objective will be achieved by regulating the number of OR patients flowing into the surgical nursing wards and considering the length of stay of patients when scheduling elective surgical admissions.

1.4 Scope

This research focusses on the OR session planning within HOH and the patient flows through the admissions department, the ORs, and the surgical nursing wards (surgical 3 and B4). The scope of this research is defined as the elective surgical admission planning for the specialism general surgery within the OR session planning of HOH. Outside the scope of this research are operating materials and personnel. This research provides the hospital an intervention to address the problem with the OR session planning and thereby a decrease in the peaks in bed demand at the surgical nursing wards. We position this research in the healthcare planning and control framework of Hans, Van Houdenhoven & Hulshof (2012) at the tactical level of the resource capacity planning (Figure 1-1). The other levels (strategic, offline operational, online operational) of the resource capacity planning will be described shortly in Chapter 2.

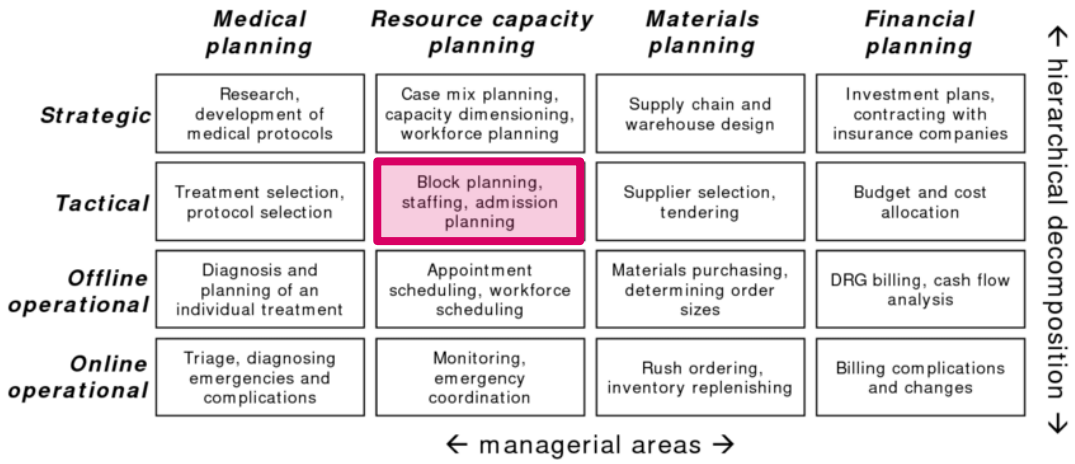


Figure 1-1 Healthcare planning and control framework, Hans et al. (2012)

1.5 Research questions

In order to fulfill the research objective, five research questions are defined.

1. What is the current influence of the OR session planning on the bed occupancy at the surgical nursing wards within HOH?

There are several influences of the OR session planning on the bed occupancy at the surgical nursing wards within HOH, we map these influences. Employees of several departments who are involved in the OR session planning are questioned. This question is answered in Chapter 2.

2. How is the current OR session planning of HOH organized?

The current OR session planning of HOH is explained using concepts known from literature. The OR scheduling system, advanced scheduling, allocation scheduling, and the OR policy is discussed. This question is answered in Chapter 3.

3. What are possible intervention options for the OR session planning within HOH?

A literature review is conducted to search for intervention options for HOH regarding the OR session planning. The literature of OR scheduling, options OR scheduling, and the recommended option will be discussed. This question is answered in Chapter 4.

4. What is the effect of the intervention for the peaks in bed demand at the surgical nursing wards within HOH?

The tool “Patient Flow Forecasting” created by Rhythm will be used to measure the effect of the intervention for the peaks in bed demand at the surgical nursing wards within HOH. The specialism general surgery will be analyzed. Within this specialism the specialists will be exchanged. This question is answered in Chapter 5.

5. What steps need to be taken by HOH to implement the most possible intervention option?

For HOH it is very important that this research results in a feasible solution. When HOH wants to implement the most possible intervention, an implementation plan is formulated in Chapter 6.

2 Context analysis

The current situation regarding the process, the OR, and the wards within HOH will be explained. This chapter describes the process description (Section 2.1), the healthcare planning and control framework (Section 2.2), planning and control - strategic level (Section 2.3), planning and control - tactical level (Section 2.4), planning and control - offline operational level (Section 2.5), planning and control - online operational level (Section 2.6), performance analysis (Section 2.7), and the conclusion (Section 2.8).

2.1 Process description

To understand the processes within HOH an overall view of the patient population (Section 2.1.1), the patient flow (Section 2.1.2), and the ward (Section 2.1.3) is given.

2.1.1 Patient population

Two important aspects for a patient, from a medical and logistical point of view, are the specialty type and the urgency level (Figure 2-1). On the specialty axis (the horizontal axis), a patient can require medical care or surgical care. On the urgency axis (the vertical axis), a patient can be admitted as an emergency patient or as an elective patient. This layout is important because it largely determines the flow of a patient leading up to the wards. In practice, it appears that emergency patients mostly need medical care and elective patients mostly need surgical care. Elective patients can be split up in clinical patients and day patients. Clinical patients are admitted to a clinical ward and usually stay one night or more. Day patients go to the day treatment and do not stay overnight.

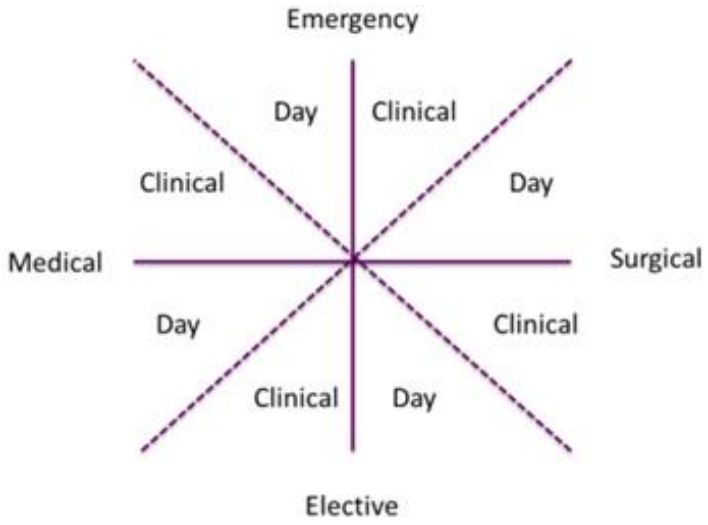


Figure 2-1 Aspects of patient types in the patient population (Glerum, 2014)

Since HOH is the only hospital on the island Aruba, it treats (almost) all patients. Data from 2017 and 2018 showed that around 10,000 patients underwent a surgery at HOH. The proportion elective versus emergency patients who had surgery in 2017 and 2018 is both 79% versus 21%. Figure 2-2 shows an overview of the elective versus emergency patients who had surgery in the year 2017 and 2018.

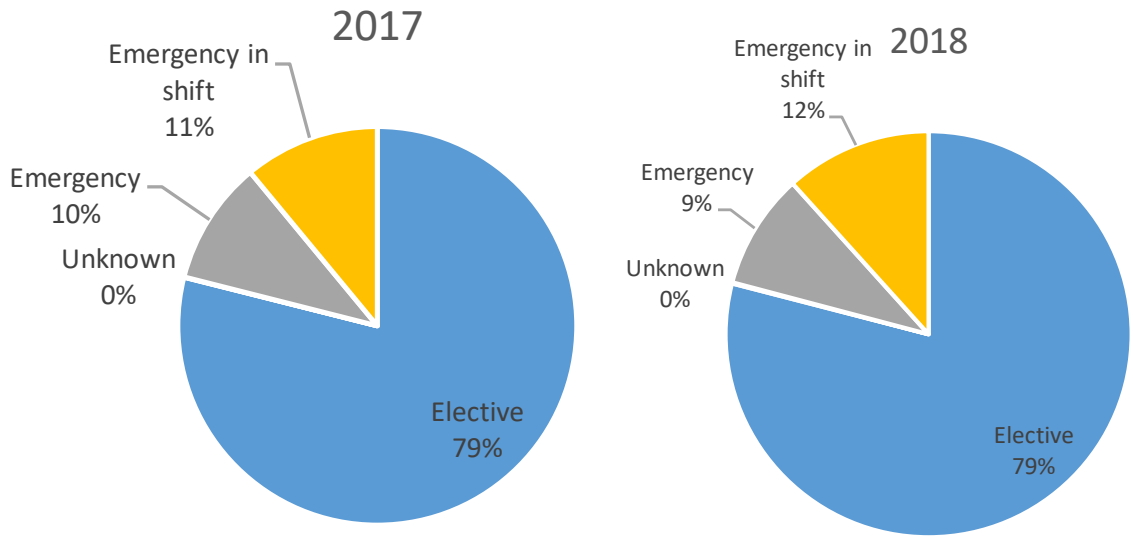


Figure 2-2 Overview elective versus emergency patients who had surgery within HOH (n=10,049, OR system HOH, 2017) (n=9,912, OR system HOH, 2018)

2.1.2 Patient flow

The patient flow through a hospital depends on the unique characteristics of the patient. Emergency patients usually enter the system through an emergency department. Elective patients usually enter the system through an outpatient clinic. All elective patients who have surgery visit the pre-operative screening and admission planners before surgery. Within HOH, in most cases the patients are placed in a bed the day before surgery. After surgery, patients always visit the recovery before arriving back at the ward. Figure 2-3 is a graphical representation of the different patient flows, where S = surgical specialty, and M = Medical specialty.

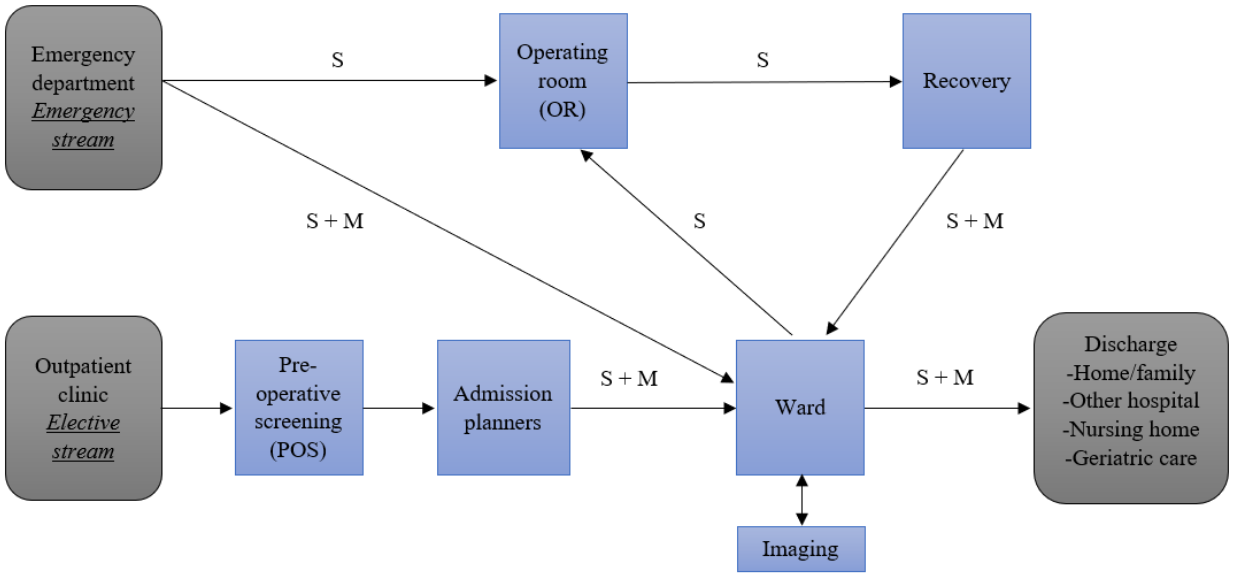


Figure 2-3 Patient flow through the system within HOH (S=Surgical specialty, M=Medical specialty)

2.1.3 Ward

HOH has six nursing wards which includes two surgical nursing wards, and it has four specialist wards. Table 2-1 gives an overview of the wards. The two surgical nursing wards have a capacity of 63 beds. HOH does not count the beds of the specialist wards as nursing beds.

Table 2-1 Overview wards HOH

Wards		**Capacity of beds**
Nursing wards	B3	30
	Non-surgical 2	33
	Non-surgical 4	23
	Day surgery	14
Surgical nursing wards	Surgical 3	33
	B4	30
Specialist wards	Neonatal & pediatrics	6 & 6
	Maternity & obstetrics	13 & 2
	Emergency room	10
	Intensive care	10

There is a difference between 'opened' beds and 'closed' beds. A bed is open when it is staffed, which means that personnel is scheduled to attend that bed. A bed is closed when the bed is physically present but is not staffed. In this research beds refer to 'opened' beds.

Inflow of the wards: When a patient leaves the OR, it almost always needs a bed on a specific ward. This is the patient 'designated ward'. On the day of surgery (or the day before surgery) a patient can be assigned to a bed. From this moment, the bed is no longer available for other patients. The hospital has control over the inflow of elective patients through the admission planning, the surgeon scheduling, and the bed planning.

Outflow of the wards: When a patient is discharged, the patient leaves the bed and the ward. The time between the intake and the discharge is known as the length of stay (LOS) of these patients. The time of the discharge depends mostly on protocol and medical indicators.

2.2 Healthcare planning and control framework

The healthcare planning and control framework of Hans, van Houdenhoven & Hulshof (2012) will be used as a tool to map the planning and control decisions regarding the OR session planning within HOH. A short explanation of the healthcare planning and control framework is given in Appendix A.

The resource capacity planning on different hierarchical levels will be discussed in the upcoming sections (the strategic level (Section 2.3), tactical level (Section 2.4), offline operational level (Section 2.5), and online operational level (Section 2.6)). Since this research focusses on the tactical level of the resource capacity planning, this level will be described in detail. The other levels of the resource capacity will be discussed shortly. The other three managerial areas fall outside the scope of this research.

2.3 Planning and control - strategic level

This section describes the planning and control decisions of HOH regarding the strategic level. The production agreement (Section 2.3.1), OR capacity (Section 2.3.2), specialties (Section 2.3.3), OR personnel (Section 2.3.4), OR committee (Section 2.3.5), and the capacity of beds (Section 2.3.6) will be discussed.

2.3.1 Production agreements

The Algemene Ziektekosten Verzekering (AZV) is a basic insurance (health insurance) that applies to every resident in Aruba. The role of the AZV is to implement the Landsverordening AZV. This means that medical expenses (e.g. general practitioner, specialist, physiotherapy, dentist, and hospital admission) are reimbursed for everyone who is registered as a resident of Aruba. AZV is cooperating with all the aforementioned care providers.

There are contracts between the AZV and the care providers that specify the reimbursements for the services they perform with their patient. The AZV also have agreements with HOH and with the independent specialists individually about their budget and yearly amount of treatments (Andringa, 2018; Groenveld, 2018).

2.3.2 OR capacity

HOH has six ORs, the sizes of the ORs are between 26.5m^2 and 41m^2. In 2021, when the rebuilding is finished, the sizes of the ORs will be between 32m^2 and 43m^2. A short explanation of the specialties per OR is given:

- OR1: Neurosurgery, general surgery, and gynecology.
- OR2: Ear Nose Throat (ENT), and gynecology.
- OR3: Urology, general surgery, and pain treatment.
- OR4: General surgery, trauma, and plastic surgery.
- OR5: Orthopedic and urology.
- OR6: Ophthalmology, plastic surgery, and general surgery.

All the ORs can serve as an emergency room. OR6 is an outpatient OR, the smallest elective surgeries take place in this OR. Figure 2-4 shows an overview of the OR complex within HOH.

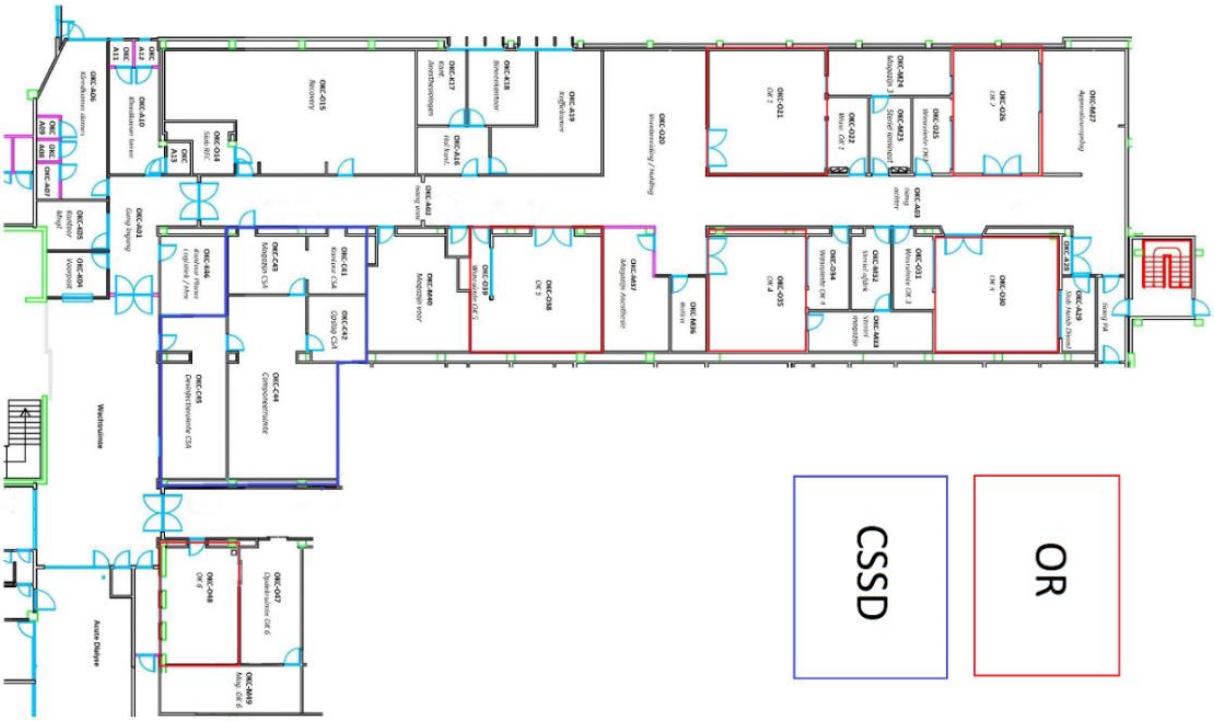


Figure 2-4 OR complex HOH

During an OR day, the personnel and performing specialists need to be present at 7:00 a.m. They can prepare so that the first surgery can start at 7:30 a.m., which is the beginning of the OR session. The end of the OR session is at 2:30 p.m., the end of the working day is at 3:00 p.m. In this way they have time to finish some activities and change clothes. During the day, the personnel and performing specialists have two lunchbreaks of 15 minutes. This is between the surgeries and the OR team decides when these lunchbreaks take place. Sometimes, two sessions are planned on one OR day. In this case the OR day is split up between a morning session and an afternoon session.

The morning session starts at 7:30 a.m. and ends at 11:00 a.m. The afternoon session starts at 11:00 a.m. and ends at 2:30 p.m. Both sessions consist of 210 minutes. Concluding: an OR day has a capacity of 390 minutes in total. Table 2-2 shows a summary of the OR capacity.

Table 2-2 Summary OR capacity HOH

Period	**From**	**To**	**Total (minutes)**
OR day	7:00 a.m.	3:00 p.m.	480
OR session	7:30 a.m.	2:30 p.m.	420
Morning session	7:30 a.m.	11:00 a.m.	210
Lunchbreak	Between surgeries		30 (2*15)
Afternoon session	11:00 a.m.	2:30 p.m.	210
OR capacity			420 – 30 = 390

2.3.3 Specialties

HOH has several specialties who use the OR capacity. Table 2-3 shows a summary of the specialists using the OR capacity. Per specialty the number of specialists is indicated. Most specialists are independent, except for four gynecologists and two urologists. These six specialists are in pay of HOH. The pain treatment is performed by a neurologist.

Table 2-3 Specialties using the OR capacity within HOH

Specialties	Number of specialists
General surgery	6
Neurosurgery	1
Cardiology	2
Gynecology	5
Plastic surgery	2
Ear, Nose, Throat (ENT)	2
Orthopedics	4
Urology	3
Ophthalmology	3
Pain treatment	1

2.3.4 OR personnel

Next to the specialists mentioned before, other OR personnel are needed. Table 2-4 gives an indication of the OR personnel. These are all employed by HOH. Per function the number of employees is indicated.

Table 2-4 OR personnel HOH

Function	Number of employees
Surgery assistant	33
Anesthetist	5
Anesthesia assistant	11
Secretariat	4
Central Sterile Supply Department (CSSD)	9
Recovery	4
OR management	2

2.3.5 OR committee

HOH has an OR committee. This committee makes decisions of different hierarchical levels regarding the OR complex. The OR committee represents all stakeholders of the OR. The goal of this committee is to treasure the quality and quantity of the services within the OR complex. Table 2-5 shows the members of the OR committee.

Table 2-5 Members OR committee HOH

Members OR committee	
Cluster manager	General surgeon
OR manager	Plastic surgeon
OR manager assistant	Anesthetist
Orthopedic surgeon	Anesthesia assistant

2.3.6 Capacity of beds

Normally, HOH has six nursing wards and a capacity of 172 beds. Nowadays, the capacity of beds is 148. The reason that there are temporarily 148 beds is because of the rebuilding of the hospital. In 2021, when the rebuilding is finished, the nursing bed capacity will be 172 again. The capacity of beds of the wards is given in Table 2-1.

2.4 Planning and control - tactical level

This section describes the tactical decisions of HOH concerning the OR session planning. The OR session planning (Section 2.4.1), influences departments on the OR session planning (Section 2.4.2), capacity for emergency surgeries (Section 2.4.3), personnel staffing (Section 2.4.4), and the bottleneck tactical level (Section 2.4.5) will be discussed.

2.4.1 OR session planning

The OR session planning of HOH is based on the OR session planning of the previous year. In the OR session planning, every specialist has one fixed session per week. There are a few exceptions, one example is the neurosurgical surgeon who has one extra session every two weeks.

Besides fixed sessions, there are flex sessions in the OR session planning. These flex sessions are not dedicated to a specialist, which means multiple specialists can make use of the same session. When a specialist wants to make use of the flex session outside the regular OR session, he/she can send a request to the OR planner. When a specialist is absent during his/her OR session, the session becomes a flex session. Figure 2-5 shows an example of the current OR session planning of HOH.

OCTOBER 2018							
Week 42		**OR 1**	**OR 2**	**OR 3**	**OR 4**	**OR 5**	**OR 6**
Monday	7:30-11:00	General surgery	Gynecologie	General surgery	General surgery	Orthopedics	Ophthalmology
15/10/2018	11:00-14:30	General surgery	Gynecologie	General surgery	General surgery	**Emergency**	Ophthalmology
Tuesday	7:30-11:00	General surgery	ENT	Urology	Plastic surgery	Orthopedics	Ophthalmology
16/10/2018	11:00-14:30	General surgery	ENT	Urology	Plastic surgery	**Emergency**	Ophthalmology
Wednesday	7:30-11:00	General surgery	Gynecologie	Urology	General surgery	Orthopedics	Ophthalmology
17/10/2018	11:00-14:30	General surgery	Gynecologie	Urology	General surgery	**Emergency**	Ophthalmology
Thursday	7:30-11:00	Gynecologie	**ENT**	General surgery	Plastic surgery	Orthopedics	Ophthalmology
18/10/2018	11:00-14:30	Gynecologie	**ENT**	General surgery	Plastic surgery	**Emergency**	Ophthalmology
Friday	7:30-11:00	**FLEX**	Gynecologie	Pain treatment	General surgery	**Orthopedics**	Plastic surgery
19/10/2018	11:00-14:30	**FLEX**	Gynecologie	Pain treatment	General surgery	**Emergency**	General surgery
OCTOBER 2018							
Week 43		**OR 1**	**OR 2**	**OR 3**	**OR 4**	**OR 5**	**OR 6**
Monday	7:30-11:00	General surgery	Gynecologie	General surgery	General surgery	Orthopedics	Ophthalmology
22/10/2018	11:00-14:30	**Emergency**	Gynecologie	General surgery	General surgery	Orthopedics	Ophthalmology
Tuesday	7:30-11:00	General surgery	ENT	Urology	Plastic surgery	Orthopedics	Ophthalmology
23/10/2018	11:00-14:30	**Emergency**	ENT	Urology	Plastic surgery	Orthopedics	Ophthalmology
Wednesday	7:30-11:00	FLEX	Gynecologie	Urology	General surgery	Orthopedics	Ophthalmology
24/10/2018	11:00-14:30	**Emergency**	Gynecologie	Urology	General surgery	Orthopedics	Ophthalmology
Thursday	7:30-11:00	Gynecologie	ENT	General surgery	General surgery	Orthopedics	Ophthalmology
25/10/2018	11:00-14:30	**Emergency**	ENT	General surgery	General surgery	Orthopedics	Ophthalmology
Friday	7:30-11:00	**General surgery**	Gynecologie	Pain treatment	Plastic surgery	**Orthopedics**	Plastic surgery
26/10/2018	11:00-14:30	**Emergency**	Gynecologie	Pain treatment	Plastic surgery	**Orthopedics**	General surgery

Figure 2-5 Example OR session planning HOH October 2018

2.4.2 Influences departments on the OR session planning

Outpatient clinic: When a patient needs to have surgery, the patient must make an appointment. The outpatient clinic does not make appointments and it cannot be checked in the system since the specialists schedule the surgeries themselves. In practice, many patients wait with making an appointment instead of making it immediately. This in turn has consequences for the pre-operative screening and ultimately the OR session planning (with the cancellation of the surgery as a result).

Pre-operative screening: All patients who must be scheduled for surgery have to undergo a screening; this is called a pre-operative screening (POS). A patient is referred from the consultation with the specialist to the screening and takes his/her personal data. Upon arrival, the personal data will be collected by the POS and an appointment will be scheduled. The patient is screened and checked to see if he/she is healthy enough for anesthesia. After completion, there will be a stamp on the papers with information: 'pre-good', or 'pre-op not good'.

If the POS is not completed, the relevant specialist will be contacted to agree on what needs to be done to be able to conduct surgery on the patient. An incomplete screening of a patient often requires additional insight from cardiologist (ECG), nephrologist (kidney specialist), or determining the blood result and blood group to be able to send the complete patient card to the admission for the planning of the procedure. In practice, when a patient needs to see a specialist for the check, the patient is often lost sight of at that moment. This has influences on the OR session planning.

Radiology: The radiology department provides imaging during operations. They need to know in advance how many patients will need imaging, to match the personnel. When there are not enough personnel, it has an influence on the OR session planning. In addition, they need to know how many hip and knee surgeries are conducted, for planning the control X-rays the next day.

Rehabilitation: The goal of HOH is to discharge all clinical patients between 9:00 a.m. and 10:15 a.m., in practice this is not always possible. In orthopedic patients, patients can only be discharged after they have received physiotherapy. The doctor of the ward must wait for the advice of the physiotherapist; until then the bed remains occupied.

2.4.3 Capacity for emergency surgeries

Up to and including June 2016, there was no OR capacity reserved for emergency surgeries. On the 4th of July 2016, the emergency OR was introduced within HOH. Every afternoon session, between 11:00 a.m. and 2:30 p.m., no elective surgeries are planned in one of the clinical ORs. In this way the capacity can be used for emergency surgeries. Figure 2-5 shows an example of the emergency sessions within the OR session planning.

Every week, one OR is available for emergency surgeries. When the emergency OR is not available before 11:00 a.m., or the emergency OR is occupied, the elective program still needs to be interrupted for emergency patients with a high urgency level.

2.4.4 Personnel staffing

Table 2-6 gives an overview of which a standard OR team consists of. There are three exceptions for a standard OR team. 1) Neurosurgery; this specialism has two surgery assistants instead of three. 2) Orthopedics; this specialism has four surgery assistants instead of three. 3) Outpatient surgeries (OR6); have two surgery assistants and no anesthetist.

Table 2-6 Standard OR team HOH

Standard OR team	Number of employees
Surgeon	1
Anesthetist	1
Surgery assistant	3
Anesthesia assistant	1

After the OR day (3:00 p.m.) there is a team available with the same composition as a standard OR team. This team is present for finishing the elective surgeries that overrun and for taking care of all emergency surgeries after 3:00 p.m. This team can go home when the last surgery is finished. However, after the team went home, it needs to be available until 7:00 a.m. for emergency surgeries. Besides this team, there is a back-up team for handling peak moments between 3:00 p.m. and 7:00 a.m.

2.4.5 Bottleneck tactical level

A bottleneck of the tactical level for surgical nursing ward (surgical 3) is the peak in bed demand at Thursday. The off-peak load of the bed demand is at Saturday and Sunday. A bottleneck of the tactical level for surgical nursing ward (B4) is the peak in bed demand at Thursday. The off-peak load of the bed demand is Saturday. A possible reason for the peak of bed demand at Thursday is that specialists wants to conduct surgery in the beginning of the week, their reason is that more beds are available at the beginning of the week and they do not want to discharge patients during

the weekend. At Thursday, you have some patients who still occupy a bed and you get new patients for a bed. Most people get discharged at Friday. The analysis of this data will be discussed in the performance analysis in Section 2.7.1.

2.5 Planning and control - offline operational level

This section describes the offline planning process of the elective surgeries within HOH. The three months up to three working days before OR day (Section 2.5.1), three working days up to 24 hours before OR day (Section 2.5.2), 24 hours before OR day (hospitalization day) (Section 2.5.3), OR day (Section 2.5.4), and the planning process elective surgeries (Section 2.5.5) will be discussed.

2.5.1 Three months up to three working days before OR day

The planning process for elective surgeries starts when the specialist decides that a patient need to have surgery after a visit in the outpatient clinic. The patient will be sent to the department and gets an indication for the date of surgery. Before surgery, all elective patients need to undergo a POS.

When there are no particularities, the nurse from the POS sends the patient to the admission department. The secretary creates a Financial Identification Number (FIN) for the patient and register the patient in Chipsoft.

A FIN is linked with a Medical Record Number (MRN) and is unique for every hospitalization. Every patient has one MRN but can have multiple FIN numbers. Chipsoft is the software program HOH uses for scheduling surgeries.

When there are particularities during the POS, the nurse consults the specialist. The specialist tells what needs to be done, so that the surgery still can take place.

2.5.2 Three working days up to 24 hours before OR day

Three working days (72 hours) before the day of surgery (OR day), the specialist needs to hand in a list of patients he/she wants to operate at the OR planner. In practice, not all specialists hand in their patient list in time.

If the OR planner received all lists, the patient cards will be picked up at the admission department. The completeness of the information will be checked, and missing information will be added.

When all information is gathered and complete, the OR planner calculates the length of the OR program with help of the program Chipsoft. In Chipsoft, every surgery has its own code. The expected duration of a surgery is calculated by taking the average of the last 25 surgeries of the same surgery type of the performing specialist. Outliers are excluded in this case.

The duration of the program should not exceed 390 minutes to prevent overtime, this is including the changeover times. The planned changeover time is 9 minutes per changeover for all surgeries, there are exceptions such as surgeries who take place in OR6. In that case, the planned changeover time is 6 minutes. When the duration of the program is too long, or there is space left in the duration of the program, the OR planner discusses with the specialist what to do.

If the duration of the program is acceptable, the OR planner sends the provisional program to all specialists in question and to the admission department. The deadline for sending the provisional program is two working days before the OR day at 12:00 p.m. In practice, this deadline is not always met.

For the sequence of the OR program, the OR planner consider the guidelines. Some surgeries must be planned first. The following surgeries are scheduled first, in order of priority: child patients, pregnant patients, patients with a metabolic disorder, and surgeries with the longest expected duration. The following surgeries are scheduled last: MRSA patients, and patients under local anesthesia.

2.5.3 24 hours before OR day (hospitalization day)

On the day preceding the OR day (hospitalization day), the bed consultation takes place at 9:15 a.m. During this consultation, the attendees (care managers of the nursing departments, hospitalization & discharge coordinator, and an employee of the admission department) discuss which patients are discharged so they know which beds are released.

The employee of the admission department informs which patients are going to be hospitalized. The attendees check whether there are enough beds available to hospitalize all patients on the OR program.

When there are not enough beds available the specialist checks if there are more patients that can be discharged. When there are still too few beds available, the specialist informs the OR planner which patient should be removed from the OR program. The admission department calls the patient with the information that the surgery is cancelled.

Hereafter, the admission department calls the clinical patients to inform them about their hospitalization. The goal of the admission department is to call these patients before 10:00 a.m., since these patients needs to be hospitalized at 12:00 p.m. When all clinical patients are informed, the patients for day surgery are called. According to the OR regulations, the patients for day surgery need to be called two working days before the OR day at 2:00 p.m. This is not possible when the provisional program is only 24 hours before the OR day available.

When patients cancel their surgery, the admission department reports this to the OR planner. The OR planner can inform the specialist(s). The specialist and the OR planner try to schedule other patients instead of the cancelled patients, this is only possible if they receive the cancellations in time. After the schedule is adjusted, the OR planner sends the final program to the specialist(s), the admission department, and the nursing department the day before the OR day at 12:00 p.m.

2.5.4 OR day

During the OR day, the specialists perform surgery on the patients that are scheduled on the OR program. Information about the surgery is stored in Chipsoft, such as timestamps of patients entering and leaving the OR, and surgery duration.

2.5.5 Planning process elective surgeries

A flowchart of the planning process of the elective surgeries within HOH is shown in Figure Appendix B- 1 (Groenveld, 2018).

2.6 Planning and control - online operational level

This section describes the online operational decisions of HOH for monitoring the process and reacting to unforeseen events. The emergency surgeries (Section 2.6.1), and the cancellations (Section 2.6.2) will be discussed.

2.6.1 Emergency surgeries

Within HOH, there are two subgroups in types of emergency. The first group consists of all emergency cases that are performed inside the OR day. These emergency cases are between 7:00 a.m. and 3:00 p.m. and are called 'emergency in OR day' ('spoed'). The second group consists of all emergency cases that are performed outside the OR day, weekend and holidays included. These emergency cases are called 'emergency in shift' ('spoed in dienst').

Most of the 'emergency in shift' cases take place in OR1 and OR5. These ORs are the largest and close to the entrance, which is easy to enter. HOH has four different priorities concerning emergency surgeries. Table 2-7 gives an overview of these four different priorities concerning emergency surgeries.

Table 2-7 Priorities concerning emergency surgeries within HOH

Urgency	**Subscription**	**Surgery**
Urgency A	Life-threatening	Surgery should start right away, with a maximum waiting time of two hours
Urgency B	Threatening irreversible condition	Surgery should start within two to six hours
Urgency C	Condition for which delaying the surgery can cause function damage	Surgery should start within 24 hours
Urgency D	Semi-urgent patients	Surgery should start within 72 hours

Emergencies during the OR day can cause delay, cancellations of elective surgeries, or overtime. Since the 4th of July 2016, HOH has an emergency OR which can be used during the afternoon sessions (see Section 2.4.3). The reason is to prevent interventions in the elective program.

2.6.2 Cancellations

In Section 2.5 the cancellations that appear when admissions call the patient are mentioned. These cancellations are known before the program is definitive. Sometimes there are cancellations that occur during the OR day, e.g. when a patient does not show up for hospitalization, or a patient is not sober. In this case the OR capacity which is reserved for the surgery cannot be used for that surgery. An option could be that the surgery which was initially scheduled after the cancelled surgery could be performed earlier. If this option is not possible, there is a gap in the schedule.

Another manner of cancellation a surgery is when the program overran, and the start of the surgery would be after 2:30 p.m. In that case, the specialist can put the patient on the request list and the OR planner tries to find an empty spot in another specialist's session to conduct the surgery. However, the usage of the request list is not mandatory, and it is up to the specialist if he/she wants to use this possibility.

2.7 Performance analysis

A performance analysis of the data is given, this will be used to give an overview of the peaks in bed demand per surgical nursing ward. Data of the 1st of February 2018 until April 30, 2019 is used for all the calculations. This section describes the overview of the bed occupancy (Section 2.7.1), occupancy of beds per specialism per day (Section 2.7.2), sessions per specialism per weekday (Section 2.7.3), amount of surgeries per session per specialism (Section 2.7.4), and the LOS of patients per specialism (Section 2.7.5).

2.7.1 Overview of the bed occupancy

An overview of the bed occupancies is given. A bed is occupied from the moment a patient is placed in a bed. The bed occupancy is given in an Excel file per hour per day. In this Excel file, the minimum and maximum bed occupancy is obtained by taking the minimum bed occupancy per day and the maximum bed occupancy per day. The maximum bed capacity of surgical 3 is 33 beds. The maximum bed capacity of B4 is 30 beds. Figure 2-6 gives an overview of the bed occupancy for the surgical nursing ward surgical 3.

Figure 2-7 gives an overview of the bed occupancy for the surgical nursing ward B4. These figures show the minimum and the maximum bed occupancy of the specific ward.

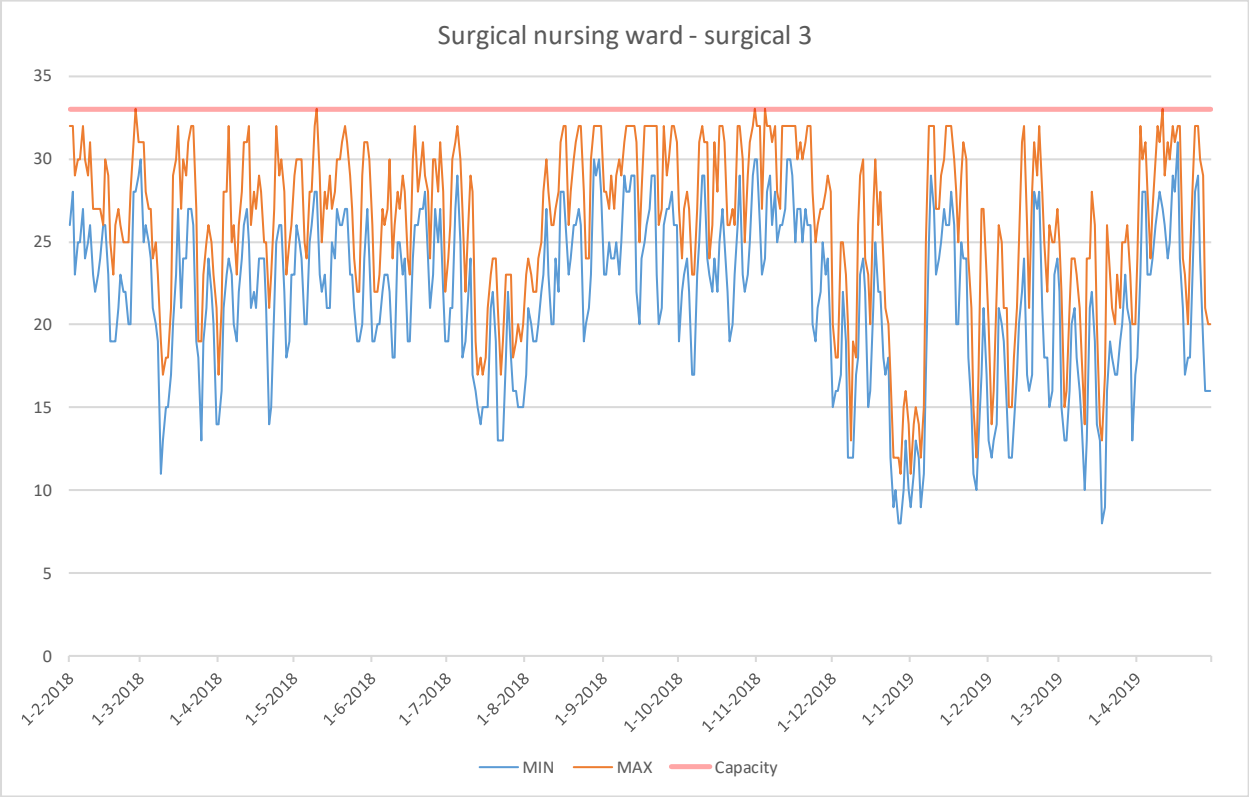


Figure 2-6 Overview of the bed occupancy for ward surgical 3 (n=2,290, OR system HOH, 2018-2019)

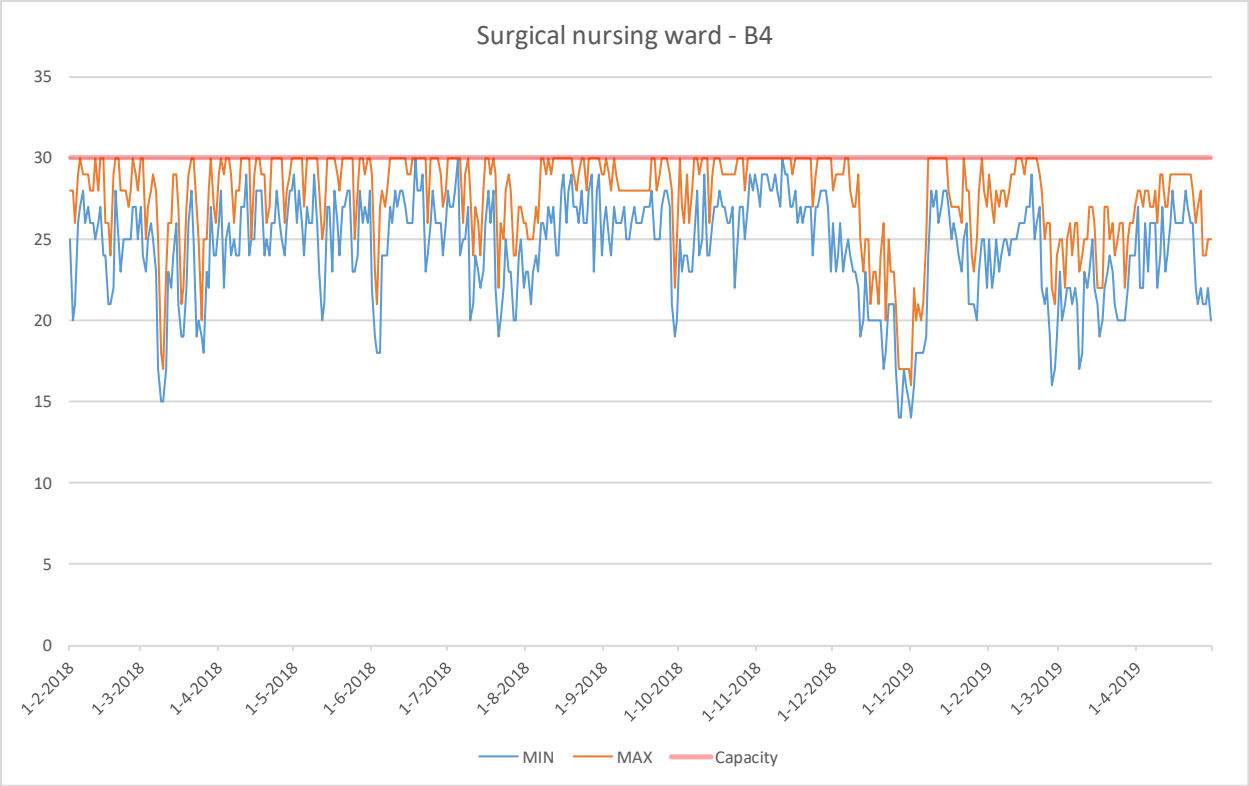


Figure 2-7 Overview of the bed occupancy for ward B4 (n=2,290, OR system HOH, 2018-2019)

Table 2-8 gives an overview of the maximum bed occupancy for ward surgical 3. The maximum capacity of 33 beds is occupied in 5 times during the period in the dataset, this is 1%. At Thursday, the maximum capacity of 33 beds is reached twice. To give more insight in the bed occupancy, the maximum capacity -1 is also given. For surgical 3 the capacity of 32 beds is occupied in 68 times during the period in this dataset. The bed occupancy is 32 or more in 16% of the time.

Table 2-8 Overview of the bed occupancy of the maximum capacity and the maximum capacity -1 for ward surgical 3

	Amount of days	MAX capacity (33 beds)	MAX capacity (%)	MAX capacity -1 (32 beds)	MAX capacity -1 (%)	32 + 33 beds occupied (%)
Monday	65	0	0%	7	11%	11%
Tuesday	65	1	2%	13	20%	22%
Wednesday	64	1	2%	15	23%	25%
Thursday	65	2	3%	20	31%	34%
Friday	65	0	0%	10	15%	15%
Saturday	65	0	0%	2	3%	3%
Sunday	65	1	2%	1	2%	3%
Total	454	5	1%	68	15%	16%

Table 2-9 gives an overview of the maximum bed occupancy of B4. The maximum capacity of 30 beds is occupied in 164 times during the period in the dataset, this is 36%. At Mondays, Tuesdays, and Wednesdays the maximum capacity of 30 beds is reached 30 times. For example: on Monday 46% of the time the maximum capacity of 30 beds is occupied. To give more insight in the bed occupancy, the maximum capacity -1 is also given. For B4 the capacity of 29 beds is occupied in 69 times during the period in this dataset. The bed occupancy is 29 or more in 51% of the time.

Table 2-9 Overview of the bed occupancy of the maximum capacity and the maximum capacity -1 for ward B4

	Amount of days	MAX capacity (30 beds)	MAX capacity (%)	MAX capacity -1 (29 beds)	MAX capacity -1 (%)	29 + 30 beds occupied (%)
Monday	65	30	46%	7	11%	57%
Tuesday	65	30	46%	11	17%	63%
Wednesday	64	30	47%	9	14%	61%
Thursday	65	28	43%	13	20%	63%
Friday	65	18	28%	10	15%	43%
Saturday	65	7	11%	6	9%	20%
Sunday	65	21	32%	13	20%	52%
Total	454	164	36%	69	15%	51%

The aforementioned tables show a peak in bed demand at the beginning of the week, and an off-peak load at Saturday. For both wards the Thursdays and Saturdays will be shown in the graphs below. Figure 2-8 gives an overview of Thursday for ward surgical 3, and Figure 2-9 gives an overview of Saturday for ward surgical 3. Figure 2-10 gives an overview of Thursday for ward B4, and Figure 2-11 gives an overview of Saturday for ward B4. In Appendix C – Overview bed occupancy per day for ward surgical 3 and B4 an overview of all days for ward surgical 3 and ward B4 are given. Where an overview of all days for ward surgical 3 can be found in: Bed occupancy surgical 3. Where an overview of all days for ward B4 can be found in: Bed occupancy B4.

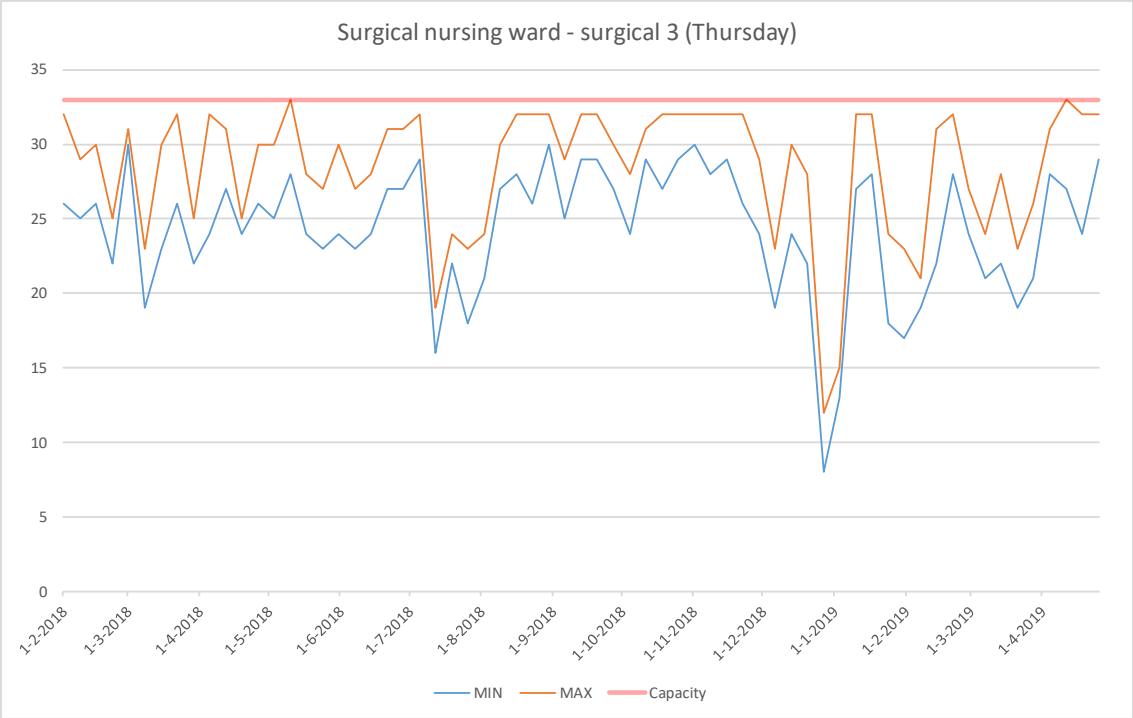


Figure 2-8 Overview of the bed occupancy for ward surgical 3 at Thursday (n=335, OR system HOH, 2018-2019)

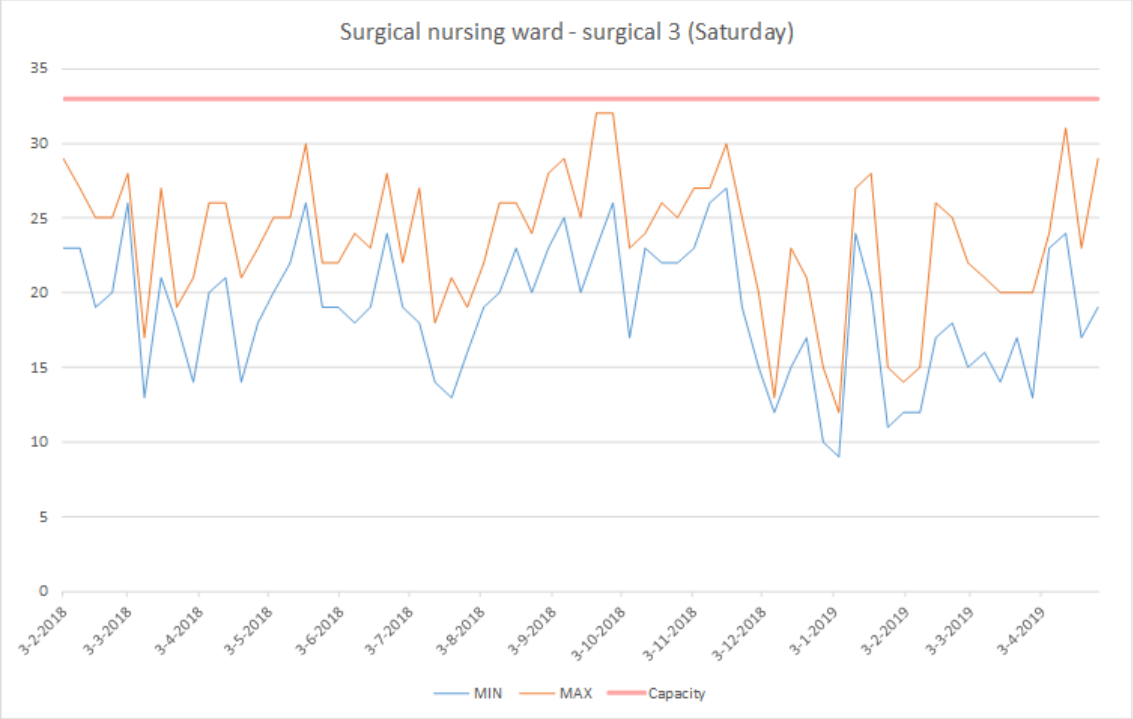


Figure 2-9 Overview of the bed occupancy for ward surgical 3 at Saturday (n=325, OR system HOH, 2018-2019)

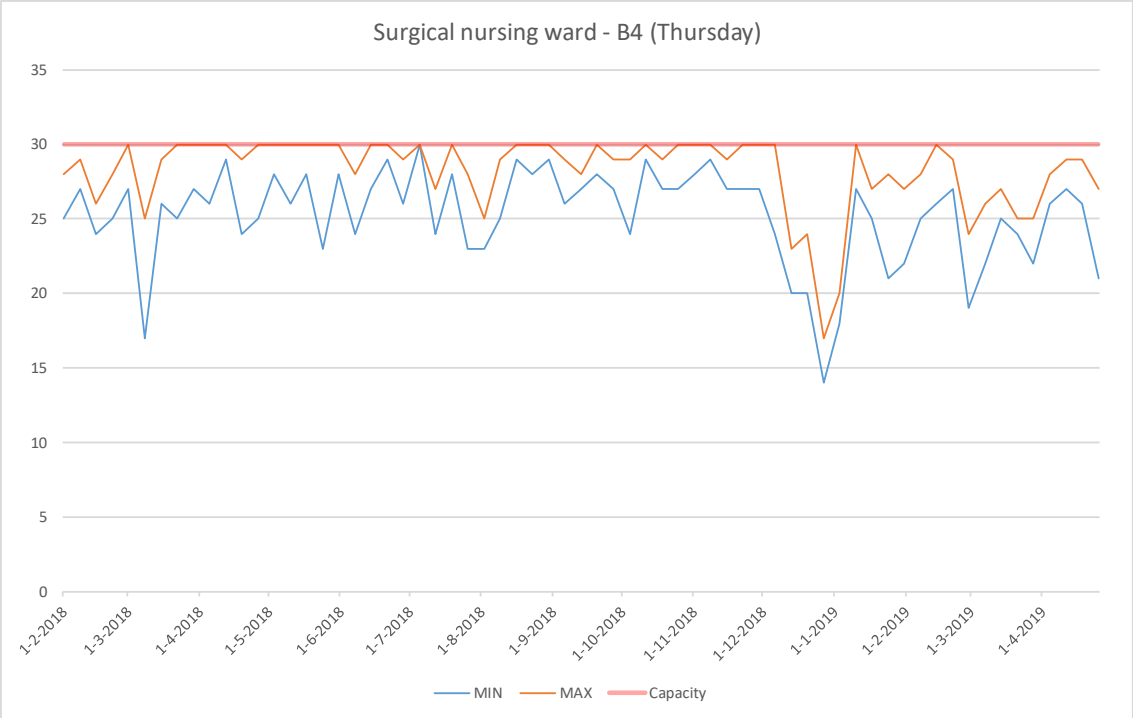


Figure 2-10 Overview of the bed occupancy for ward B4 at Thursday (n=335, OR system HOH, 2018-2019)

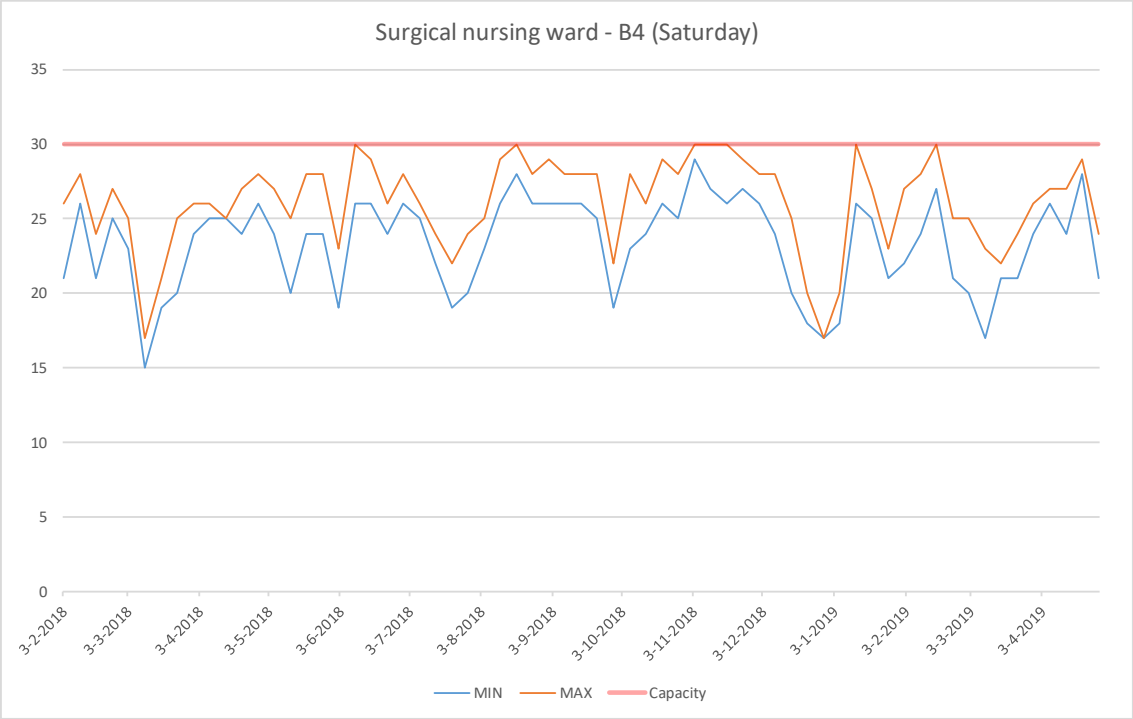


Figure 2-11 Overview of the bed occupancy for ward B4 at Saturday (n=325, OR system HOH, 2018-2019)

Patients of the following specialisms are placed in ward surgical 3: urology, orthopedics, gynecology, and general surgery. Patients of the following specialisms are placed in ward B4: general surgery. An overview of the bed occupancy of these 4 specialisms will be given in the following sections, since these patients belong to the surgical nursing wards. In practice, patients of other specialisms can go these wards, but these are not included.

2.7.2 Occupancy of beds per specialism per day

As mentioned in section 2.7.1, an overview of the following specialisms will be given for ward surgical 3: general surgery, gynecology, orthopedics, and urology. An overview of the specialism general surgery will be given for ward B4. The dataset contains the occupancy of beds for every hour per day. Data of the wards surgical 3 and B4 are used since these wards are inside the scope of this research. The patients that are selected are inpatients. Not all inpatients underwent a surgery, sometimes patients died, or their surgery was cancelled. However, these patients did occupy a bed, so they are included. Since many surgical patients enter through the Emergency Department (ED), it is not valid only considering the elective patients. Therefore, the non-scheduled OR patients (emergency) during 7:30 a.m. – 2:30 p.m. are also included.

The average bed occupancies of the four discussed specialisms per day are shown in the figures below. Figure 2-12 gives an overview of the average bed occupancy for ward surgical 3. Figure 2-13 gives an overview of the average bed occupancy for ward B4. The average bed occupancy per day is calculated with the following formula:

$$Average\ bed\ occupancy\ per\ specialism\ per\ day = \sum_{h=0}^{23} \sum_{Y=1}^{m} \frac{time\ occupied\ bed\ for\ specialism\ X\ on\ day\ (Y \cdot 7 - 6)}{24 \cdot m}$$

Where *m* is 64 for Wednesday, and 65 for the other days of the week.

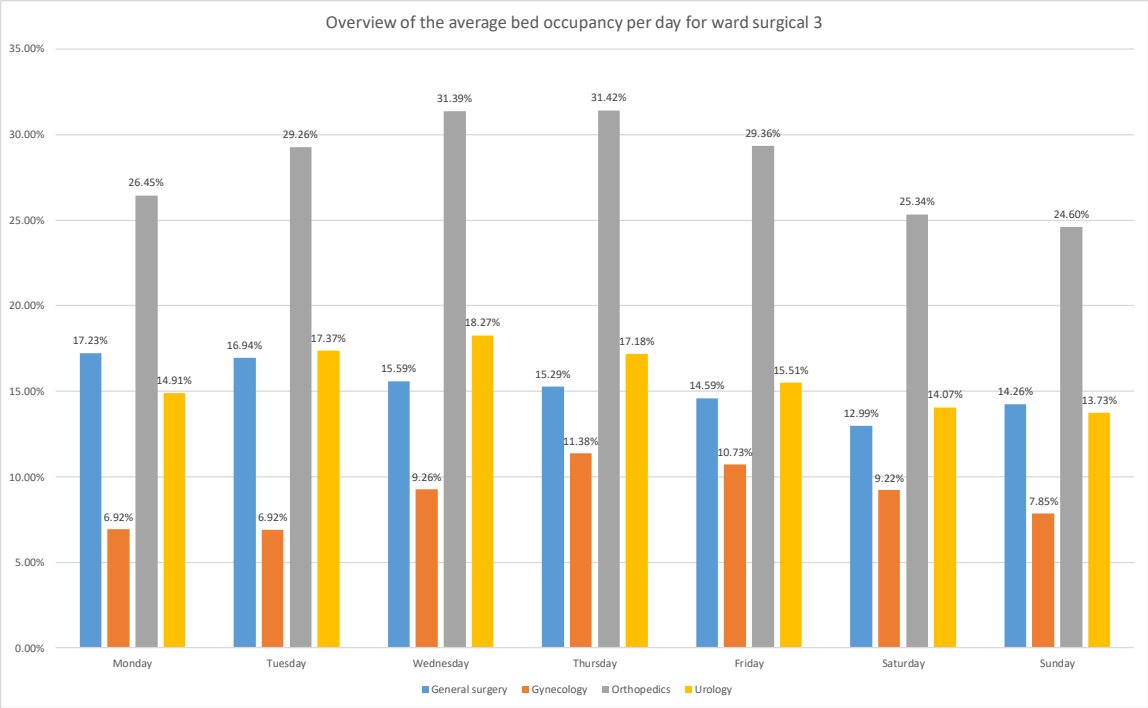


Figure 2-12 Overview of the average bed occupancy per day for ward surgical 3 (n=2,290, OR system HOH, 2018-2019)

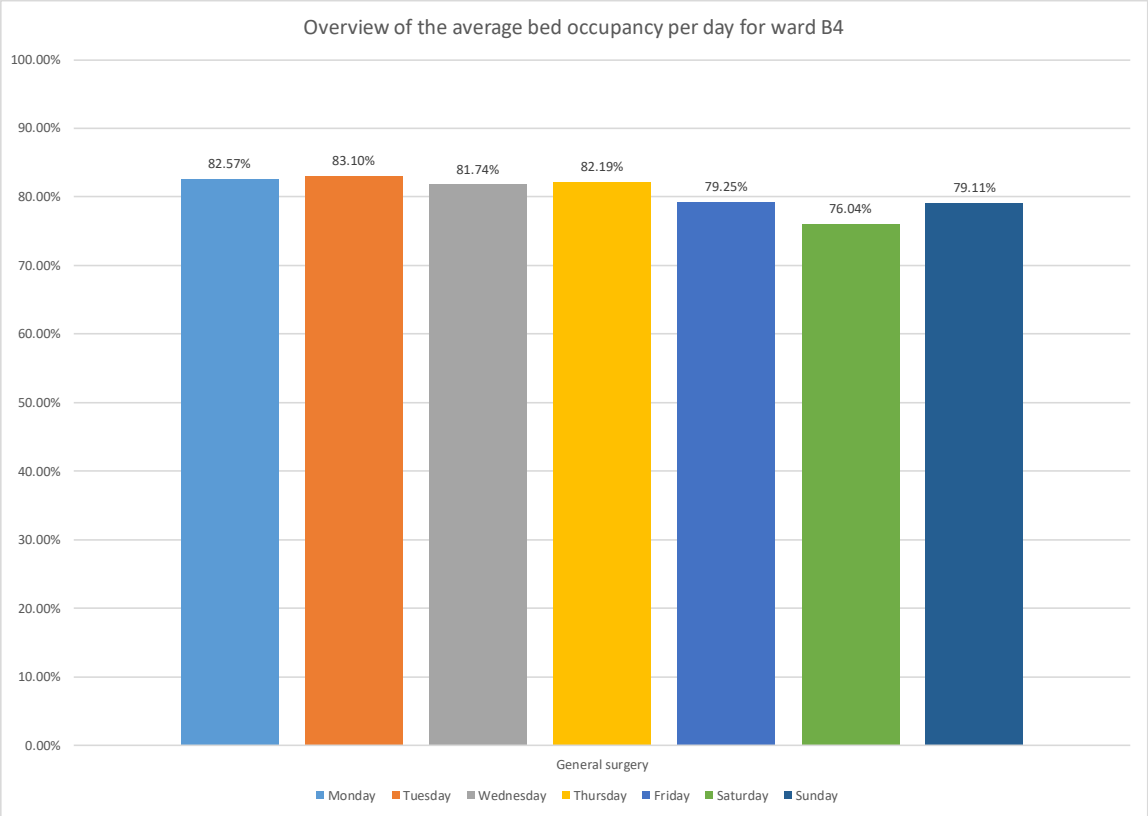


Figure 2-13 Overview of the average bed occupancy per day for ward B4 (n=2,290, OR system HOH, 2018-2019)

Orthopedics has the highest average bed occupancy per day for ward surgical 3. General surgery has the highest bed occupancy at Tuesday for ward B4.

2.7.3 Sessions per specialism per weekday

Figure 2-14 gives an overview of the average amount of sessions for the specialisms: general surgery, gynecology, orthopedics, and urology per weekday. The total amount of sessions per day are 12, since there are six ORs and there are two sessions per day. The performed surgeries of the discussed specialisms are calculated with the following formula:

$$Average\ amount\ of\ sessions\ per\ specialism\ per\ day = \sum_{Y=1}^{m} \frac{Sessions\ performed\ by\ specialism\ X\ on\ day\ (Y \cdot 7 - 6)}{m}$$

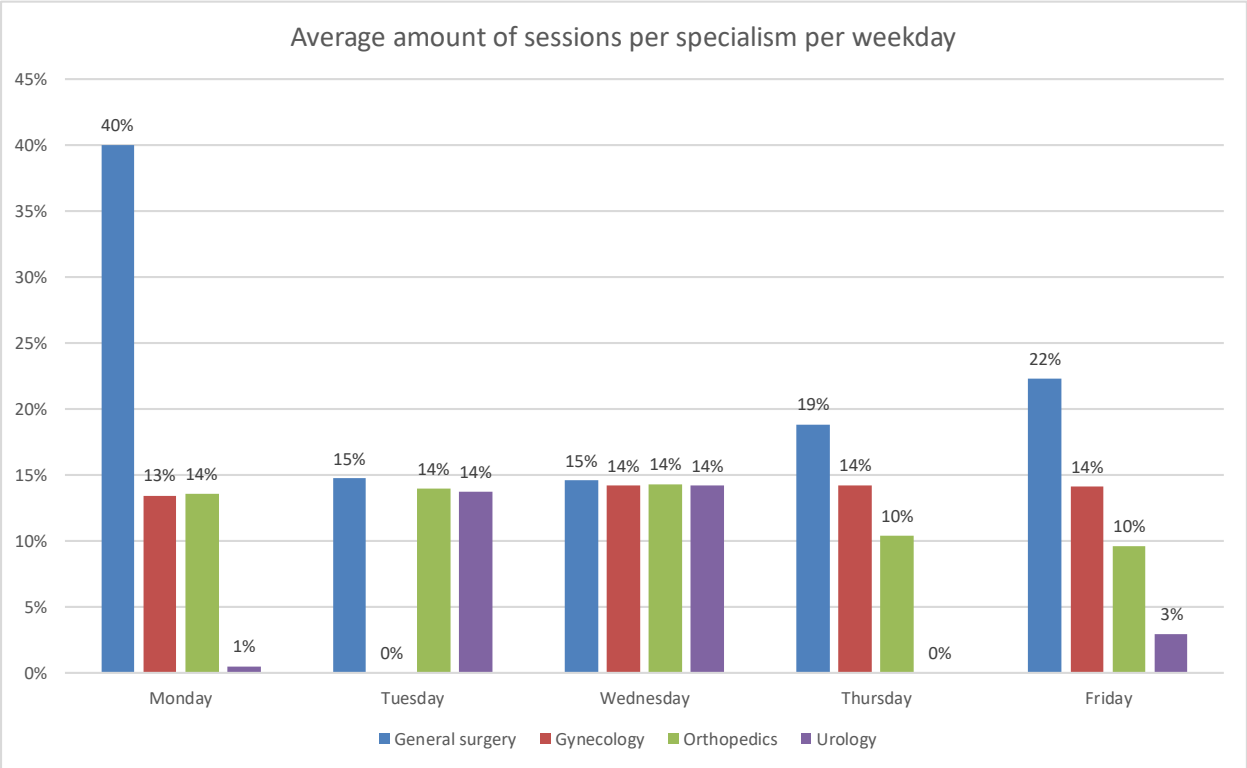


Figure 2-14 Overview average amount of sessions per specialism per weekday (n=2,034, OR system HOH, 2018-2019)

General surgery has every day the highest average amount of sessions. The peak of the average amount of sessions is at Monday. 40% of all sessions on Monday are planned for general surgery.

2.7.4 Amount of surgeries per session per specialism

Figure 2-15 gives an overview of the average amount of surgeries per session per specialism per day. The amount of surgeries per session per specialism per weekday is calculated with the following formula:

$$Average\ amount\ of\ surgeries\ per\ specialism\ per\ day = \frac{Number\ of\ surgeries\ per\ session\ per\ specialism\ X\ on\ day\ Y}{(Amount\ of\ days\ Y\ in\ dataset) \cdot (Average\ amount\ of\ sessions\ per\ specialism\ per\ day)}$$

Figure 2-15 Overview average amount of surgeries per session per specialism per weekday (n=5,048, OR system HOH, 2018-2019)

General surgery has the highest amount of surgeries per session at Tuesday, Wednesday, Thursday, and Friday. Urology has the highest amount of surgeries per session at Monday.

2.7.5 LOS of patients per specialism

The average LOS of patients per specialism is calculated, to give more insight in the bed occupancy per specialism per weekday. Figure 2-16 gives an overview of the average LOS per specialism per weekday. The LOS per specialism per weekday is calculated with the following formula:

$$Average\ LOS\ of\ patients\ per\ specialism\ per\ weekday = \frac{Sum\ of\ LOS\ per\ specialism\ X\ on\ day\ Y}{Amount\ of\ surgeries\ per\ specialism\ per\ day\ Y}$$

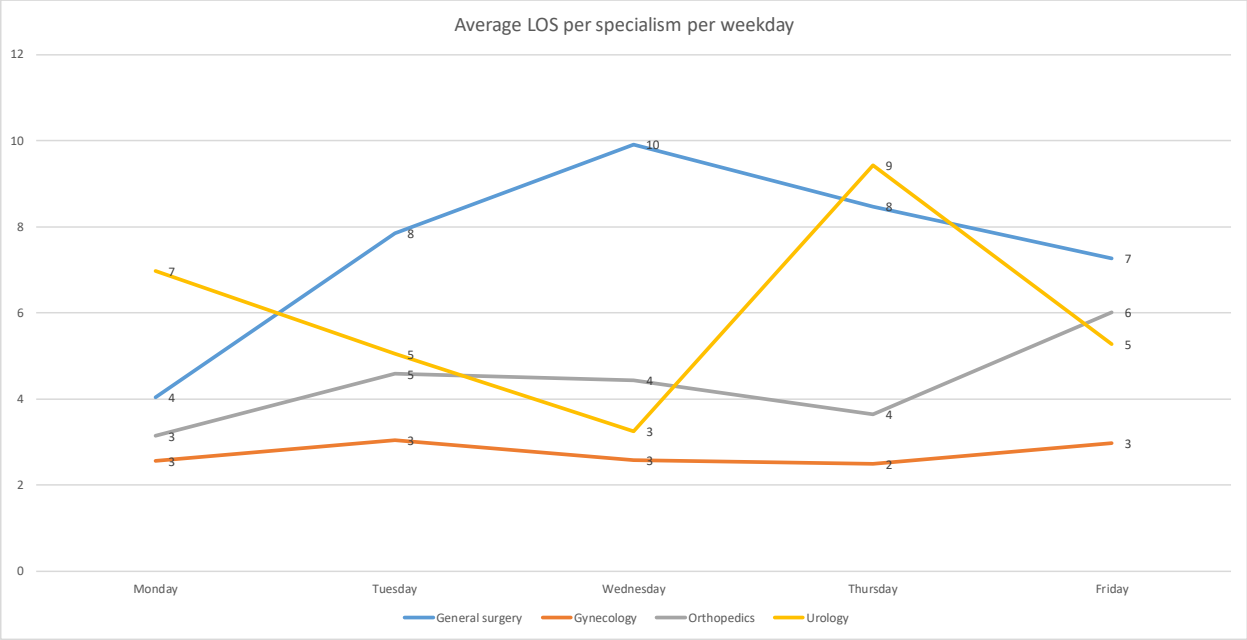


Figure 2-16 Overview average LOS per specialism per weekday (n=6,114, OR system HOH, 2018-2019)

The average LOS of patients is the highest for general surgery. There is a peak at Wednesday and an off-peak load at Monday. Gynecology has the lowest LOS of patients, there is not a peak or an off-peak load for this specialism.

2.8 Conclusion

The first research question is discussed in this chapter.

What is the current influence of the OR session planning on the bed occupancy in the surgical nursing wards within HOH?

An overview of the bed occupancy is given for both wards. In this overview 1% of the time the maximum capacity is reached for ward surgical 3, and in 36% of the time the maximum capacity is reached for ward B4. When calculating the maximum capacity -1 the bed occupancy is 32 or more in 16% of the time for surgical 3, and the bed occupancy is 29 or more in 51% of the time for ward B4.

There is a peak in bed occupancy at the beginning of the week, and an off-peak load at Saturday for both wards. A possible reason for the peak of bed demand at the beginning of the week is that specialists wants to conduct surgery in the beginning of the week, their reason is that more beds are available at the beginning of the week and they do not want to discharge patients during the weekend. Most people get discharged at Friday. An overview is given of the average sessions per specialism per day. The biggest peak of the week in the amount of sessions is for general surgery on Monday. 40% of all sessions on Monday are planned for general surgery. General surgery has the highest amount of surgeries per session at Tuesday, Wednesday, Thursday, and Friday. Urology has the highest amount of surgeries per session at Monday. The average LOS of patients is the highest for general surgery. There is a peak at Wednesday and an off-peak load at Monday. Gynecology has the lowest LOS of patients, there is not a peak or an off-peak load for this specialism.

The maximum capacity of beds is often reached for ward B4. This ward is designated for the patients of the specialism general surgery. In addition, general surgery has the most sessions, the highest amount of surgeries per session, and the highest LOS of patients. General surgery has a major impact on the bed demand. Since the OR session planning has a big influence on the planned sessions per specialism, this research will focus on the OR session planning within the specialism general surgery.

3 Current OR scheduling HOH

The current OR scheduling of HOH is explained using concepts known from the literature. This chapter describes the OR scheduling system (Section 3.1), advanced scheduling (Section 3.2), allocation scheduling (Section 3.3), OR policy (Section 3.4), and the conclusion (Section 3.5).

3.1 OR scheduling system

Gupta (2007) and Patterson (1996) identified three different scheduling systems, namely: open scheduling, block scheduling, and modified block scheduling. Open scheduling is the situation in which OR sessions are not assigned to a specialist, and patients are treated according to the First Come First Serve (FCFS) policy. Block scheduling is when OR sessions are blocked for an assigned specialist in advance. Modified block scheduling is a combination of the aforementioned systems, most OR sessions are blocked but they can be released at an agreed-upon time before surgery for other specialists. HOH maintains this block scheduling policy. Every specialist is assigned to one OR session per week. However, HOH created some flexibility within the block scheme via flex sessions and a request list (see Section 2.4.1). Nevertheless, HOH does not have an agreed-upon time before surgery that a specialist can release his/her OR session.

3.2 Advanced scheduling

According to Guerriero & Guido (2011), the assignment of patients to ORs is called advanced scheduling. A common policy for advanced scheduling is FCFS, which is applied in HOH. This algorithm schedules an arriving patient on the first available OR session which is assigned to the performing specialist and has enough open time available to operate the patient. Local search methods are used to improve a schedule. Hans, Wullink, van Houdenhoven, & Kazemier (2008) use an effective local search, namely simulated annealing (SA) to optimize the OR schedule. First, an initial schedule is made, e.g. with FCFS. With random swaps, e.g. changing two scheduled surgeries with each other, or random moves, SA tries to improve the initial schedule. Not all individual swaps or moves result directly in an improved schedule, but it can contribute to an improved schedule in the long run. Therefore, a swap or move that does not improve the schedule, is accepted with a certain probability (Andringa, 2018).

3.3 Allocation scheduling

The process of determining the sequence of the surgeries during an OR session after the advanced schedule is known is called allocation scheduling. HOH schedules according to the following priority: child patients, pregnant patients, patients with a metabolic disorder, and surgeries with the longest expected duration. The following surgeries are scheduled last: MRSA patients and patients under local anesthesia (see Section 2.5.2). The scheduling algorithm in which the longest expected duration is scheduled first (longest expected processing times, LEPT), is a commonly used allocation scheduling algorithm in OR planning. The shortest expected processing times (SEPT) is also an allocation scheduling algorithm in which the surgeries with the shortest expected durations are scheduled first. A disadvantage of this algorithm relative to LEPT can be that more surgeries with long expected duration are cancelled due to overrun of the OR program (Andringa, 2018).

3.4 OR policy

According to van Riet & Demeulemeester (2015), there are three types of OR policies to manage the arrival of emergency patients: dedicated policy, flexible policy, and hybrid policy. A dedicated policy means that elective and emergency patients are treated in different ORs, i.e., an elective patient can only be operated in an elective OR and an emergency patient in an emergency OR. In a flexible policy, elective patients and emergency patients can both be operated in all ORs. A hybrid policy is a combination of the dedicated and the flexible policy. In this policy there are ORs that are dedicated to only elective or emergency patients, but also ORs that handle both categories. HOH uses the hybrid policy. During the afternoon sessions, one OR is reserved for emergency patients (see Section 2.4.3). When the emergency OR is not available before 11:00 a.m., or the emergency OR is occupied, the elective program needs to be interrupted for emergency patients with a high urgency level.

3.5 Conclusion

The second research question is discussed in this chapter.

How is the current OR session planning of HOH organized?

Within HOH the modified block scheduling is used, which means there are fixed sessions and flexible sessions in the OR session planning. Every specialist has one fixed session per week, the flex sessions are not dedicated to a specialist. The advanced scheduling within HOH has a common policy for using the FCFS. This algorithm schedules an arriving patient on the first available OR session which is assigned to the performing specialist and has enough open time available to operate the patient. The allocation scheduling of HOH is according to the following priority: child patients, pregnant patients, patients with a metabolic disorder, and surgeries with the longest expected duration. The OR policy of HOH is hybrid. In this policy there are ORs which are dedicated to only elective or emergency patients, but also ORs that handle both categories. Figure 2-5 shows an example of the OR session planning within HOH.

4 Intervention options

A literature review is conducted to search for intervention options for HOH regarding the OR session planning. This chapter describes the literature on OR scheduling (Section 4.1), options OR sessions planning (Section 4.2), chosen intervention option (Section 4.3), and the conclusion (Section 4.4).

4.1 Literature OR scheduling

The planning and scheduling of an OR can be complicated due to the number of stakeholders and different objectives involved in the process. According to Van Oostrum et al., (2008), the OR is one of the most expensive resources in the hospital. An important goal for the organization is to optimize utilization. According to Guerriero & Guido (2011) is the OR the most expensive resource in most hospitals. ORs are clearly connected with other "downstream" resources, for example the post-anesthesia care unit (PACU), the intensive care unit (ICU), and the general patient wards hereafter referred to as 'wards'. A high level of utilization in hospital wards leads to a higher discharge rate of patients (Anderson, Price, Golden, Jank, & Wasil, 2011), which might reduce the quality of care. In addition, downstream units should also be considered in surgery planning for medical reasons. When planning the ORs and the downstream units, the decision makers consider a trade-off between the high complexity of a holistic view and the danger of suboptimal solutions resulting from focusing on isolated units (Vanberkel, Boucherie, Hans, Hurink, & Litvak, 2010).

4.2 Options OR session planning

The current OR session planning within HOH originated from the past. Research to the OR session planning has not been done before. Some options of OR session planning will be mentioned for optimizing the current OR session planning of HOH. There are planning and optimization models for all three levels of planning (strategic, tactical, and operational) for a wide range of OR scheduling problems. According to Yahia, Harraz, & Eltawil (2014) scheduling the OR can be divided into three scheduling problems: The Case-Mix Scheduling Problem (CMP), the Master Surgery Scheduling Problem (MSSP), and the Surgery Scheduling Problem (SSP).

The CMP is the strategic decision of assigning the OR time to the different specialties. The MSSP is the tactical decision, the total OR time is already assigned and then ORs and the OR days get assigned to the specialties. The SSP is the operational decision of assigning a patient to a day, an OR, and a start time.

4.3 Chosen intervention option

As mentioned in section 1.4, this research is going to be positioned at the tactical level of the resource capacity planning. Therefore, we will focus on the Master Surgery Scheduling.

4.3.1 Master Surgery Scheduling

Master Surgery Scheduling (MSS) allocates surgeons and surgical specialties to a specific OR time block, a day and a room, for a weekly planning horizon. Each OR time block is either not used or fully used. Partial use of a shift in any room is not allowed in the hospital. According to Marques, Captivo, & Barros (2019), there are four options to manage OR time blocks. An OR time block can be: 1) assigned to a single surgeon; 2) shared by a group of (two or three) surgeons; 3) assigned to a surgical specialty; 4) left blank. Figure 4-1 gives an overview of the four different ways to allocate OR time blocks using a simple case of an MSS with four rooms, two shifts, and two days (Tuesday and Thursday).

Day & Shift \ Room		1		2		3		4	
		Surgical specialty's ID	Surgeon's ID	Surgical specialty's ID	Surgeon's ID	Surgical specialty's ID	Surgeon's ID	Surgical specialty's ID	Surgeon's ID
Tuesday	M	OTO OTO	SRG 2 SRG 208	OTO OTO OTO	SRG 69 SRG 145 SRG 215	GYN		GYN GYN	SRG 59 SRG 39
	A	OPH	SRG 120	OTO		GES GES	SRG 86 SRG 116	GYN GYN GYN	SRG 47 SRG 119 SRG 168
Thursday	M	OPH	SRG 104	OTO OTO	SRG 69 SRG 145			VAS	SRG 49
	A	OPH	SRG 120	OTO	SRG 139	GES GES GES	SRG 143 SRG 34 SRG 16	VAS	SRG 49

Figure 4-1 Example of an MSS with four ORs, two shifts, and two days

MSS determines which surgeons have enough workflow to receive OR time individually. The surgeons with reasonable workflow may be grouped and share the same OR time block with one or two other surgeons. In this case, the proportion of time assigned to each surgeon is also a decision which needs to be taken. In addition, an OR block time can be assigned to a surgical specialty. The surgeons who do not receive OR time can use the OR time assigned to their specialty.

The blank OR time blocks are left open for any surgical case in a first-come-first-served basis. These are slacks in the tactical decision level to accommodate cases (e.g. urgency). The daily output of the ORs is uncertain and depends of the duration of the performed surgeries. Random variables representing the duration of a surgery (in minutes) are considered.

Marques, Captivo, & Barros (2019), tried to adjust a theoretical statistical distribution to the duration of the surgeries, but no statistical evidence was obtained in the data collected. Therefore, the empirical distribution of the random variables is fitted for the data available. The duration of a surgery includes induction and waking up times as they are also performed in the OR. The cleaning and disinfecting protocols are also included in the duration of a surgery, in order to better estimate the weekly time required for each surgeon in terms of OR occupation. The uncertainty in the duration of a surgery is considered through an input random variable. The MSS also considers daily and weekly operating time limits for the surgeons that receive individual OR time blocks.

According to Vanberkel et al., (2011) there are several assumptions inherent to the model that are discussed to provide perspective on what the model can and cannot be used for. Patients are counted as ‘occupying a bed’ on the day of admission, not on the day of discharge. Thus, issues with overlapping patients on the same day are not quantified. The assumption is made that the MSS is cyclical, which means that it does not change from week to week. In practice, the MSS does occasionally change because of seasonal patterns. During these periods, certain OR blocks are canceled, meaning the model overestimates the ward occupancy during these weeks. Nevertheless, it still may be helpful as an upper bound. Finally, the model assumes that there is always a bed available for a patient after surgery.

This suggests that procedures are never canceled because of bed shortages. Perhaps this is an idealized situation, although it is representative of hospitals that call in additional staff when demand is higher than expected. The frequency of 'calling in additional staff' follows from the model. In practice, additional staff may not always be available. The model output may overestimate the bed requirements, although only slightly when cancellations are uncommon.

4.4 Conclusion

The third research question is discussed in this chapter.

What are possible intervention options for the OR session planning within HOH?

MSS is a possible intervention option for optimizing the OR session planning within HOH. MSS focusses on the tactical decision in the resource capacity planning. Since this research is going to be positioned at the tactical level of the resource capacity planning, we will focus on the MSS. MSS allocates surgeons and surgical specialties to a specific OR time block, a day and a room, for a weekly planning horizon. For this research we will focus on the specialism general surgery.

5 Analysis

This research focusses on the analysis of the specialism general surgery. Within this specialism, some specialists are exchanged to optimize the OR session planning. This chapter describes the background information (Section 5.1), input data (Section 5.2), results (Section 5.3), best intervention option (Section 5.4), and the conclusion (Section 5.5).

5.1 Background information

The tool which is used for the analysis is created by Rhythm. The name of the tool is: Patient Flow Forecasting (PFF). For every block, the tool will count how many times (e.g. over the period 1st February 2018 until April 30, 2019) *k* patients were operated $k \in \{0,1, \dots\}$ i.e. f_k. With this, we can determine an empirical discrete distribution: $P(X = k) = \frac{f_k}{\sum_i f_i}$. The same will be conducted for the LOS of these patients. Note: all aforementioned distributions are independent, as patients do not interfere.

The definition of convolutions (indicated by a *): Let *A* and *B* be two independent discrete distributions. Where *A* is the amount of surgeries per specialist at day Y, where *B* is the LOS of patients at day Y. Then *C* = *A* * *B*, which is computed by:

$$P(C = x) = \sum_{k=0}^{\tau} P(A = k)P(B = x - k)$$

Equation 1 Definition of convolutions

Where τ is the largest x -value that can result from A * B.

$$C(x) = \sum_{k=0}^{\tau} A(k)B(x - k) = A * B$$

Equation 2 Discrete convolution

The aggregate number of patients in each ward can be computed with discrete convolutions of the surgery frequency and LOS probability functions. The definition of the discrete convolution: Here, *A* and *B* are independent discrete distributions, τ is the largest x that can result from *A* * *B*, where * is used to indicate a convolution.

5.2 Input data

Data of the 1st of February 2018 until April 30, 2019 of HOH is used. To measure the effects of the beds, the following data is used in the tool: SessionID, start date and time of admission, end date and time of admission, specialist, start time session, end time session, and the OR number. Duplications have been deleted in the dataset. When two specialists conducted a surgery within one session, the second specialist was removed from the dataset since the session was assigned to the first specialist.

Two separate datasets have been created since the analysis is conducted for the realization and the plan of HOH. For the analysis of the realization, three datasets have been made of the 1st of February 2018 until April 30, 2019. Dataset 1 gives a total overview of all surgeries conducted by general surgery within HOH. Dataset 2 included all surgeries which were only conducted in the morning sessions and the afternoon sessions. Ultimately dataset 3 is used for the analysis of the current situation, this dataset included all surgeries which were only conducted in the morning sessions and the afternoon sessions and which were planned for general surgery. With this final dataset the exchanges between specialists can be made. Table 5-1 gives an overview of the datasets.

The dataset for the plan of HOH consists of one dataset. In this dataset the data of 1st of February 2019 until April 30, 2019 is used. In this dataset the plan is made for the specialism general surgery which includes all surgeries conducted in the morning sessions and afternoon sessions, and which were planned for general surgery. With this dataset the exchanges between specialists can be made. Table 5-2 gives an overview of the dataset.

Table 5-1 Overview of the datasets of the realization

	Dataset R-1	**Dataset R-2**	**Dataset R-3**
	General surgery	General surgery	General surgery
	Inpatient	Inpatient	Inpatient
	Planned	Planned	Planned
	Urgency A	Urgency A	Urgency A
	Urgency B	Urgency B	Urgency B
	Urgency C	Urgency C	Urgency C
	Urgency D	Urgency D	Urgency D
		Morning sessions	Morning sessions
		Afternoon sessions	Afternoon sessions
			Planned sessions for general surgery
N =	**1545**	**1003**	**596**

Table 5-2 Overview of the dataset of the plan

	Dataset P-1
	General surgery
	Inpatient
	Planned
	Urgency A
	Urgency B
	Urgency C
	Urgency D
	Morning sessions
	Afternoon sessions
	Planned sessions for general surgery
N =	**229**

In dataset R-1 and dataset R-2 some extra morning and afternoon sessions are deleted, since all morning and afternoon sessions were included even in the weekend. The morning and afternoon sessions in the weekend are deleted, because HOH does not plan surgeries during the weekend. In dataset R-1, 200 surgeries were eventually removed that took place during the weekend. In dataset R-2, 100 surgeries were eventually removed that took place during the weekend. In dataset R-3 the weekends are automatically excluded since this dataset filtered on the planned sessions for general surgery, and HOH only plan the surgeries for the weekdays.

In the current OR session planning of HOH there are some flex sessions. A specialist can register for a flex session when he/she needs extra time. A total of 53 surgeries in the entire dataset were performed in the flex sessions, of which 26 were performed by general surgery. These flex sessions are not included in the OR session planning because it can change every week. However,

it is good to take this into account since this does affects the bed demand. The amount of conducted surgeries by general surgery in the flex sessions 49.06%.

The dataset revealed that general surgery performed surgeries under a session that was planned for another specialism. Due to an unknown error in the data, there are also seven surgeries performed by general surgery under the specialism '0'. These errors affect the bed demand, but does not influence the calculation in dataset 3, since this dataset is filtered on the planned sessions for general surgery.

During the summer holiday there is a 'recess period'. Every week, one different OR is blocked, so that employees can go on holiday. The planned specialist who has OR time that week knows he has the chance to go on holiday. It is possible that in this period another specialist conducts a surgery in the OR which is blocked in the planning. Ultimately, this data was not taken into account because specialists can also indicate that they can conduct a surgery in a different week. In addition, one OR is only closed for one week.

The full dataset for the realization consists of the 1st of February 2018 until April 30, 2019. Data from 1st of June 2018 until January 31, 2019 has been used to estimate the probability distribution of the bed occupancy. The reason is that this data is more recent. This way, the remaining three months February, March, and April can be used to cross-check whether the forecast matches the data that has been collected. The dataset for the plan consists of the 1st of February 2019 until April 30, 2019. This data has been used to estimate the probability distribution of the bed occupancy. In addition, the two surgical wards have been merged in the prediction: PFF makes a calculation for the total number of surgical beds. The prediction for the number of beds was measured in hours, since this is the most relevant information for a ward. The forecast can display a maximum of 100 days.

5.3 Results

In this section the results will be described. Two separate analyses were made. The first analysis is the reality of the current situation which will be referred in this research to 'realization'. The second analysis is the fictional reality of the situation, in this case we assume that the planned

sessions for specialist X are conducted by specialist X, which will be referred in this research to 'plan'. This section describes the current situation (Section 5.3.1), results of the realization (Section 5.3.2), intervention options realization (Section 5.3.3), results of the plan (Section 5.3.4), and the intervention options plan (Section 5.3.5).

5.3.1 Current situation

Based on the data obtained, first an overview is given of the current situation for the planned and performed surgeries, number of emergencies, surgeries, sessions, LOS per specialist, and the PFF.

Planned and performed surgeries

703 surgeries were performed during the morning and afternoon sessions that were planned for general surgery in the period of the 1st of June 2018 until April 30, 2019. Of these, 596 surgeries were performed by general surgery. This means that 85% of the performed surgeries took place in the planned session for general surgery. 15% of the performed surgeries in the planned sessions for general surgery were performed by another specialism. Appendix D – Planned and performed surgeries per specialism gives a total overview of the planned and performed sessions per specialism.

A total of 1003 surgeries were performed by general surgery in the morning and afternoon sessions. Of these 1003 surgeries, 596 surgeries were performed in the planned sessions for general surgery. This means that 407 surgeries were performed by general surgery in sessions that were planned for a different specialism. Of these 407 surgeries, 170 surgeries were performed for emergency surgeries. The specialism general surgery asks a lot of extra surgery time, since specialists of general surgery have a waiting list. When another specialism does not need the planned session, general surgery can perform surgeries in that session. That is why many surgeries were performed by general surgery in sessions that were planned for a different specialism. Appendix D – Planned and performed surgeries per specialism gives a total overview of the planned and performed sessions per specialism.

Number of emergency surgeries

In the period of the 1st of June 2018 until April 30, 2019 there were 2,817 emergencies in the morning sessions and afternoon sessions. Of all these emergencies, 36% were performed by general surgery. In total there were 1,081 emergencies outside the morning sessions and afternoon sessions. Of all these emergencies, 50% were performed by general surgery. Figure 5-1 gives an overview of the type of specialism for the emergency surgeries that took place in the morning and afternoon sessions. Figure 5-2 gives an overview of the type of specialism for the emergency surgeries that took place outside the morning and afternoon session.

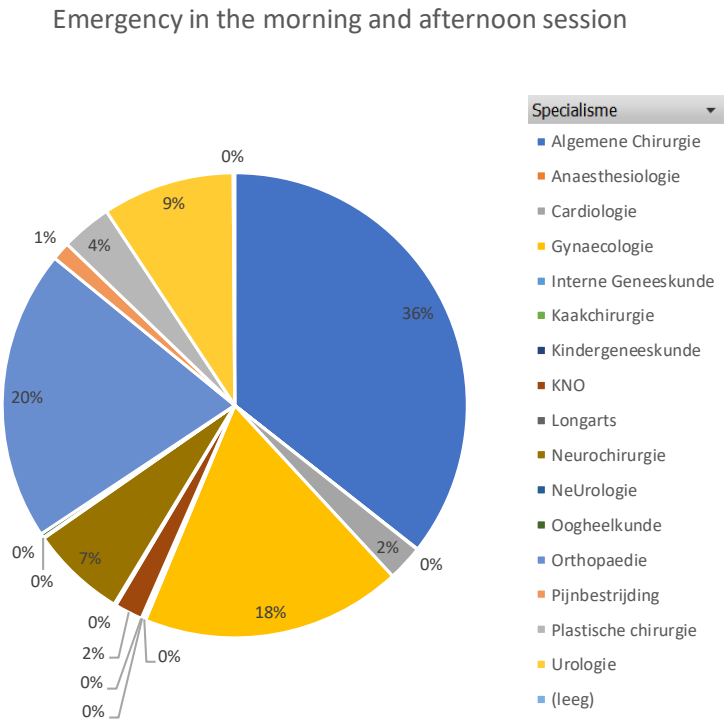


Figure 5-1 Type of specialism for the emergency surgeries in the morning and afternoon session (n=2,817, OR system HOH, 2018-2019)

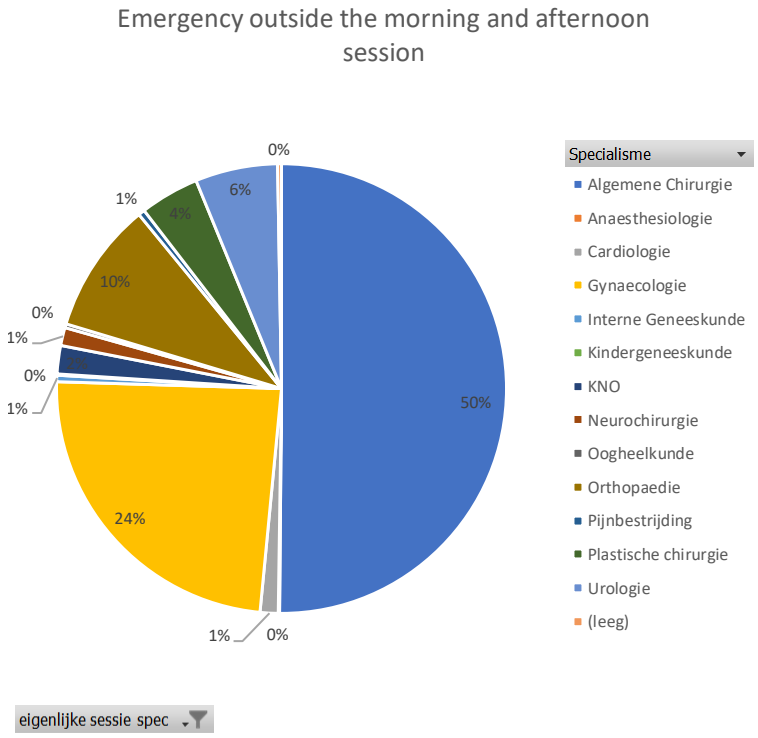


Figure 5-2 Type of specialism for the emergency surgeries outside the morning and afternoon session (n=1,081, OR system HOH, 2018-2019)

The emergencies are divided into urgency A, urgency B, urgency C, and urgency D (see Section 2.6.1). Table 5-3 contains an overview of all urgencies and the session in which they occur. Session 1 is the morning session, session 2 is the afternoon session, session 3 is outside the morning and afternoon session. For example: 11% of all urgencies A performed by general surgery was performed in session 1 (morning session).

Table 5-3 Overview of all urgencies (session 1 = morning session, session 2 = afternoon session, session 3 = outside morning and afternoon session)

Emergency			
	Session		
	1	2	3
Urgency A	11%	17%	72%
Urgency B	5%	29%	66%
Urgency C	5%	45%	51%
Urgency D	11%	64%	26%
Total	6%	37%	57%

Table 5-4 gives an overview of the urgencies in the morning and afternoon session, and outside the morning and afternoon session. For example: of all urgencies A, 28% is performed in the morning and afternoon session, and 72% is performed outside the morning and afternoon session.

Table 5-4 Overview urgencies morning and afternoon session, and outside the morning and afternoon session

Morning and afternoon session			**Outside the morning and afternoon session**		
Urgency A	28%		Urgency A	72%	
Urgency B	34%		Urgency B	66%	
Urgency C	49%		Urgency C	51%	
Urgency D	74%		Urgency D	26%	
Total	43%		Total	57%	

Surgeries, sessions, LOS per specialist

Dataset R-3 is used to calculate how many surgeries have been performed per specialist, how many sessions have been performed per specialist, and the LOS per specialist. Ultimately, dataset R-3 can only be used for the analysis in PFF since we want to analyze if there could be a better distribution of the bed occupancy for the current situation, which is why the calculations are based on this dataset. Based on the number of surgeries and the LOS of the specialists, we look at which specialists can be exchanged.

Appendix E – Surgeries, sessions, LOS per specialist gives an overview of the surgeries, sessions, and LOS per specialist. In PFF the session load is given per specialist, we compare this session load with the results obtained from the calculations in Excel from dataset R-3.

5.3.2 Results of the realization

As previously indicated, dataset R-3 was used to calculate the forecast and to ultimately exchange with the specialists. The data from 1st June 2018 to January 31, 2019 was used within this dataset. This gives a better representation of the results (the most recent results). Ultimately, this research looks at the forecast for the months February, March, and April 2019. Figure 5-3 shows an overview of March 5, 2019 to April 11, 2019 of the forecast of the bed occupancy of the current situation.

The dark blue line in Figure 5-3 shows the percentage between percentile 10 and percentile 90. For example, percentile 90 = 8, means that in 90% of the time eight beds or fewer are occupied. Percentile 10 = 3 means that in 10% of the time three beds or less are occupied. The light blue line in Figure 5-3 shows the percentage between 1 and 99.

The black line in Figure 5-3 shows the expected value. That is the amount of beds that PFF predicts based on the data provided. The red line in Figure 5-3 is the realization. That is what the demand for beds has been. The black and red line must therefore be as close as possible to each other in order to make a good forecast.

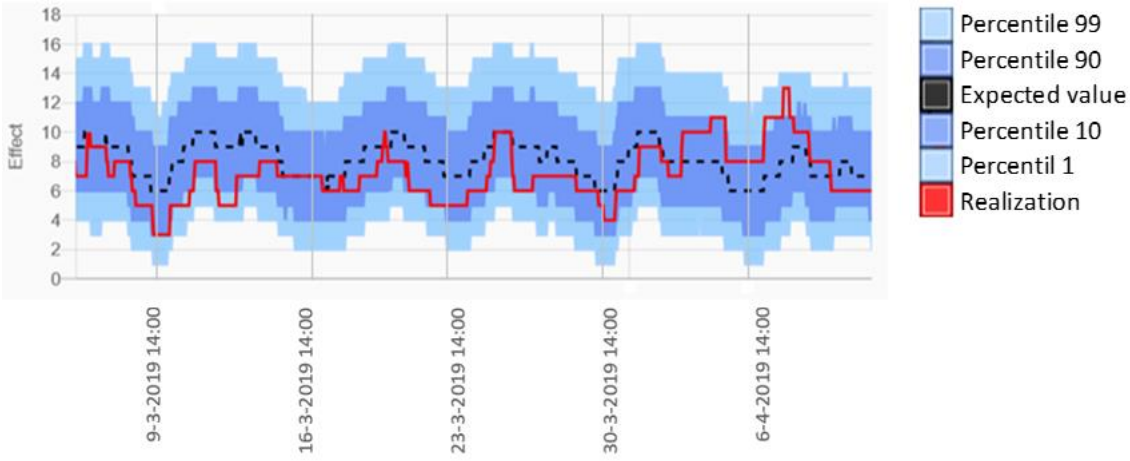


Figure 5-3 Forecast bed occupancy on Saturdays of the current situation HOH (n=94, PFF Rhythm, 2018-2019)

Figure 5-3 shows a pattern during the weekends and weekdays. The data which is shown on the x-axis are Saturdays. In the weekends there is an off-peak load of the bed occupancy. The ultimate off-peak load is on Saturday, and it increases during the day on Sunday. Within HOH, almost all patients are admitted one day before surgery which is why there is an increase in bed demand on Sunday. All the peaks have an expected value of ten beds. The first, third, fourth, and fifth off-peak load have an expected value of six beds. The second off-peak load has an expected value of seven beds. There is a difference of three and four beds between the peaks and off-peak loads.

Table 5-5 gives an overview of the descriptive statistics of the bed occupancy for the realization and the expected value of the current situation of the months February, March, and April per hour. For example: the minimum bed occupancy for the realization is 3 and the minimum bed occupancy for the expected value is 4. The expected value is the most important since we want to work with the expected value in PFF. The standard deviation of the expected value is 1.64. This means that in 68.2% of the time the average bed occupancy is 7.67 +/- 1.64, under the assumption that the data is normally distributed. The realization is what the bed demand has been, the standard deviation of the realization 2.00. This means that in 68.2% of the time the average bed occupancy is 7.37 +/- 2.00, under the assumption that the data is normally distributed. The expected value shows less variability then the realization and appears to have a more stable bed occupancy. The realization will only be shown for the current situation. Furthermore, in this research, we focus on the expected value. In Appendix F – Descriptive statistics of the bed occupancy - Current situation the descriptive statistics of the bed occupancy is given of the expected value and the realization per hour, per day, and per month for the current situation.

Table 5-5 Descriptive statistics of the bed occupancy for the current situation HOH

	Realization	Percentile 1	Percentile 10	Expected value	Percentile 90	Percentile 99
STANDARD DEVIATION	2.00	1.41	1.47	1.64	1.76	1.84
MIN	3.00	0.00	2.00	4.00	7.00	9.00
MAX	14.00	6.00	8.00	11.00	15.00	18.00
AVERAGE	7.37	2.89	4.81	7.67	10.71	13.59
MEDIAN	7.00	3.00	5.00	8.00	11.00	14.00

Figure 5-4 shows the validity of the forecast of the current situation (how well do the used probability distributions fit with reality). The values of the forecast are displayed differently. A forecast distribution has emerged from the forecast that indicates the probability of x occupied beds during each hour in the forecast of the period 1st of February 2019 until April 30, 2019. When the actual bed occupancy is added to this data, you can look up the probability from the probability distribution that the actual achievements are achieved. This is a cumulative chance: all the chances of lower realizations are added up to x. 0.01 means that the realization is very low compared to the forecast. 0.99 means that the realization is very high compared to the

forecast. Figure 5-4 is a representation of all these opportunities. This graph is sorted from low probability to high probability. The hours in the forecast on the x-axis are completely mixed.

The sorting is done to quickly visualize whether the forecast gives an overestimate, underestimation, or correct prediction of the bed occupancy. In this case, the overestimate is somewhat larger than the underestimate. This means that the forecast predicted more beds than in reality were necessary. Especially in the left part of Figure 5-4 the overestimate is bigger than in the right part. In the right part is an underestimation of bed occupancy.

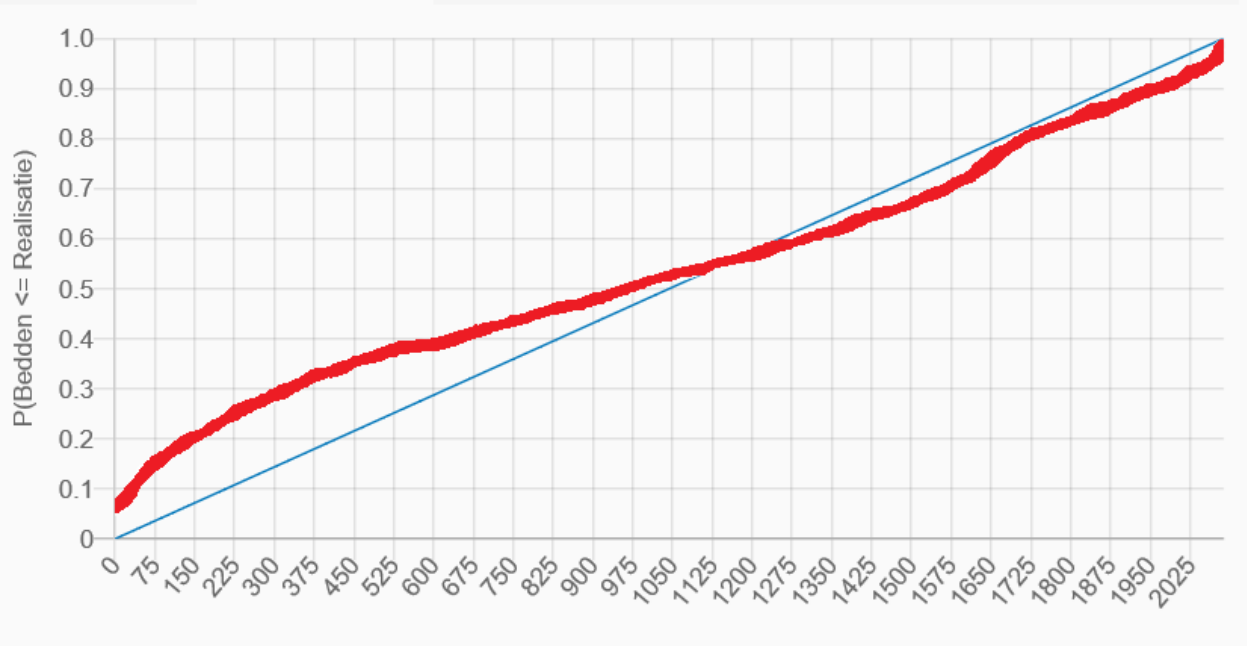


Figure 5-4 Validation forecast current situation HOH (n=432, Rhythm, 2018-2019)

Realization

The realizations of the three datasets are given in Appendix G –Realization 1, 2, and 3. This provides insight into the number of additional beds for the specialism general surgery at the surgical nursing wards, regardless of the planned surgeries. Since this research focuses on optimizing the OR session planning, the realizations are outside the scope of this research.

5.3.3 Intervention options realization

In order to optimize the OR session plan and to decrease the peak in bed demand at the surgical nursing wards, specialists from the specialism general surgery are exchanged. In total three intervention options are analyzed with PFF.

The three exchange options are listed below, option 1 is described in this section. In Appendix H – Intervention options 1, 2, and 3 of the realization, all three intervention options of the realization are described in detail.

Option 1: General surgery E (Monday) exchange with General surgery C (Thursday).

Option 2: General surgery A (Monday) exchange with General surgery C (Thursday).

Option 3: Move General surgery A from Monday to Friday

The reason for the change of option 1 is because the average LOS of General surgery E is shorter than the average LOS of General surgery C. The patients of General surgery C occupy a bed for about a week, so on average they will be discharged either on Sunday or on Monday. The expectation is that this change will increase the bed occupancy during the weekend. A disadvantage of this option is that General surgery E performed 30 surgeries, of which 21 on Monday.

The session load of the specialists is given in PFF. The session load calculates the expected value (y-axis) of the amount of occupied beds when specialist X conducts a surgery. The x-axis is in hours, where 0 is the start of the session. Table 5-6 gives an overview of the session load of General surgery E and General surgery C. For example: the expected value that a bed is occupied 24 hours after General surgery E has conduct a surgery is 1.111. The expected value that a bed is occupied 24 hours after General surgery C has conduct a surgery is 1.263. Figure 5-5 gives an overview of the session load of General surgery E. Figure 5-6 gives an overview of the session load of General surgery C.

Table 5-6 Overview session load General surgery E and General surgery C

Session load		
	General surgery E	General surgery C
24 hours	1.111	1.263
48 hours	0.778	0.702
72 hours	0.222	0.456
96 hours	0.222	0.368
120 hours	0.222	0.333

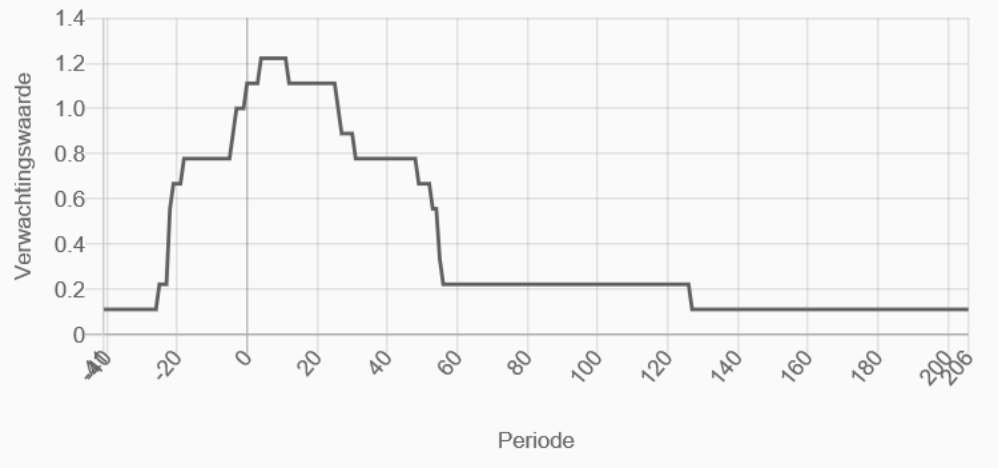


Figure 5-5 Session load of General surgery E (n=9, PFF Rhythm, 2018-2019)

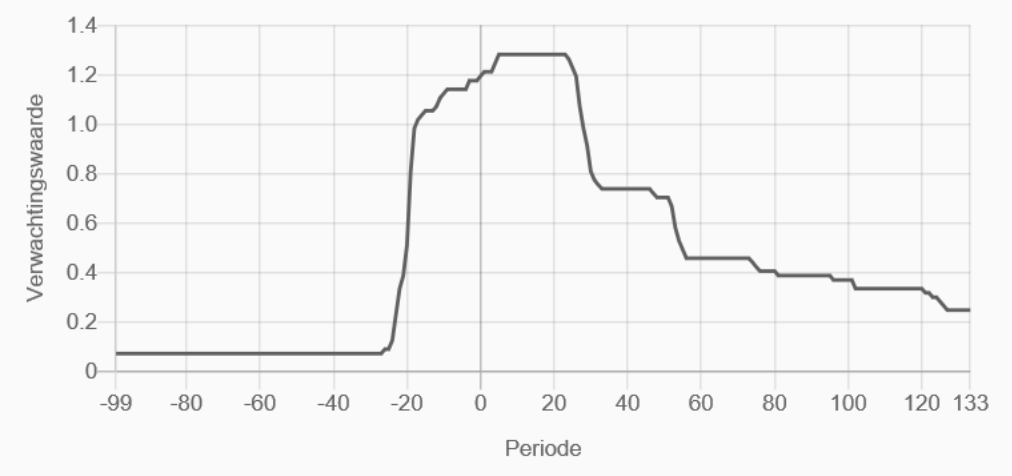


Figure 5-6 Session load of General surgery C (n=57, PFF Rhythm, 2018-2019)

The differences of session load between those two specialists is that the chance a bed is occupied is higher and longer for General surgery C then for General surgery E.

Figure 5-7 shows an overview of March 5, 2019 to April 11, 2019 of the forecast of the bed occupancy of intervention option 1.

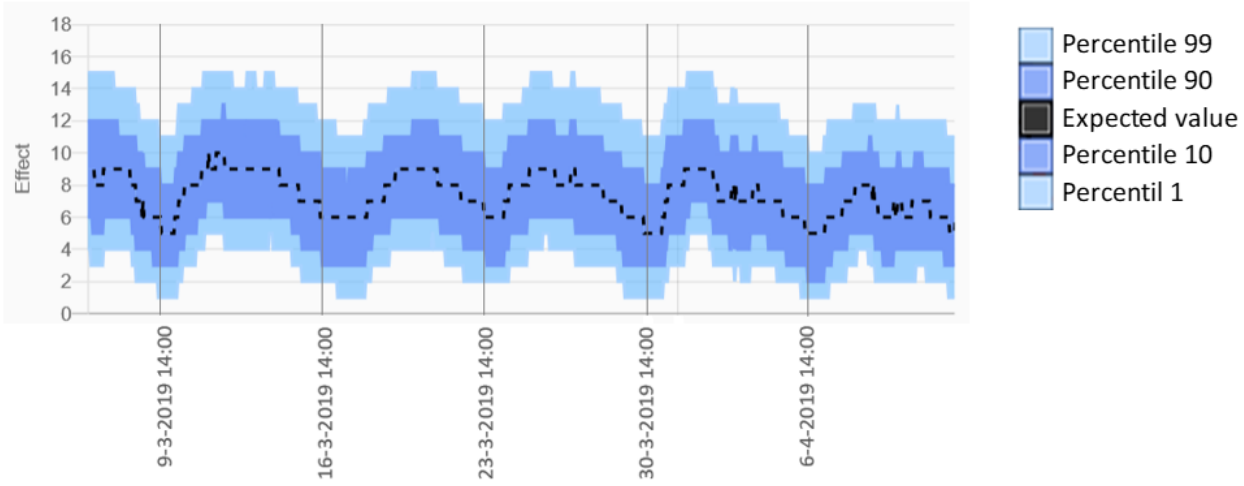


Figure 5-7 Forecast bed occupancy on Saturdays of intervention option 1 HOH (n=94, PFF Rhythm, 2018-2019)

Figure 5-7 shows a pattern during the weekends and weekdays. The data which is shown on the x-axis are Saturdays. In the weekends there is an off-peak load of the bed occupancy. The ultimate off-peak load is on Saturday, and it increases during the day on Sunday. The first peak has an expected value of ten beds. The second, third, and fourth peaks have an expected value of nine beds. The fifth peak has an expected value of eight beds. The first, fourth, and fifth off-peak load have an expected value of five beds. The second, and third off-peak load have an expected value of six beds. There is a difference of three, four, and five beds between the peaks and off-peaks load.

Table 5-7 gives an overview of the descriptive statistics of the bed occupancy for intervention option 1 of the months February, March, and April per hour. For example: the minimum bed occupancy for the expected value is 3. The standard deviation of the expected value is 1.66. This means that in 68.2% of the time the average bed occupancy is 7.16 +/- 1.66, under the assumption that the data is normally distributed. In Appendix F – Descriptive statistics of the bed occupancy - Intervention option 1 the descriptive statistics of the bed occupancy is given of the expected value per hour, per day, and per month for intervention option 1.

Table 5-7 Descriptive statistics of the bed occupancy for intervention option 1

	Percentile 1	Percentile 10	Expected value	Percentile 90	Percentile 99
STANDARD DEVIATION	1.38	1.53	1.66	1.78	1.87
MIN	0.00	1.00	3.00	6.00	8.00
MAX	6.00	8.00	11.00	15.00	18.00
AVERAGE	2.64	4.45	7.16	10.07	12.83
MEDIAN	3.00	5.00	7.00	10.00	13.00

A short overview of the results of the three intervention options will be described below.

Results intervention option 1:

There is a difference of three, four, and five beds between the peaks and off-peaks load. The standard deviation of the expected value is 1.66, this means that in 68.2% of the time the average bed occupancy is 7.16 +/- 1.66, under the assumption that the data is normally distributed. The minimum bed occupancy of the expected value is 3, the maximum bed occupancy of the expected value is 11.

Results intervention option 2:

There is a difference of three and four beds between the peaks an off-peaks load. The standard deviation of the expected value is 1.74, this means that in 68.2% of the time the average bed occupancy is 7.61 +/- 1.74. The minimum bed occupancy of the expected value is 3, the maximum bed occupancy of the expected value is 12.

Results intervention option 3:

There is a difference of three, four, and five beds between the peaks an off-peaks load. The standard deviation of the expected value is 1.58, this means that in 68.2% of the time the average bed occupancy is 7.72 +/- 1.58. The minimum bed occupancy of the expected value is 5, the maximum bed occupancy of the expected value is 11.

Quantile distribution:

To compare the current situation and the three intervention options, the 5% and 95% quantiles (respectively the Lower Control Limit (LCL) and the Upper Control Limit (UCL)) of the distribution of the bed occupancy for the current situation and the intervention options are calculated.

The LCL and UCL are calculated with the following formulas, based on the assumption of a normal distribution:

$$LCL = Average - (2 * standard\ deviation)$$

$$UCL = Average + (2 * standard\ deviation)$$

These quantiles and the bandwidth between the two quantiles are given in Table 5-8. Intervention option 3 is the best option compared to intervention option 1 and intervention option 2 since this option is the only option that shows a smaller bandwidth compared to the current situation. There is not enough difference between the current situation and intervention option 3 to apply this intervention in practice.

Table 5-8 Standard deviation, average, minimum, maximum, LCL, UCL, and the bandwidth of the distribution of the bed occupancy of all options

	Standard deviation	Average	Min	Max	LCL	UCL	Bandwidth (UCL-LCL)
Current situation	1.64	7.67	4	11	4.39	10.95	6.56
Intervention option 1	1.66	7.16	3	11	3.84	10.48	6.64
Intervention option 2	1.74	7.62	3	12	4.14	11.10	6.96
Intervention option 3	1.58	7.72	5	11	4.56	10.88	6.32

5.3.4 Results of the plan

As previously indicated, dataset P-1 was used to calculate the forecast for the plan and to ultimately exchange with the specialists. The data from 1st February 2019 to January 31, 2019 was used within this dataset. For this plan, we assume that the planned sessions for specialist X are conducted by specialist X.

Within HOH, the specialists have a fixed day to perform surgeries. In many cases this planning is not adhered to. Figure 5-8 and Figure 5-9 shows the planned and performed surgeries per specialist. For example: General surgery A performs 79% of the surgeries during the planned surgeries, and 44% of the surgeries are performed by General surgery A which were not planned for General surgery A.

In addition, General surgery A exchanges the most with General surgery C and General surgery B. Reasons for specialists to exchange between themselves are because of holidays, attending a congress, or materials that are not yet present.

Inpatient	Algemene Chirurgie A	Algemene Chirurgie B	Algemene Chirurgie C	Algemene Chirurgie D	Algemene Chirurgie E	Algemene Chirurgie F	Algemene Chirurgie G	Algemene Chirurgie H	Algemene Chirurgie I	Algemene Chirurgie J	Algemene Chirurgie K	Algemene Chirurgie L	Algemene Chirurgie M	Total	Planned and performed
Algemene Chirurgie A	128	5	12	1	0	3	0	0	0	1	0	0	0	162	79%
Algemene Chirurgie B	12	69	3	2	1	3	6	0	0	0	0	0	0	104	66%
Algemene Chirurgie C	23	1	103	1	0	1	4	0	0	0	0	0	0	143	72%
Algemene Chirurgie D	4	4	2	95	0	3	1	1	0	1	0	0	0	130	73%
Algemene Chirurgie E	5	3	1	7	28	0	0	0	0	0	0	0	0	68	41%
Algemene Chirurgie F	6	0	2	1	1	35	2	0	0	2	3	2	0	81	43%
Algemene Chirurgie G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
Algemene Chirurgie H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
Algemene Chirurgie I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
Algemene Chirurgie J	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
Algemene Chirurgie K	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
Algemene Chirurgie L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
Algemene Chirurgie M	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0%
KNO	4	4	1	3	0	2	0	0	0	0	0	2	0	76	54%
Neurochirurgie	9	5	1	2	4	3	4	0	1	0	0	0	0	212	75%
Orthopaedie	4	8	3	2	5	2	4	0	0	0	1	0	0	505	88%
Gynaecologie	12	4	9	5	1	9	4	0	0	2	0	0	0	400	83%
Cardiologie	3	0	0	4	2	1	1	0	0	0	0	0	0	47	64%
Plastische chirurgie	11	4	2	4	1	1	1	0	0	0	0	0	0	116	59%
Urologie	7	0	2	1	0	1	0	0	0	0	0	0	0	218	89%
Total	228	107	141	128	43	65	27	1	1	6	4	4	0		
% surgeries performed not planned for specialist	44%	36%	27%	26%	35%	46%	100%	100%	100%	100%	100%	100%	0%		

Figure 5-8 Planned and performed surgeries per specialist of general surgery (n=687, OR system HOH, 2018-2019)

Inpatient	KNO	Neurochirurgie	Orthopaedie	Gynaecologie	Cardiologie	Plastische chirurgie	Urologie	Total	Planned and performed
Algemene Chirurgie A	0	1	2	6	1	1	1	162	79%
Algemene Chirurgie B	2	0	2	2	1	1	0	104	66%
Algemene Chirurgie C	0	0	4	5	0	0	1	143	72%
Algemene Chirurgie D	0	1	9	8	0	1	0	130	73%
Algemene Chirurgie E	1	6	6	4	3	3	1	68	41%
Algemene Chirurgie F	0	0	5	10	0	1	11	81	43%
Algemene Chirurgie G	0	0	0	0	0	0	0	0	0%
Algemene Chirurgie H	0	0	0	0	0	0	0	0	0%
Algemene Chirurgie I	0	0	0	0	0	0	0	0	0%
Algemene Chirurgie J	0	0	0	0	0	0	0	0	0%
Algemene Chirurgie K	0	0	0	0	0	0	0	0	0%
Algemene Chirurgie L	0	0	0	0	0	0	0	0	0%
Algemene Chirurgie M	0	0	0	0	0	0	0	1	0%
KNO	41	0	6	8	0	2	3	76	54%
Neurochirurgie	0	159	10	11	1	1	1	212	75%
Orthopaedie	0	3	442	14	6	2	9	505	88%
Gynaecologie	1	0	11	333	8	0	1	400	83%
Cardiologie	0	0	2	3	30	0	1	47	64%
Plastische chirurgie	1	0	6	14	0	69	2	116	59%
Urologie	0	0	5	7	1	1	193	218	89%
Total	46	170	510	425	51	82	224		
% surgeries performed not planned for specialist	11%	6%	13%	22%	41%	16%	14%		

Figure 5-9 Planned and performed surgeries per specialist of general surgery (n=687, OR system HOH, 2018-2019)

Figure 5-10 gives an overview of the MSS of the current situation for the specialism general surgery within HOH.

		OR 1	OR 2	OR 3	OR 4	OR 5	OR 6
Monday	7:30-11:00	General surgery A		General surgery F	General surgery E		
Monday	11:00-14:30	General surgery A		General surgery F	General surgery E		
Tuesday	7:30-11:00	General surgery D					
Tuesday	11:00-14:30	General surgery D					
Wednesday	7:30-11:00				General surgery B		
Wednesday	11:00-14:30				General surgery B		
Thursday	7:30-11:00			General surgery C			
Thursday	11:00-14:30			General surgery C			
Friday	7:30-11:00						
Friday	11:00-14:30						General surgery A

		OR 1	OR 2	OR 3	OR 4	OR 5	OR 6
Monday	7:30-11:00	General surgery A		General surgery F	General surgery E		
Monday	11:00-14:30	General surgery A		General surgery F	General surgery E		
Tuesday	7:30-11:00	General surgery D					
Tuesday	11:00-14:30	General surgery D					
Wednesday	7:30-11:00				General surgery B		
Wednesday	11:00-14:30				General surgery B		
Thursday	7:30-11:00			General surgery C			
Thursday	11:00-14:30			General surgery C			
Friday	7:30-11:00						General surgery D
Friday	11:00-14:30						General surgery B

Figure 5-10 MSS current situation for general surgery HOH

Figure 5-11 shows an overview of March 5, 2019 to April 11, 2019 of the forecast of the bed occupancy of the MSS of the current situation. We assume that the planned sessions for specialist X are conducted by specialist X.

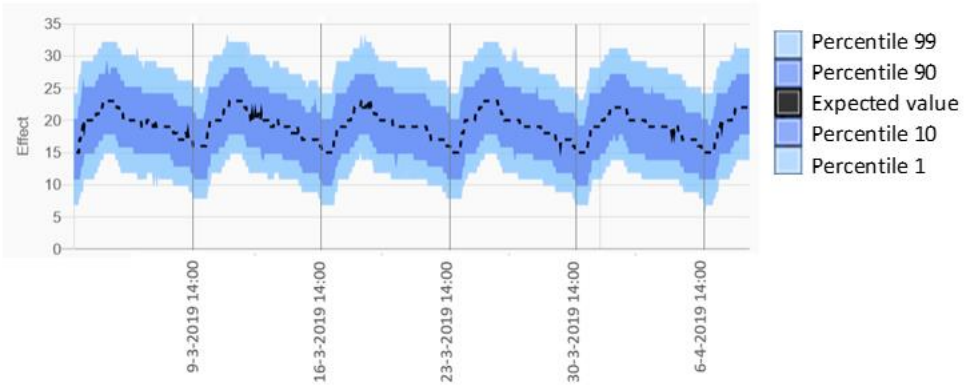


Figure 5-11 Forecast bed occupancy on Saturdays of the MSS current situation HOH (n=229, PFF Rhythm, 2018-2019)

Figure 5-11 shows a pattern during the weekends and weekdays. The data which is shown on the x-axis are Saturdays. In the weekends there is an off-peak load of the bed occupancy. The ultimate off-peak load is on Saturday, and it increases during the day on Sunday. The first, second, third, and fourth peak have an expected value of 23 beds, the fifth peak has an expected value of 22 beds. The first off-peak load has an expected value of 16 beds, the other four off-peak loads have an expected value of 15 beds. There is a difference of seven and eight beds between the peak and off-peak load.

Table 5-9 gives an overview of the descriptive statistics of the bed occupancy for the MSS current situation of the months February, March, and April per hour. We assume that the planned sessions for specialist X are conducted by specialist X. For example: the minimum bed occupancy for the expected value is 12. The standard deviation of the expected value is 2.33. This means that in 68.2% of the time the average bed occupancy is 18.63 +/- 2.33, under the assumption that the data is normally distributed. In Appendix F – Descriptive statistics of the bed occupancy- MSS current situation the descriptive statistics of the bed occupancy is given of the expected value per hour, per day, and per month for the MSS current situation.

Table 5-9 Descriptive statistics of the bed occupancy for the MSS current situation

	Percentile 1	Percentile 10	Expected value	Percentile 90	Percentile 99
STANDARD DEVIATION	2.13	2.22	2.33	2.48	2.57
MIN	5.00	8.00	12.00	16.00	20.00
MAX	15.00	18.00	23.00	28.00	32.00
AVERAGE	10.84	14.14	18.63	23.28	27.47
MEDIAN	11.00	14.00	19.00	24.00	28.00

5.3.5 Intervention options plan

In order to optimize the OR session plan and to decrease the peak in bed demand at the surgical nursing wards, specialists from the specialism general surgery are exchanged. In total three intervention options are analyzed with PFF. We assume that the planned sessions for specialist X are conducted by specialist X. The three intervention options for the MSS are the same options as for the realization. MSS intervention option 1 is described in this section. More information about this option is described in section 5.3.3. In Appendix I – MSS intervention options 1, 2, and 3all three options are described in detail.

Figure 5-12 shows an overview of March 5, 2019 to April 11, 2019 of the forecast of the bed occupancy of MSS intervention option 1.

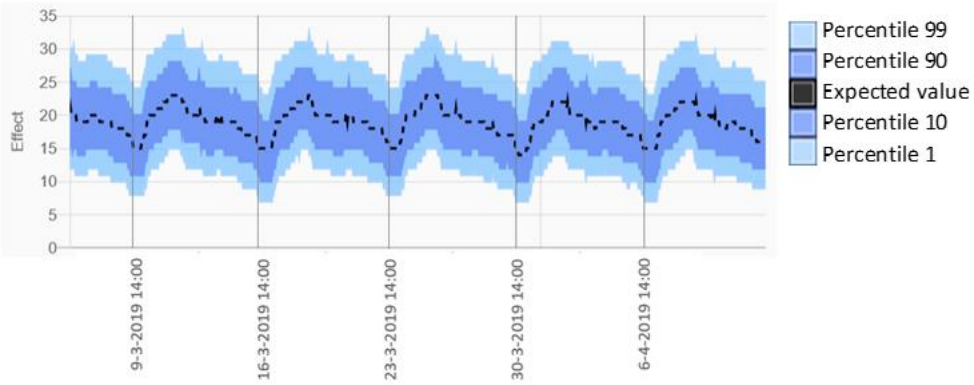


Figure 5-12 Forecast bed occupancy on Saturdays of MSS intervention option 1 HOH (n=229, PFF Rhythm, 2018-2019)

Figure 5-12 shows a pattern during the weekends and weekdays. The data which is shown on the x-axis are Saturdays. In the weekends there is an off-peak load of the bed occupancy. The ultimate off-peak load is on Saturday, and it increases during the day on Sunday. All the peaks have an expected value of 23 beds. The first, second, third, and fifth off-peak load have an expected value of 15 beds, the fourth off-peak load has an expected value of 14 beds. There is a difference of eight and nine beds between the peaks and off-peaks load.

Table 5-10 gives an overview of the descriptive statistics of the bed occupancy for MSS intervention option 1 of the months February, March, and April per hour. For example: the minimum bed occupancy for the expected value is 12. The standard deviation of the expected value is 2.30. This means that in 68.2% of the time the average bed occupancy is 18.62 +/- 2.30, under the assumption that the data is normally distributed. In Appendix F – Descriptive statistics of the bed occupancy - MSS intervention option 1 the descriptive statistics of the bed occupancy is given of the expected value per hour, per day, and per month for MSS intervention option 1.

Table 5-10 Descriptive statistics of the bed occupancy for MSS intervention option 1

	Percentile 1	Percentile 10	Expected value	Percentile 90	Percentile 99
STANDARD DEVIATION	2.16	2.22	2.30	2.39	2.47
MIN	5.00	8.00	12.00	16.00	20.00
MAX	15.00	19.00	23.00	28.00	32.00
AVERAGE	10.83	14.11	18.62	23.30	27.47
MEDIAN	11.00	14.00	19.00	24.00	28.00

A short overview of the results of the three MSS intervention options will be described below.

Results MSS intervention option 1:

There is a difference of eight and nine beds between the peaks and off-peaks load. The standard deviation of the expected value is 2.30, this means that in 68.2% of the time the average bed occupancy is 18.62 +/- 2.30, under the assumption that the data is normally distributed. The minimum bed occupancy of the expected value is 12, the maximum bed occupancy of the expected value is 23.

Results MSS intervention option 2:

There is a difference of seven and eight beds between the peaks an off-peaks load. The standard deviation of the expected value is 2.28, this means that in 68.2% of the time the average bed occupancy is 18.70 +/- 2.28, under the assumption that the data is normally distributed. The minimum bed occupancy of the expected value is 11, the maximum bed occupancy of the expected value is 22.

Results MSS intervention option 3:

There is a difference of five and six beds between the peaks an off-peaks load. The standard deviation of the expected value is 1.84, this means that in 68.2% of the time the average bed occupancy is 18.63 +/- 1.84, under the assumption that the data is normally distributed. The minimum bed occupancy of the expected value is 12, the maximum bed occupancy of the expected value is 22.

Quantile distribution:

To compare the MSS current situation and the three MSS intervention options, the 5% and 95% quantiles (respectively the Lower Control Limit (LCL) and the Upper Control Limit (UCL)) of the distribution of the bed occupancy for the MSS current situation and the MSS intervention options are calculated.

The LCL and UCL are calculated with the following formulas, based on the assumption of a normal distribution:

$$LCL = Average - (2 * standard\ deviation)$$

$$UCL = Average + (2 * standard\ deviation)$$

These quantiles and the bandwidth between the two quantiles are given in Table 5-11. MSS intervention option 3 is the best option compared to MSS intervention option 1 and MSS intervention option 2 since this option is the only option that shows a smaller bandwidth compared to the MSS current situation. There is a difference of two beds between MSS intervention option 3 and MSS current situation.

Table 5-11 Standard deviation, average, minimum, maximum, LCL, UCL, and the bandwidth of the distribution of the bed occupancy of all MSS options

	Standard deviation	Average	Min	Max	LCL	UCL	Bandwidth (UCL-LCL)
MSS current situation	2.33	18.63	12	23	13.97	23.29	9.32
MSS intervention option 1	2.30	18.62	12	23	14.02	23.22	9.20
MSS intervention option 2	2.28	18.70	11	22	14.14	23.26	9.12
MSS intervention option 3	1.84	18.63	12	22	14.95	22.31	7.36

5.4 Best intervention option

Realization

Looking at the current situation and the three intervention options that were analyzed, the current situation will not be optimized. There is still an off-peak load during the weekends. The differences in beds between the peaks and off-peak loads for those options are three, four, and five beds. To compare the current situation and the three intervention options, the 5% and 95% quantiles (respectively the Lower Control Limit (LCL) and the Upper Control Limit (UCL)) of the

distribution of the bed occupancy for the current situation and the intervention options are calculated.

Intervention option 3 is the best option compared to intervention option 1 and intervention option 2 since this option is the only option that shows a smaller bandwidth compared to the current situation. There is not enough difference between the current situation and intervention option 3 to apply this intervention in practice.

Plan

In this case we assume that the planned sessions for specialist X are conducted by specialist X. MSS intervention option 3 has the best distribution of beds, especially during the week. There is still an off-peak load during the weekends. The difference in beds between the peak and off-peak load for option 3 is five and six beds. The difference in beds between the peak and off-peak load for the MSS current situation, MSS intervention option 1, and MSS intervention option 2 is seven and eight beds. The variation in bed occupancy would decrease with two beds. To compare the MSS current situation and the three MSS intervention options, the 5% and 95% quantiles (respectively the Lower Control Limit (LCL) and the Upper Control Limit (UCL)) of the distribution of the bed occupancy for the MSS current situation and the MSS intervention options are calculated.

MSS intervention option 3 is the best option compared to MSS intervention option 1 and MSS intervention option 2 since this option is the only option that shows a smaller bandwidth compared to the MSS current situation. There is a difference of two beds between MSS intervention option 3 and MSS current situation.

MSS intervention option 3 has been worked out in an MSS (Figure 5-13). This is the best intervention option for the specialism general surgery within HOH.

		OR 1	OR 2	OR 3	OR 4	OR 5	OR 6
Monday	7:30-11:00			General surgery F	General surgery E		
Monday	11:00-14:30			General surgery F	General surgery E		
Tuesday	7:30-11:00	General surgery D					
Tuesday	11:00-14:30	General surgery D					
Wednesday	7:30-11:00				General surgery B		
Wednesday	11:00-14:30				General surgery B		
Thursday	7:30-11:00			General surgery C			
Thursday	11:00-14:30			General surgery C			
Friday	7:30-11:00	General surgery A					
Friday	11:00-14:30	General surgery A					Observer general surgery A

		OR 1	OR 2	OR 3	OR 4	OR 5	OR 6
Monday	7:30-11:00			General surgery F	General surgery E		
Monday	11:00-14:30			General surgery F	General surgery E		
Tuesday	7:30-11:00	General surgery D					
Tuesday	11:00-14:30	General surgery D					
Wednesday	7:30-11:00				General surgery B		
Wednesday	11:00-14:30				General surgery B		
Thursday	7:30-11:00			General surgery C			
Thursday	11:00-14:30			General surgery C			
Friday	7:30-11:00	General surgery A					General surgery D
Friday	11:00-14:30	General surgery A					General surgery B

Figure 5-13 Best intervention option MSS for the specialism general surgery within HOH

5.5 Conclusion

The fourth research question is discussed in this chapter.

> *What is the effect of the intervention for the peaks in bed demand at the surgical nursing wards within HOH?*

The specialists of HOH have a fixed day to perform surgeries, in many cases this planning is not adhered to. Therefore, this research focused on the realization and the plan within HOH. The realization is what occurs in practice, for the plan we assume that the planned sessions for specialist X are conducted by specialist X. For both categories, the current situation is shown with three intervention options.

Option 1: General surgery E (Monday) exchange with General surgery C (Thursday).

Option 2: General surgery A (Monday) exchange with General surgery C (Thursday).

Option 3: Move General surgery A from Monday to Friday

Realization

In many cases, the specialists of general surgery do not adhere to the plan, therefore the data which is used for this research is very small and cannot be optimally exchanged with specialists. Looking at the current situation and the three intervention options that were analyzed, the current situation will not be optimized. There is still an off-peak load during the weekends. The differences in bed occupancy between the peaks and off-peak loads for those options are three, four, and five beds (see Table 5-12). To compare the current situation and the three intervention options, the 5% and 95% quantiles (respectively the Lower Control Limit (LCL) and the Upper Control Limit (UCL)) of the distribution of the bed occupancy for the current situation and the intervention options are calculated.

Intervention option 3 is the best option compared to intervention option 1 and intervention option 2 since this option is the only option that shows a smaller bandwidth compared to the current situation. There is not enough difference between the current situation and intervention option 3 to apply this intervention in practice. Table 5-12 gives an overview of the differences in bed occupancy between the peaks and off-peak loads, LCL, UCL, and the bandwidth of the distribution of the bed occupancy of all options.

Table 5-12 Overview of the differences in bed occupancy, LCL, UCL, and te bandwidth of the distribution of the bed occupancy of all options

	Differences in bed occupancy	**LCL**	**UCL**	**Bandwidth**
Current situation	3 and 4	4.39	10.95	6.56
Intervention option 1	3, 4, and 5	3.84	10.48	6.64
Intervention option 2	3 and 4	4.14	11.10	6.96
Intervention option 3	3, 4, and 5	4.56	10.88	6.32

Plan

This research has shown that the surgeries that are planned for general surgery are not always performed within general surgery. A dataset has been created that only includes the performed surgeries which were also planned for general surgery.

Within this dataset, specialists were exchanged to analyze the effect of the intervention on the peak in bed demand for general surgery and the surgical nursing wards. In this case we assume that the planned sessions for specialist X are conducted by specialist X. MSS intervention option 3 has the best distribution of beds, especially during the week. There is still an off-peak load during the weekends. The differences in bed occupancy between the peak and off-peak load for MSS intervention option 3 is five and six beds (see Table 5-13). The differences in bed occupancy between the peak and off-peak load for the MSS current situation, MSS intervention option 2, and MSS intervention option 3 is seven, eight, and nine beds. To compare the MSS current situation and the three MSS intervention options, the 5% and 95% quantiles (respectively the Lower Control Limit (LCL) and the Upper Control Limit (UCL)) of the distribution of the bed occupancy for the MSS current situation and the MSS intervention options are calculated.

MSS intervention option 3 is the best option compared to MSS intervention option 1 and MSS intervention option 2 since this option is the only option that shows a smaller bandwidth compared to the MSS current situation. There is a difference of two beds between MSS intervention option 3 and MSS current situation. Table 5-13 gives an overview of the differences in bed occupancy between the peaks and off-peak loads, LCL, UCL, and the bandwidth of the distribution of the bed occupancy of all MSS options.

Table 5-13 Overview of the differences in bed occupancy, LCL, UCL, and the bandwidth of the distribution of the bed occupancy of all MSS options

	Differences in bed occupancy	**LCL**	**UCL**	**Bandwidth**
MSS current situation	7 and 8	13.97	23.29	9.32
MSS intervention option 1	8 and 9	14.02	23.22	9.20
MSS intervention option 2	7 and 8	14.14	23.26	9.12
MSS intervention option 3	5 and 6	14.95	22.31	7.36

MSS intervention option 3 has been worked out in an MSS (Figure 5-13). This is the best intervention option for the specialism general surgery within HOH.

6 Implementation

We discuss the implementation of the intervention options for specialists of general surgery in HOH. This chapter describes the OR session planning (Section 6.1), step-by-step plan (Section 6.2), and the conclusion (Section 6.3).

6.1 OR session planning

PFF calculated the peaks in bed demand per specialist of the specialism general surgery, based on the performed surgeries. In the current situation, there is an off-peak load in bed demand during the weekends at the surgical nursing wards. We also see that general surgery deviates a lot from the OR session planning. Before HOH wants to implement a change, it will first have to be examined why people deviate so much and if it is worth implementing an MSS within HOH.

Since there is no optimal change for the realization within specialists of general surgery, it is possible that the specialists from the aforementioned options can exchange with each other without affecting the peaks in bed demand. However, the analysis has shown that there is an improvement possible in the peaks in bed demand if HOH adheres to an MSS. When moving within the MSS, there is a significant improvement when MSS intervention option 3 is used. Within this option there is a move from general surgery A from Monday to Friday.

The following section describes the steps that must be taken when HOH thinks an MSS will work in practice or HOH want to implement one of the possible intervention options in the OR session planning.

6.2 Step-by-step plan

To implement an MSS or one of the possible intervention options, a step-by-step plan is created. The following steps are included:

1. The OR committee should create a roadmap

Since the OR committee makes the decisions concerning the OR complex, this organ should be central in the implementation plan. First, the OR committee should be convinced about the results of this research.

The most important findings of the analysis, results, and the main conclusion of Chapter 5 should be presented to the OR committee. When the OR committee is convinced, they should create a roadmap. The roadmap should at least include how to involve specialists and OR personnel, what is needed to implement the intervention, and evaluate the changes after a certain period. The OR committee can decide which possible intervention option HOH can implement. We shortly discuss this in the steps below.

2. Involve specialists and OR personnel

The specialists are represented in the OR committee by three specialists, of which one specialist of general surgery. However, all specialists of the specialism general surgery should be involved in the implementation. Besides the specialists, the OR personnel also need to be involved. Especially the OR planners need to know what changes are made and what the OR planners need to do differently. The current staff meetings are suitable to involve specialists and OR personnel.

3. Implementation OR session planning

When one intervention option is chosen, the OR session planning needs to change. The OR planners need to know which specialists performs surgery at what day. For example: if General surgery A wants to exchange Monday with Friday the OR planners cannot plan surgeries on Monday for this specialist.

4. Evaluate the changes

During this process of implementation, the OR committee need to evaluate several times to observe the progress of the implementation. During these evaluation sessions, the OR committee can decide to make changes in the implementation.

6.3 Conclusion

The fifth research question is discussed in this chapter:

What steps need to be taken by HOH to implement the most possible intervention option?

This research has shown that general surgery deviates a lot from the OR session planning. Before HOH wants to implement a change, it will first have to be examined why people deviate so much and if it is worth implementing an MSS within HOH.

Since there is no optimal change for the realization within specialists of general surgery, it is possible that the specialists from the aforementioned options can exchange with each other without affecting the peaks in bed demand. However, the analysis has shown that there is an improvement possible in the peaks in bed demand if HOH adheres to the MSS. When moving within the MSS, there is a significant improvement when MSS intervention option 3 is used. Within this option there is a move from general surgery A from Monday to Friday.

There are several steps who need to be taken by HOH when implementing an MSS or a possible intervention option. First, the OR committee should be convinced within the results of this research. The most important findings of the analysis, results, and the main conclusion should be present to the OR committee. When the OR committee is convinced, they should create a roadmap. Second, all specialists of the specialism general surgery, and the OR personnel should be involved in the implementation. Third, when one intervention option is chosen, the OR session planning need to change. The OR planners need to know which specialists performs surgery at what day. Fourth, the progress of the implementation should be evaluated several times by the OR committee. To realize the interventions, we suggest a step-by-step plan that contains the following main steps:

1. The OR committee should create a roadmap
2. Involve specialists and OR personnel
3. Implementation OR session planning
4. Evaluate the changes

7 Conclusions

The conclusions of our research will be described. Our research objective is to derive recommendations for optimizing the OR session planning within HOH such that the peaks in bed demand at the nursing wards can be decreased. In the remainder of this section, we repeat all research questions and summarize the answer to these questions.

1. ***What is the current influence of the OR session planning on the bed occupancy in the surgical nursing wards within HOH?***

By applying the healthcare framework of Hans, Van Houdenhoven & Hulshof (2012) on HOH, we identified HOH's resource capacity planning on different hierarchical levels. Besides, we gave an overview of the influences of the OR session planning at the surgical nursing ward and the bed demand within HOH. This is all discussed in Chapter 2.

An overview of the bed occupancy is given for both wards. In this overview 1% of the time the maximum capacity is reached for ward surgical 3, and in 36% of the time the maximum capacity is reached for ward B4. When calculating the maximum capacity -1 the bed occupancy is 32 or more in 16% of the time for surgical 3, and the bed occupancy is 29 or more in 51% of the time for ward B4.

There is a peak in bed occupancy at the beginning of the week, and an off-peak load at Saturday for both wards. A possible reason for the peak of bed demand at the beginning of the week is that specialists wants to conduct surgery in the beginning of the week, their reason is that more beds are available at the beginning of the week and they do not want to discharge patients during the weekend. Most people get discharged at Friday. An overview is given of the average sessions per specialism per day. The biggest peak of the week in the amount of sessions is for general surgery on Monday. 40% of all sessions on Monday are planned for general surgery. General surgery has the highest amount of surgeries per session at Tuesday, Wednesday, Thursday, and Friday. Urology has the highest amount of surgeries per session at Monday. The average LOS of patients is the highest for general surgery. There is a peak at Wednesday and an off-peak load at Monday.

Gynecology has the lowest LOS of patients, there is not a peak or an off-peak load for this specialism. The maximum capacity of beds is often reached for ward B4. This ward is designated for the patients of the specialism general surgery. In addition, general surgery has the most sessions, the highest amount of surgeries per session, and the highest LOS of patients.

General surgery has a major impact on the bed demand. Since the OR session planning has a big influence on the planned sessions per specialism, this research will focus on the OR session planning within the specialism general surgery.

2. ***How is the current OR session planning of HOH organized?***

Chapter 3 discusses the current organization of the OR session planning of HOH. Within HOH the modified block scheduling is used, which means there are fixed sessions and flexible sessions in the OR session planning. The advanced scheduling within HOH has a common policy for using the FCFS. The allocation scheduling of HOH is according to the following priority: child patients, pregnant patients, patients with a metabolic disorder, and surgeries with the longest expected duration. The OR policy of HOH is hybrid. In this policy there are ORs which are dedicated to only elective or emergency patients, but also ORs that handle both categories.

3. ***What are possible intervention options for the OR session planning within HOH?***

In Chapter 4, a literature review is conducted to search for intervention options for HOH regarding the OR session planning. A possible intervention for optimizing the OR session planning within HOH is: MSS. It focusses on the tactical decision in the resource capacity planning. MSS allocates surgeons and surgical specialties to a specific OR time block, a day and a room, for a weekly planning horizon. We will focus on the MSS for the specialism general surgery.

4. ***What is the effect of the intervention for the peaks in bed demand at the surgical nursing wards within HOH?***

In Chapter 5, we analyzed the results with PFF. The specialists of HOH have a fixed day to perform surgeries, in many cases this planning is not adhered to. Therefore, this research focused on the realization and the plan within HOH.

The realization is what occurs in practice, for the plan we assume that the planned sessions for specialist X are conducted by specialist X. For both categories, the current situation is shown with three intervention options.

Option 1: General surgery E (Monday) exchange with General surgery C (Thursday).

Option 2: General surgery A (Monday) exchange with General surgery C (Thursday).

Option 3: Move General surgery A from Monday to Friday

Realization

In many cases, the specialists of general surgery do not adhere to the plan, therefore the data which is used for this research is very small and cannot be optimally exchanged with specialists. Looking at the current situation and the three intervention options that were analyzed, the current situation will not be optimized. There is still an off-peak load during the weekends. The differences in bed occupancy between the peaks and off-peak loads for those options are three, four, and five beds (see Table 5-12). To compare the current situation and the three intervention options, the 5% and 95% quantiles (respectively the Lower Control Limit (LCL) and the Upper Control Limit (UCL)) of the distribution of the bed occupancy for the current situation and the intervention options are calculated.

Intervention option 3 is the best option compared to intervention option 1 and intervention option 2 since this option is the only option that shows a smaller bandwidth compared to the current situation. There is not enough difference between the current situation and intervention option 3 to apply this intervention in practice. Table 5-12 gives an overview of the differences in bed occupancy between the peaks and off-peak loads, LCL, UCL, and the bandwidth of the distribution of the bed occupancy of all options.

Table 7-1 Overview of the differences in bed occupancy, LCL, UCL, and te bandwidth of the distribution of the bed occupancy of all options

	Differences in bed occupancy	LCL	UCL	Bandwidth
Current situation	3 and 4	4.39	10.95	6.56
Intervention option 1	3, 4, and 5	3.84	10.48	6.64
Intervention option 2	3 and 4	4.14	11.10	6.96
Intervention option 3	3, 4, and 5	4.56	10.88	6.32

Plan

This research has shown that the surgeries that are planned for general surgery are not always performed within general surgery. A dataset has been created that only includes the performed surgeries which were also planned for general surgery.

Within this dataset, specialists were exchanged to analyze the effect of the intervention on the peak in bed demand for general surgery and the surgical nursing wards. In this case we assume that the planned sessions for specialist X are conducted by specialist X. MSS intervention option 3 has the best distribution of beds, especially during the week. There is still an off-peak load during the weekends. The differences in bed occupancy between the peak and off-peak load for MSS intervention option 3 is five and six beds (see Table 5-13). The differences in bed occupancy between the peak and off-peak load for the MSS current situation, MSS intervention option 2, and MSS intervention option 3 is seven, eight, and nine beds. To compare the MSS current situation and the three MSS intervention options, the 5% and 95% quantiles (respectively the Lower Control Limit (LCL) and the Upper Control Limit (UCL)) of the distribution of the bed occupancy for the MSS current situation and the MSS intervention options are calculated.

MSS intervention option 3 is the best option compared to MSS intervention option 1 and MSS intervention option 2 since this option is the only option that shows a smaller bandwidth compared to the MSS current situation. There is a difference of two beds between MSS intervention option 3 and MSS current situation. Table 5-13 gives an overview of the differences in bed occupancy between the peaks and off-peak loads, LCL, UCL, and the bandwidth of the distribution of the bed occupancy of all MSS options.

Table 7-2 Overview of the differences in bed occupancy, LCL, UCL, and the bandwidth of the distribution of the bed occupancy of all MSS options

	Differences in bed occupancy	LCL	UCL	Bandwidth
MSS current situation	7 and 8	13.97	23.29	9.32
MSS intervention option 1	8 and 9	14.02	23.22	9.20
MSS intervention option 2	7 and 8	14.14	23.26	9.12
MSS intervention option 3	5 and 6	14.95	22.31	7.36

MSS intervention option 3 has been worked out in an MSS (Figure 5-13). This is the best intervention option for the specialism general surgery within HOH.

5. ***What steps need to be taken by HOH to implement the most possible intervention option?***

In Chapter 6, we discuss the steps who need to be taken when HOH wants to implement one of the discussed interventions. This research has shown that general surgery deviates a lot from the OR session planning. Before HOH wants to implement a change, it will first have to be examined why people deviate so much and if it is worth implementing an MSS within HOH.

Since there is no optimal change for the realization within specialists of general surgery, it is possible that the specialists from the aforementioned options can exchange with each other without affecting the peaks in bed demand.

However, the analysis has shown that there is an improvement possible in the peaks in bed demand if HOH adheres to the MSS. When moving within the MSS, there is a significant improvement when MSS intervention option 3 is used. Within this option there is a move from general surgery A from Monday to Friday.

There are several steps who need to be taken by HOH when implementing an MSS or a possible intervention option. First, the OR committee should be convinced within the results of this research. The most important findings of the analysis, results, and the main conclusion should be present to the OR committee. When the OR committee is convinced, they should create a roadmap. Second, all specialists of the specialism general surgery, and the OR personnel should be involved in the implementation. Third, when one intervention option is chosen, the OR session planning need to change.

The OR planners need to know which specialists performs surgery at what day. Fourth, the progress of the implementation should be evaluated several times by the OR committee. To realize the interventions, we suggest a step-by-step plan that contains the following main steps:

1. The OR committee should create a roadmap
2. Involve specialists and OR personnel
3. Implementation OR session planning
4. Evaluate the changes

By answering all these research questions, we succeeded in accomplishing the research objective.

8 Discussion

This chapter describes the strengths (Section 8.1), limitations (Section 8.2), contribution to practice and literature (Section 8.3), and topics for further research (Section 8.4) will be proposed.

8.1 Strengths

Data from 1st of June 2018 until January 31, 2019 has been used to draw up the probability distributions of the bed occupancy of HOH. This data is the most recent data and valuable for the analysis. Ultimately dataset 3 is used for the analysis since this reflects reality. With this dataset the exchanges between specialists can be made.

Within HOH, this is the first time a research was conducted within the OR session planning for specialists of the specialism general surgery. During this research it emerged that there is no optimization possible with the suggested options of the current OR session planning, since the suggested options do not improve the peak in bed demand. This is of course also a result that HOH can use.

An implementation plan has been described for HOH. When HOH wants to implement an MSS or specialists of the suggested options want to exchange between themselves, HOH can implement these exchanges.

8.2 Limitations

This research has several limitations, this section discusses these limitations.

The first limitation encountered during this research is that, in practice, surgeries which were planned for specialists of general surgery are not always performed within general surgery. Within this specialism, exchanges often occurred. Reasons for specialists to exchange between themselves are because of holidays (general surgeons have at least eight weeks holiday per year), attending a congress, or materials that are not yet present. In this way it is difficult to exchange with specialists from general surgery since there is no continuity.

The second limitation is that the number of beds has changed over the years in connection with the rebuilding; this would be finished in 2021. It could be a possibility that doctors discharge their patients earlier because they need beds, while these patients would otherwise have had a longer LOS. This could influence the LOS per specialist, but it can also reduce the quality of care (see section 4.1).

8.3 Contribution to practice and literature

This research provides HOH insight about the current situation of the OR sessions planning for the specialism general surgery. In practice, general surgery deviates a lot from the OR session planning. However, the analysis has shown that there is an improvement possible in the peaks in bed demand if HOH adheres to an MSS. When moving within the MSS, there is a significant improvement when MSS intervention option 3 is used. Finally, we give a couple of suggestions for further research, so that HOH can try to optimize the OR session planning for other specialists.

The most important contribution to literature is that this research is an OR optimization case-study.

8.4 Further research

This section discusses topics for further research.

Master Surgery Schedule: Our main recommendation is to implement an MSS. Currently, HOH does not use an MSS. To create more insight and order, an MSS would improve the OR session planning for the specialism general surgery. For optimizing this OR session planning, HOH should use and implement MSS intervention option 3.

Master Surgery Schedule implementing within HOH: This research has shown that general surgery deviates a lot from the OR session planning. Before HOH wants to implement a change, it will first have to be examined why people deviate so much and if it is worth implementing an MSS within HOH.

Master Surgery Schedule all specialists: Furthermore, it would be optimal if specialists from all specialisms are examined and that for the best option an MSS would create. This research has only focused at the specialism general surgery, but a change in another specialism may also give a better outcome in the demand for beds.

Admission: As mentioned earlier (section 2.1), patients are admitted one day before surgery. In this way, extra beds are occupied, while this is not necessary. This influences the demand for beds. In most cases, patients can be admitted the same morning before surgery (this currently also happens for day treatment patients, so it should be possible). In addition, it requires more logistical insight than just the demand for beds, such as admitting patients.

Insight in waiting lists specialists: HOH has no insight in the waiting lists of specialists because the specialists are independent, and the specialists classify the patients. The specialists do not share these waiting lists with the hospital. HOH wonders whether each specialism has the correct number of OR time per week. Since HOH does not have insight in the waiting lists, they cannot make a statement about this. Since January 2019, the Electronic Medical Record (EMR) has been introduced, from which HOH could extract data when a patient underwent a POS and when the surgery was conducted. Further research can be done here, since this also can influence the OR session planning.

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Appendix A – Healthcare planning and control framework

The healthcare planning and control framework of Hans, van Houdenhoven & Hulshof (2012) exists of four different hierarchical levels and four different managerial areas (Figure 1-1). First, the hierarchical levels will be explained shortly:

- **Strategic** decisions are long term (one year or more) management decisions based on annual forecasts. A strategic decision on the OR planning, can be renovating the OR complex to increase capacity.
- **Tactical** decisions are intermediate term (weeks-months) management decisions based on given and expected workload. A tactical decision on the OR planning is the allocation of the OR capacity to specialisms.
- **Offline operational** decisions are short-term (days-weeks) management decisions based on given workload (actual patients). An offline operational decision on the OR planning can be scheduling elective patients.
- **Online operational** decisions are now (real-time) decisions that are made to monitor and control the process. Reacting to (unforeseen) events. An online operational decision is intervening the elective OR planning when an emergency patient needs to have surgery.

The four managerial areas will be explained shortly:

- **Medical planning** decisions are made by clinicians. A medical decision can be about medical protocols, treatments, and diagnoses.
- **Resource capacity planning** decisions are made by staff management. A resource capacity decision can be about planning, scheduling, and monitoring resources like staff, equipment and facilities.
- **Materials planning** decisions are made by management of materials. A material planning decision can be about warehouse (storage) and inventory purchasing.

Financial planning decisions are made by financial management. A financial planning decision can be about budgeting and controlling financial flows.

Appendix B – Flowchart planning process elective surgeries

Figure Appendix B- 1 shows a flowchart of the planning process (Groenveld, 2018). The asterisks in the flowchart indicates the differences between the OR regulations and practice. There are four differences identified, which are explained below.

*The deadline for specialists to hand in their patient list to the OR planner is three working days before the OR day. In practice, this deadline is not always met.

**It is the responsibility of the specialists to hand in their patient list in time. When it is not handed in on time, the specialists are not allowed to perform surgery on the OR day according to the planning rules formulated by the OR management. The reason for this rule is to make sure specialists will hand in their patient list on time. In practice, the OR planners request the patient list at the specialist(s) if they did not send their patient lists. Officially, it is not the task of the OR planners, but it happens much in practice. Specialists communicate also the changes in their patient lists often after the deadline.

***The deadline for sending the provisional program is two working days before the OR day at 12:00 p.m. In practice, this deadline is not always met.

****Patients for day surgery should be called after the provisional program is known, two working days before the OR at 2:00 p.m. In practice, the provisional program is often available one day before the OR day. Day surgery patients can be called after the clinical patients are called, since clinical patients get priority.

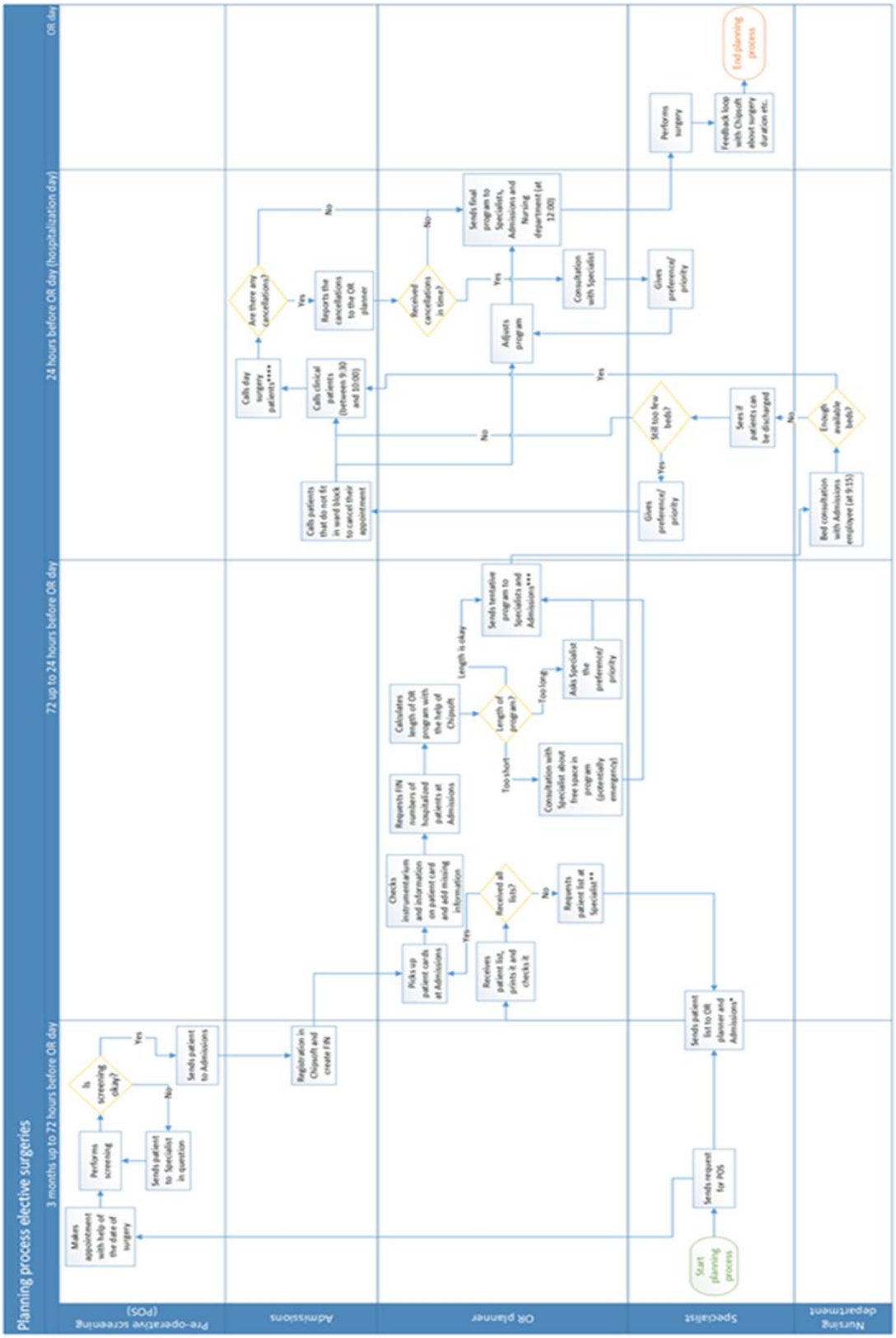

Figure Appendix B- 1 Flowchart planning process HOH (Groenveld, 2018)

Appendix C – Overview bed occupancy per day for ward surgical 3 and B4

Bed occupancy surgical 3

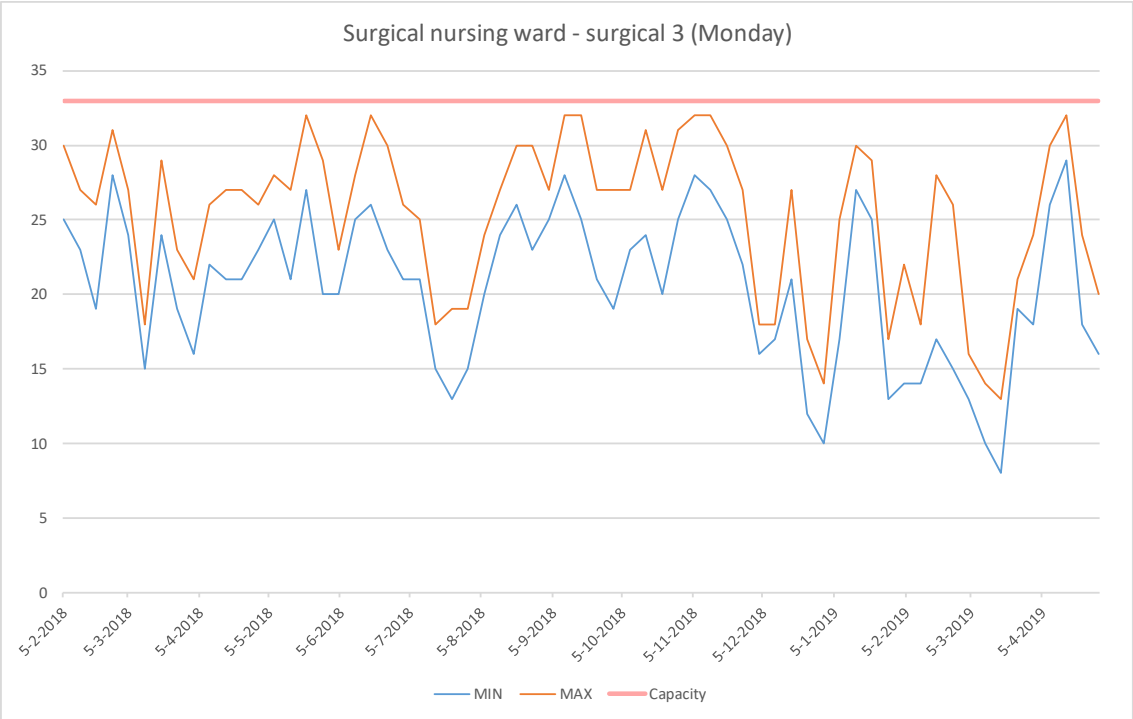

Figure Appendix C - 1 Overview of the bed occupancy for ward surgical 3 at Monday (n=325, OR system HOH, 2018-2019)

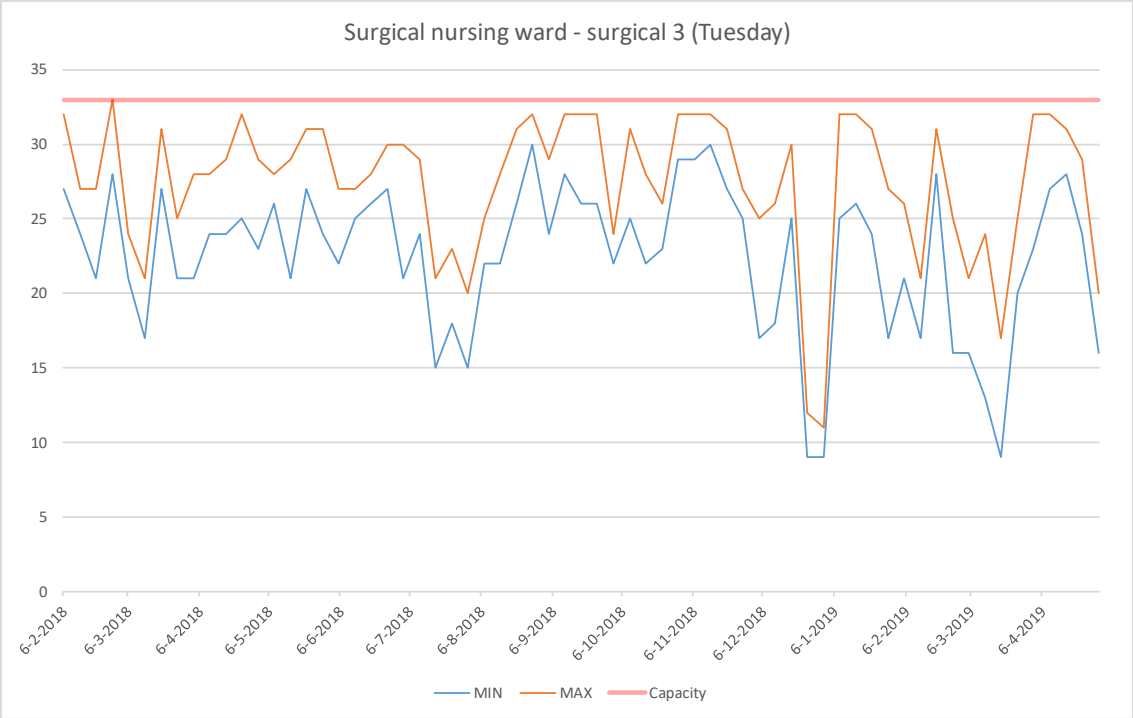

Figure Appendix C - 2 Overview of the bed occupancy for ward surgical 3 at Tuesday (n=325, OR system HOH, 2018-2019)

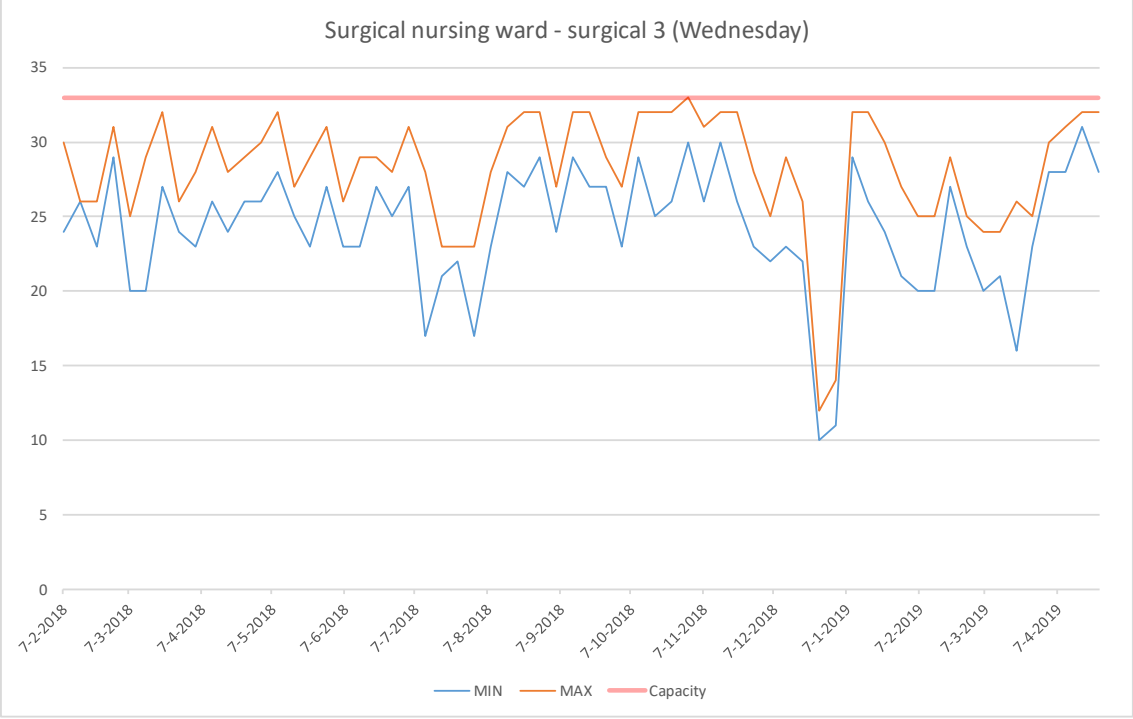

Figure Appendix C - 3 Overview of the bed occupancy for ward surgical 3 at Wednesday (n=320, OR system HOH, 2018-2019)

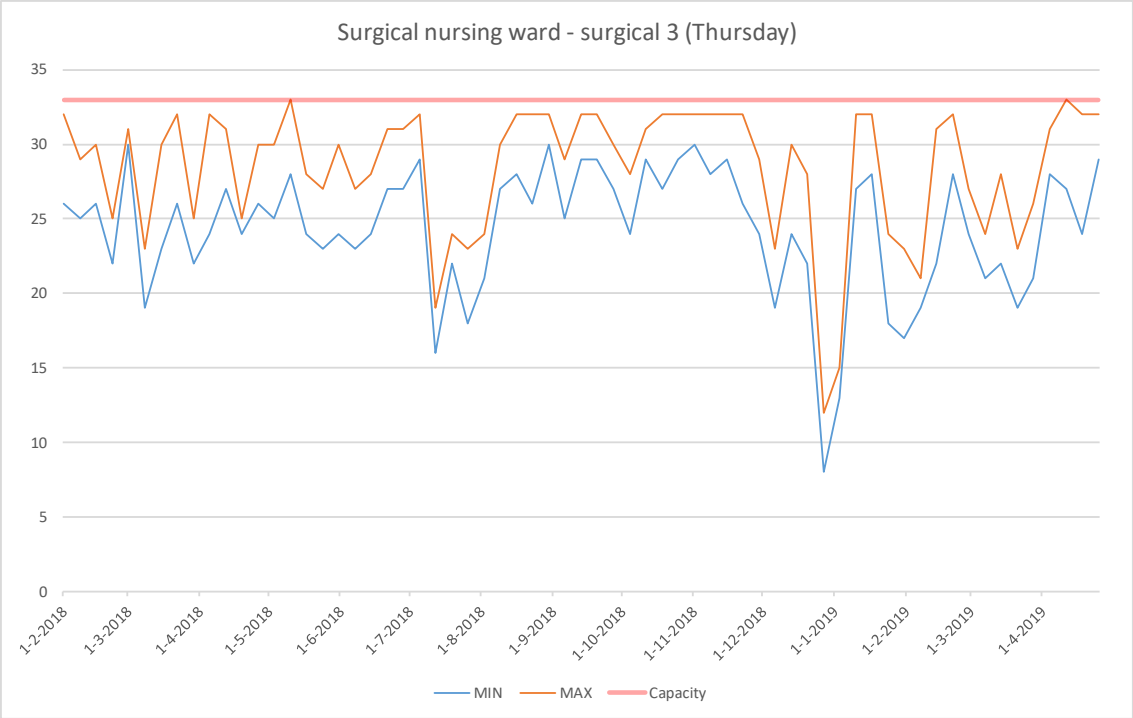

Figure Appendix C - 4 Overview of the bed occupancy for ward surgical 3 at Thursday (n=335, OR system HOH, 2018-2019)

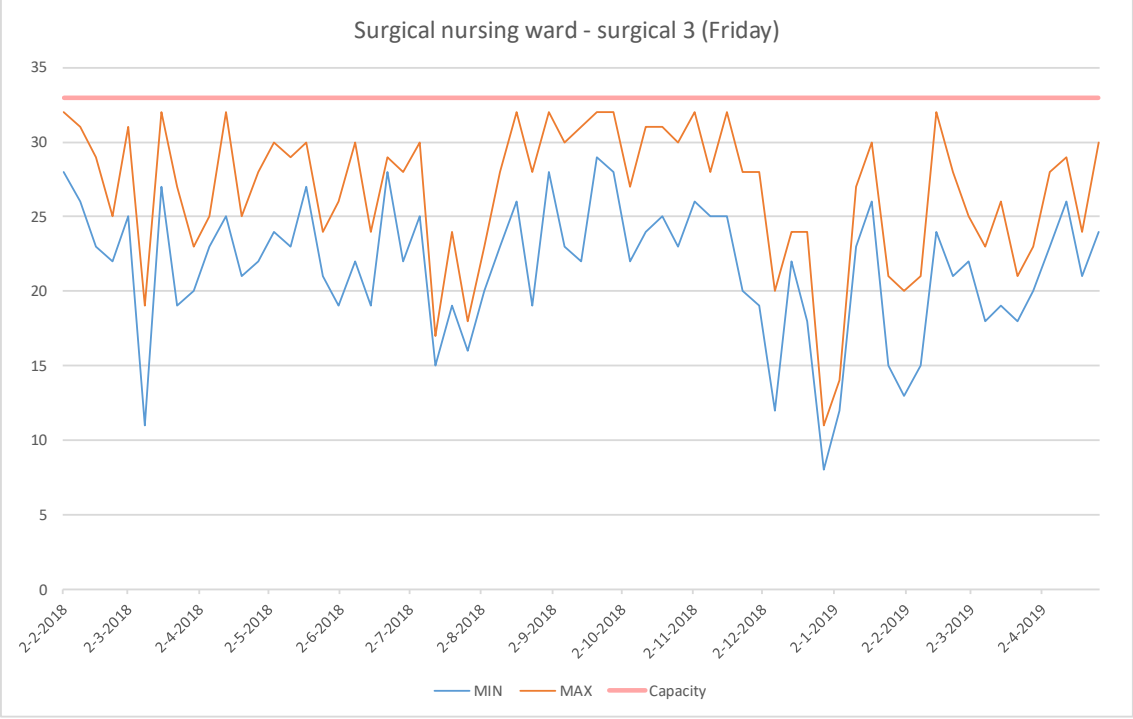

Figure Appendix C - 5 Overview of the bed occupancy for ward surgical 3 at Friday (n=335, OR system HOH, 2018-2019)

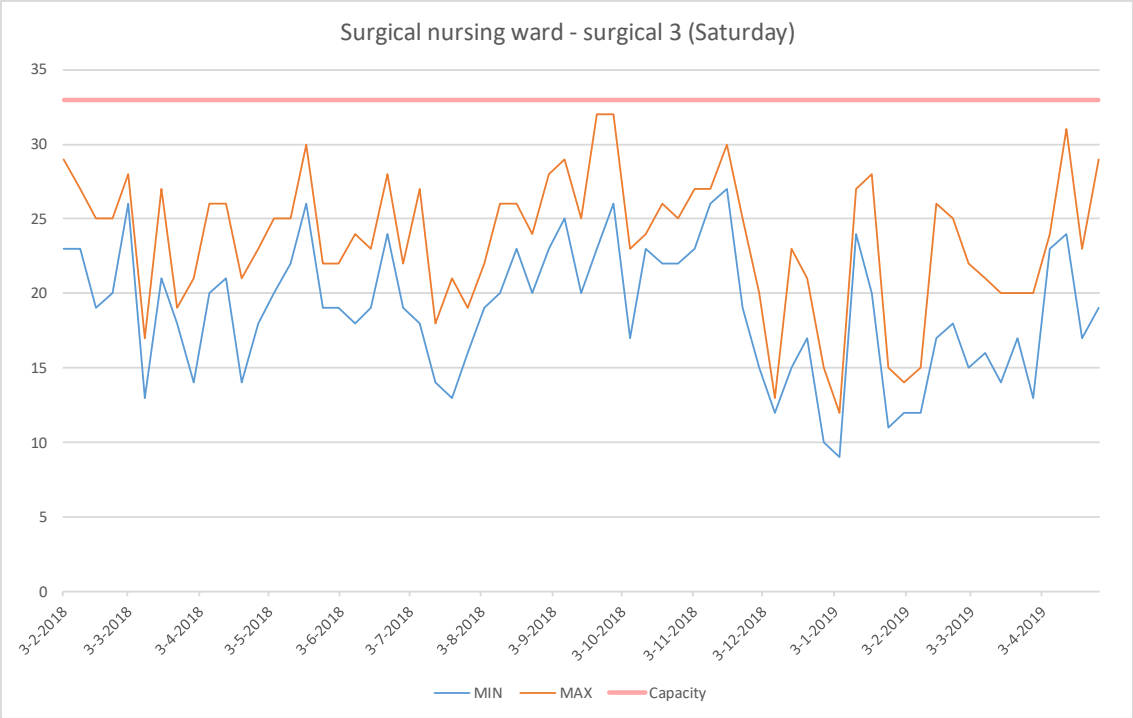

Figure Appendix C - 6 Overview of the bed occupancy for ward surgical 3 at Saturday (n=325, OR system HOH, 2018-2019)

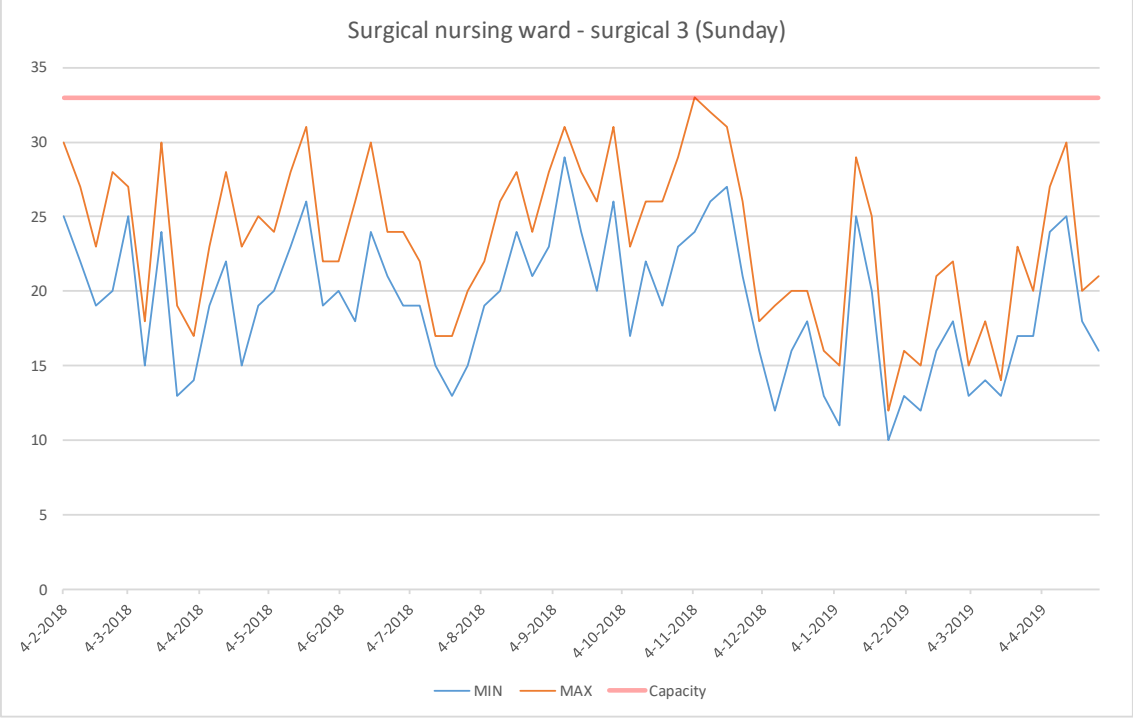

Figure Appendix C - 7 Overview of the bed occupancy for ward surgical 3 at Sunday (n=325, OR system HOH, 2018-2019)

Bed occupancy B4

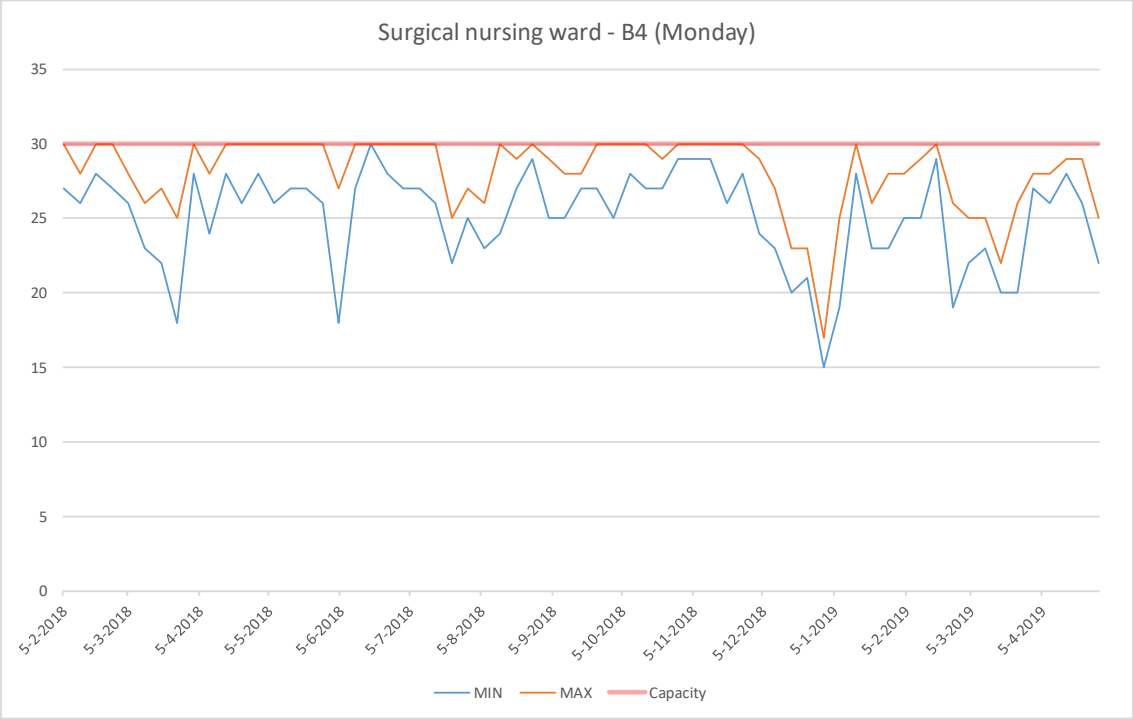

Figure Appendix C - 8 Overview of the bed occupancy for ward B4 at Monday (n=325, OR system HOH, 2018-2019)

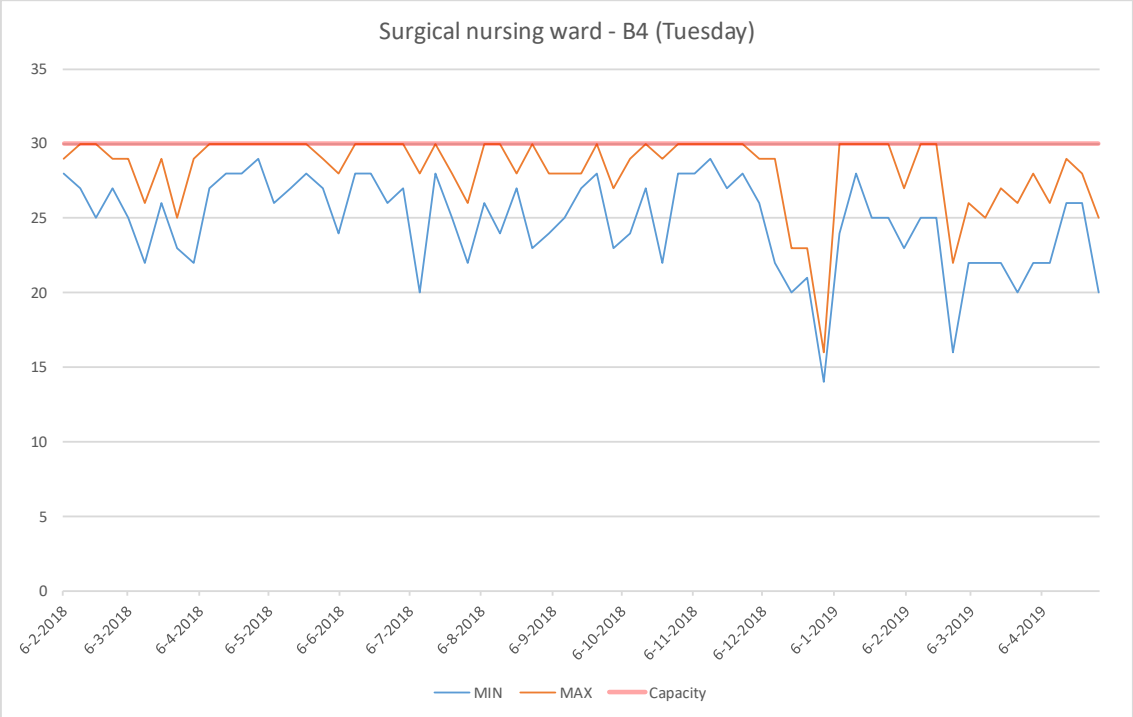

Figure Appendix C - 9 Overview of the bed occupancy for ward B4 at Tuesday (n=325, OR system HOH, 2018-2019)

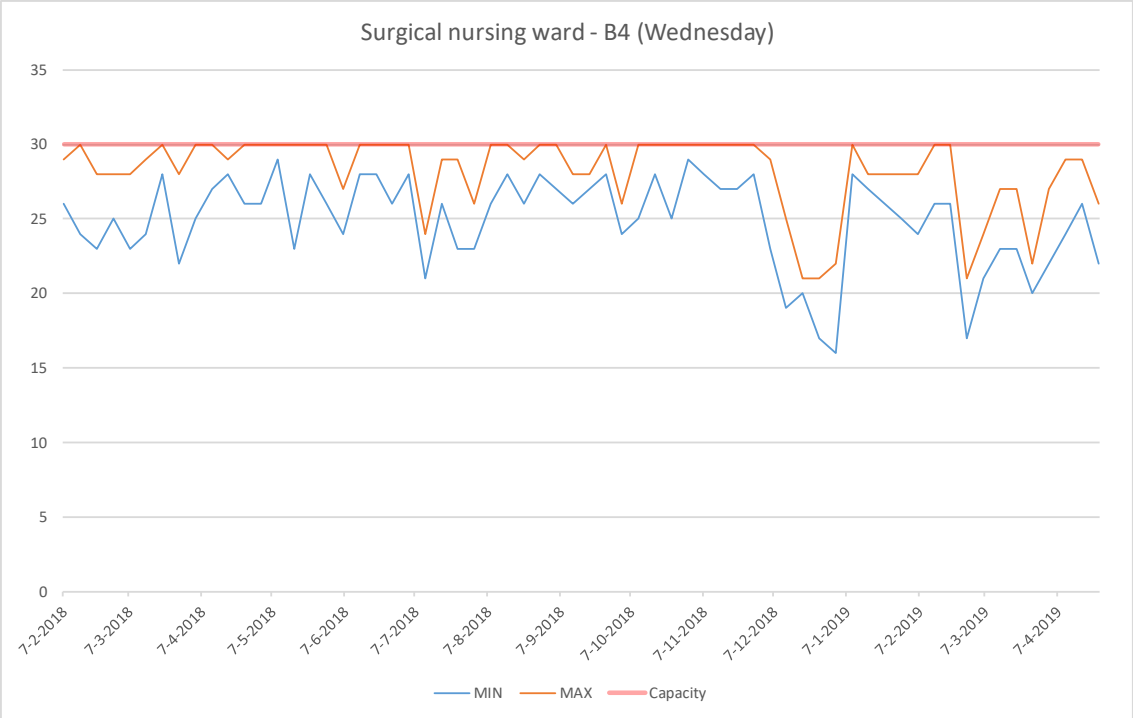

Figure Appendix C - 10 Overview of the bed occupancy for ward B4 at Wednesday (n=320, OR system HOH, 2018-2019)

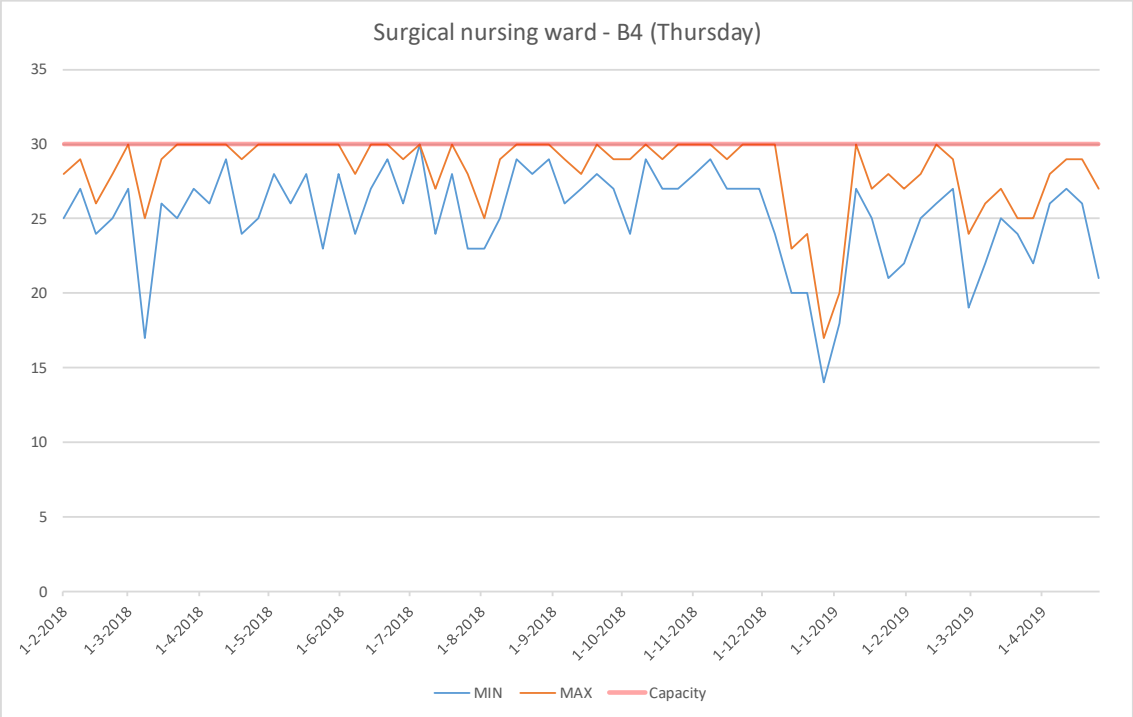

Figure Appendix C - 11 Overview of the bed occupancy for ward B4 at Thursday (n=335, OR system HOH, 2018-2019)

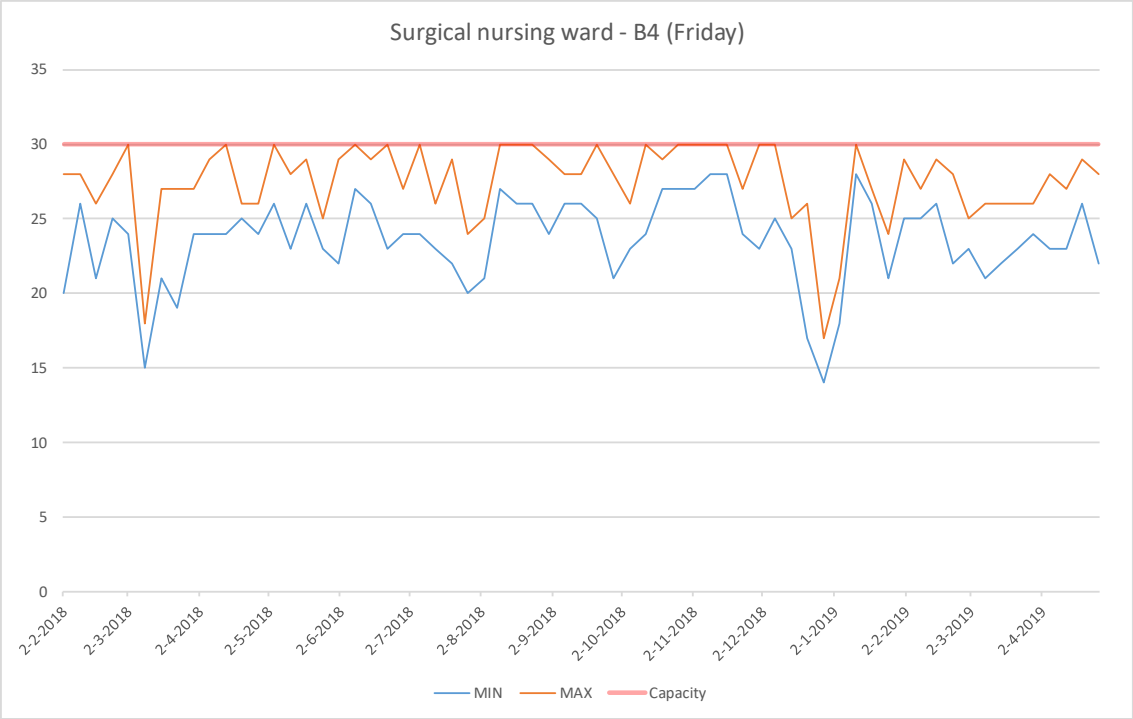

Figure Appendix C - 12 Overview of the bed occupancy for ward B4 at Friday (n=335, OR system HOH, 2018-2019)

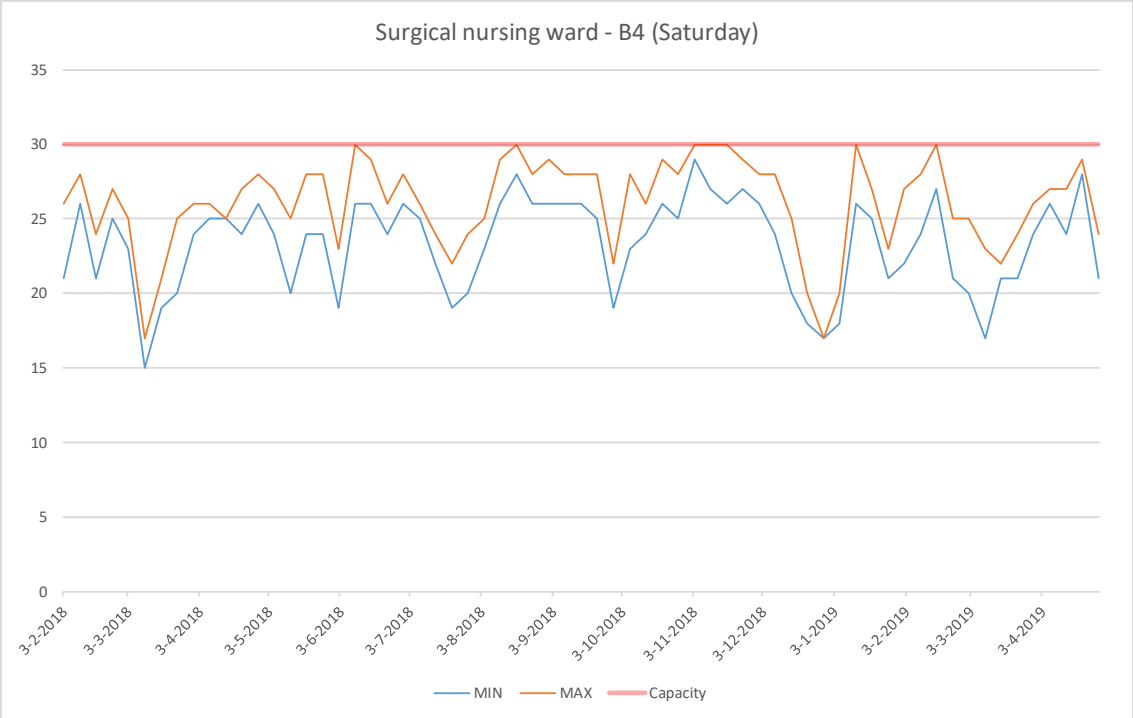

Figure Appendix C - 13 Overview of the bed occupancy for ward B4 at Saturday (n=325, OR system HOH, 2018-2019)

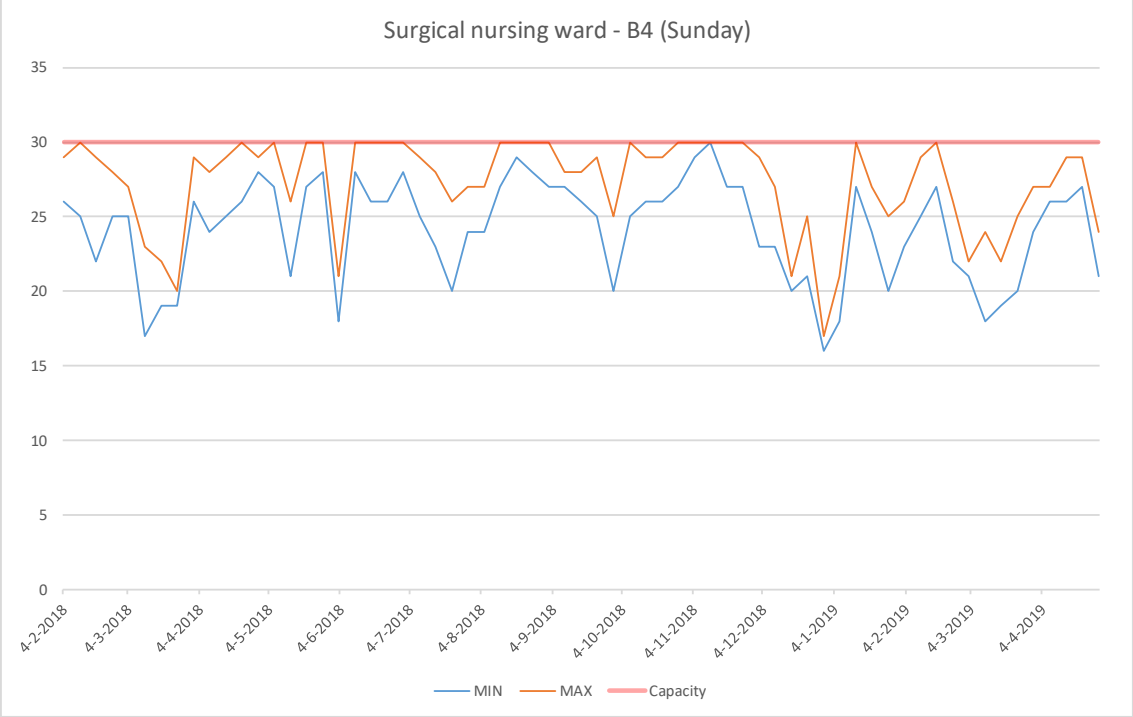

Figure Appendix C - 14 Overview of the bed occupancy for ward B4 at Sunday (n=325, OR system HOH, 2018-2019)

Appendix D – Planned and performed surgeries per specialism

Figure Appendix D - 1 Overview of the planned and performed surgeries per specialism (n=2811, OR system HOH, 2018-2019) gives an overview of the planned and performed surgeries per specialism.

Aantal van Urgentie	Kolomlabels																						
Rijlabels	0	Algemene Chirurgie	Cardiologie	FLEX	Gynaecologie	KNO	Maag Darm Lever	Neurochirurgie	Oogheelkunde	Orthopaedie	Pijnbestrijding	Plastische chirurgie	PODACA	SPOED	Tandheelkunde	Urologie	Eindtotaal		Right session	Another session
Algemene Chirurgie	7	596	11	26	46	16		29	23	29	14	24	1	170		11	1003		59%	41%
Anaesthesiologie																1	1		0%	100%
Cardiologie	1	5	30	5	8			1	2	6				11		1	70		43%	57%
Gynaecologie	4	39	3	8	333	8		11	2	14	6	14		62		7	511		65%	35%
Interne Geneeskunde							1				1			2		1	5		20%	80%
Kaakchirurgie						3											3		0%	100%
Kindergeneeskunde											1						1		0%	100%
KNO		3			1	40						1		9			54		74%	26%
Longarts					1	1								2			4		0%	100%
Neurochirurgie		8		2				159		3	2			12		1	187		85%	15%
NeUrologie		1												1			2		0%	100%
Oogheelkunde									7					1			8		88%	13%
Orthopaedie	2	28	2	3	11	6		10	5	440	5	6		45		5	568		77%	23%
Pijnbestrijding				1	1					1	26	1		5		1	36		72%	28%
Plastische chirurgie	1	7		4		2		1	1	2	1	69		10		1	99		70%	30%
Urologie		14	1	4	1	3		1		9	13	2	3	13		192	256		75%	25%
(leeg)		2			1												3		0%	100%
Eindtotaal	**15**	**703**	**47**	**53**	**403**	**79**	**1**	**212**	**40**	**505**	**68**	**117**	**4**	**343**	**1**	**220**	**2811**			
Planned and performed:	47%	85%	64%	0%	83%	51%	100%	75%	18%	87%	38%	59%	25%	0%	0%	87%				

Figure Appendix D - 1 Overview of the planned and performed surgeries per specialism (n=2811, OR system HOH, 2018-2019)

General surgery:

703 surgeries were performed in the planned session for general surgery during the morning and afternoon sessions. Of these, 596 surgeries were performed by general surgery. This means that 85% of the performed surgeries took place in the planned session for general surgery. 15% of the performed surgeries in the planned sessions for general surgery were performed by a different specialism.

A total of 1,003 surgeries were performed by general surgery in the morning and afternoon sessions. Of these 1,003 surgeries, 596 surgeries were performed in the planned sessions for general surgery. This means that 407 surgeries were performed by general surgery in sessions that were planned for a different specialism. Of these 407 surgeries, 170 surgeries were performed for emergency surgeries. The specialism general surgery asks a lot extra surgery time. When another specialism does not need the planned session, general surgery can perform surgeries in that session. That is why they that many surgeries were performed by general surgery in sessions that were planned for a different specialism.

Appendix E – Surgeries, sessions, LOS per specialist

Surgeries per specialist

Table Appendix E - 1 Amount of surgeries per specialist

General surgery A	179
General surgery B	84
General surgery C	123
General surgery D	110
General surgery E	30
General surgery F	46
General surgery G	14
General surgery H	1
General surgery I	0
General surgery J	4
General surgery K	3
General surgery L	2
Total	**596**

Table Appendix E - 2 Amount of surgeries per specialist per day

	Monday	Tuesday	Wednesday	Thursday	Friday	**Total**
General surgery A	120	5	10	30	14	179
General surgery B	7	2	56	0	19	84
General surgery C	17	3	5	80	18	123
General surgery D	14	72	3	5	16	110
General surgery E	21	0	1	0	8	30
General surgery F	30	4	2	4	6	46
General surgery G	3	1	4	4	2	14
General surgery H	0	1	0	0	0	1
General surgery I	0	0	0	0	0	0
General surgery J	3	1	0	0	0	4
General surgery K	3	0	0	0	0	3
General surgery L	2	0	0	0	0	2
Total	220	89	81	123	83	**596**

Sessions per specialist

Table Appendix E - 3 Amount of sessions per specialist

General surgery A	114
General surgery B	64
General surgery C	97
General surgery D	85
General surgery E	25
General surgery F	38
General surgery G	12
General surgery H	1
General surgery I	0
General surgery J	3
General surgery K	2
General surgery L	2

Table Appendix E - 4 Amount of sessions per specialist per day

Amount of sessions per specialist per day					
	Monday	Tuesday	Wednesday	Thursday	Friday
General surgery A	75	3	6	18	12
General surgery B	6	2	40	0	16
General surgery C	14	3	4	60	16
General surgery D	12	54	3	4	12
General surgery E	18	0	1	0	6
General surgery F	24	4	2	4	4
General surgery G	3	1	4	3	1
General surgery H	0	1	0	0	0
General surgery I	0	0	0	0	0
General surgery J	2	1	0	0	0
General surgery K	2	0	0	0	0
General surgery L	2	0	0	0	0

Table Appendix E - 5 Amount of sessions per specialist per day for the morning session

	Monday	Tuesday	Wednesday	Thursday	Friday	Total
General surgery A	41	2	4	10	6	63
General surgery B	3	0	21	0	4	28
General surgery C	10	1	2	37	11	61
General surgery D	5	38	2	3	6	54
General surgery E	12	0	0	0	3	15
General surgery F	16	1	1	2	2	22
General surgery G	1	0	1	1	1	4
General surgery H	0	1	0	0	0	1
General surgery I	0	0	0	0	0	0
General surgery J	2	1	0	0	0	3
General surgery K	1	0	0	0	0	1
General surgery L	1	0	0	0	0	1

Table Appendix E - 6 Amount of sessions per specialist per day for the afternoon session

	Monday	Tuesday	Wednesday	Thursday	Friday	Total
General surgery A	34	1	2	8	6	51
General surgery B	3	2	19	0	12	36
General surgery C	4	2	2	23	5	36
General surgery D	7	16	1	5	6	31
General surgery E	6	0	1	6	3	10
General surgery F	8	3	1	3	2	16
General surgery G	2	1	3	2	0	8
General surgery H	0	0	0	0	0	0
General surgery I	0	0	0	0	0	0
General surgery J	0	0	0	0	0	0
General surgery K	1	0	0	0	0	1
General surgery L	1	0	0	0	0	1

LOS per specialist

Table Appendix E - 7 LOS per specialist

General surgery A	763
General surgery B	1947
General surgery C	871
General surgery D	959
General surgery E	109
General surgery F	328
General surgery G	271
General surgery H	4
General surgery I	0
General surgery J	56
General surgery K	3
General surgery L	3

Table Appendix E - 8 Average LOS per specialist

General surgery A	4.3
General surgery B	23.2
General surgery C	7.1
General surgery D	8.7
General surgery E	3.6
General surgery F	7.1
General surgery G	19.4
General surgery H	4.0
General surgery I	0.0
General surgery J	14.0
General surgery K	1.0
General surgery L	1.5

Table Appendix E - 9 LOS per specialist per day

	Monday	Tuesday	Wednesday	Thursday	Friday
General surgery A	345	35	121	193	69
General surgery B	220	64	1070	0	593
General surgery C	100	18	65	553	135
General surgery D	135	422	134	133	135
General surgery E	66	0	1	0	42
General surgery F	132	83	28	11	74
General surgery G	77	25	128	28	13
General surgery H	0	4	0	0	0
General surgery I	0	0	0	0	0
General surgery J	12	44	0	0	0
General surgery K	3	0	0	0	0
General surgery L	3	0	0	0	0

Table Appendix E - 10 Average LOS per specialist per day

	Monday	Tuesday	Wednesday	Thursday	Friday
General surgery A	2.9	7.0	12.1	6.4	4.9
General surgery B	31.4	32.0	19.1	0.0	31.2
General surgery C	5.9	6.0	13.0	6.9	7.5
General surgery D	9.6	5.9	44.7	26.6	8.4
General surgery E	3.1	0.0	0.0	0.0	5.3
General surgery F	4.4	20.8	14.0	2.8	12.3
General surgery G	25.7	25.0	32.0	7.0	6.5
General surgery H	0.0	4.0	0.0	0.0	0.0
General surgery I	0.0	0.0	0.0	0.0	0.0
General surgery J	4.0	44.0	0.0	0.0	0.0
General surgery K	1.0	0.0	0.0	0.0	0.0
General surgery L	1.5	0.0	0.0	0.0	0.0

Appendix F – Descriptive statistics of the bed occupancy

Current situation

	ST. DEV realization	ST. DEV expected value	MIN realization	MIN expected value	MAX realization	MAX expected value	Average realization	Average expected value	Median realization	Median expected value
00:00	1.99	1.66	3.00	4.00	12.00	11.00	7.27	7.65	7.00	8.00
01:00	1.97	1.66	3.00	4.00	12.00	11.00	7.28	7.67	7.00	8.00
02:00	1.97	1.66	3.00	4.00	12.00	11.00	7.28	7.67	7.00	8.00
03:00	1.98	1.69	3.00	4.00	12.00	11.00	7.29	7.71	7.00	8.00
04:00	1.98	1.68	3.00	4.00	12.00	11.00	7.29	7.75	7.00	8.00
05:00	1.98	1.68	3.00	4.00	12.00	11.00	7.29	7.75	7.00	8.00
06:00	1.98	1.67	3.00	4.00	12.00	11.00	7.30	7.72	7.00	8.00
07:00	2.06	1.69	3.00	4.00	13.00	11.00	7.40	7.75	7.00	8.00
08:00	2.08	1.69	3.00	4.00	13.00	11.00	7.41	7.79	7.00	8.00
09:00	2.08	1.62	4.00	4.00	13.00	11.00	7.62	7.78	7.00	8.00
10:00	1.00	1.62	4.00	4.00	13.00	11.00	7.70	7.75	7.00	8.00
11:00	2.11	1.63	4.00	4.00	14.00	11.00	7.75	7.72	7.00	8.00
12:00	2.08	1.61	4.00	4.00	14.00	11.00	7.75	7.72	7.00	8.00
13:00	2.07	1.60	4.00	4.00	14.00	11.00	7.54	7.72	7.00	8.00
14:00	2.01	1.59	3.00	4.00	13.00	11.00	7.39	7.63	7.00	8.00
15:00	2.00	1.64	3.00	4.00	13.00	11.00	7.32	7.64	7.00	8.00
16:00	1.99	1.64	3.00	4.00	12.00	11.00	7.30	7.61	7.00	8.00
17:00	1.99	1.63	3.00	4.00	12.00	11.00	7.30	7.57	7.00	8.00
18:00	1.95	1.61	3.00	4.00	12.00	11.00	7.28	7.57	7.00	8.00
19:00	1.96	1.65	3.00	4.00	12.00	11.00	7.24	7.57	7.00	8.00
20:00	1.96	1.65	3.00	4.00	12.00	11.00	7.24	7.59	7.00	8.00
21:00	1.98	1.65	3.00	4.00	12.00	11.00	7.24	7.59	7.00	8.00
22:00	2.00	1.65	3.00	4.00	12.00	11.00	7.24	7.59	7.00	8.00
23:00	2.00	1.65	3.00	4.00	12.00	11.00	7.28	7.6	7.00	8.00

Figure Appendix F - 1 Descriptive statistics bed occupancy current situation per hour

	ST. DEV realization	ST. DEV expected value	MIN realization	MIN expected value	MAX realization	MAX expected value	Average realization	Average expected value	Median realization	Median expected value
Monday	2.14	1.47	5.00	6.00	13.00	11.00	8.31	8.48	8	9
Tuesday	1.83	1.37	5.00	6.00	13.00	11.00	8.47	8.80	8	9
Wednesday	1.89	1.53	4.00	5.00	14.00	11.00	7.87	8.37	8	9
Thursday	1.88	1.61	4.00	5.00	12.00	11.00	7.68	8.13	7	9
Friday	1.71	1.32	4.00	4.00	11.00	9.00	6.98	7.23	7	7
Saturday	1.25	1.02	3.00	4.00	9.00	8.00	6.02	6.23	6	6
Sunday	1.85	1.15	3.00	4.00	11.00	9.00	6.51	6.69	6	7

Figure Appendix F - 2 Descriptive statistics bed occupancy current situation per day

	ST. DEV realization	ST. DEV expected value	MIN realization	MIN expected value	MAX realization	MAX expected value	Average realization	Average expected value	Median realization	Median expected value
February	2.33	1.84	4.00	5.00	14.00	11.00	7.72	7.82	8.00	8.00
March	1.43	1.21	3.00	6.00	10.00	10.00	6.52	8.09	6.00	8.00
April	1.85	1.66	5.00	4.00	13.00	10.00	7.97	7.06	8.00	7.00

Figure Appendix F - 3 Descriptive statistics bed occupancy current situation per month

Intervention option 1

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
00:00	1.64	3.00	10.00	7.06	7.00
01:00	1.64	3.00	10.00	7.10	7.00
02:00	1.65	3.00	10.00	7.09	7.00
03:00	1.71	3.00	11.00	7.16	7.00
04:00	1.71	3.00	11.00	7.17	7.00
05:00	1.69	4.00	11.00	7.22	7.00
06:00	1.70	4.00	11.00	7.23	7.00
07:00	1.69	4.00	11.00	7.25	7.00
08:00	1.75	4.00	11.00	7.31	7.00
09:00	1.70	4.00	11.00	7.34	7.00
10:00	1.68	4.00	11.00	7.31	7.00
11:00	1.65	4.00	11.00	7.31	7.00
12:00	1.64	4.00	11.00	7.30	7.00
13:00	1.65	4.00	11.00	7.24	7.00
14:00	1.67	4.00	11.00	7.16	7.00
15:00	1.66	4.00	11.00	7.15	7.00
16:00	1.66	3.00	11.00	7.13	7.00
17:00	1.64	3.00	10.00	7.09	7.00
18:00	1.63	3.00	10.00	7.05	7.00
19:00	1.62	3.00	10.00	7.02	7.00
20:00	1.66	3.00	11.00	7.06	7.00
21:00	1.64	3.00	10.00	7.03	7.00
22:00	1.64	3.00	10.00	7.02	7.00
23:00	1.64	3.00	10.00	7.02	7.00

Figure Appendix F - 4 Descriptive statistics bed occupancy intervention option 1 per hour

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
Monday	1.44	5.00	11.00	7.76	8.00
Tuesday	1.58	5.00	11.00	8.22	9.00
Wednesday	1.60	5.00	11.00	7.90	8.00
Thursday	1.58	4.00	11.00	7.66	8.00
Friday	1.34	4.00	9.00	6.79	7.00
Saturday	1.07	3.00	8.00	5.84	6.00
Sunday	1.30	3.00	9.00	6.17	6.00

Figure Appendix F - 5 Descriptive statistics bed occupancy intervention option 1 per day

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
February	1.82	5.00	11.00	7.58	8.00
March	1.28	5.00	10.00	7.53	8.00
April	1.57	3.00	10.00	6.33	6.00

Figure Appendix F - 6 Descriptive statistics bed occupancy intervention option 1 per month

Intervention option 2

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
00:00	7.53	3.00	11.00	7.53	8.00
01:00	7.56	3.00	11.00	7.56	8.00
02:00	7.56	3.00	11.00	7.56	8.00
03:00	7.64	3.00	11.00	7.64	8.00
04:00	7.66	3.00	11.00	7.66	8.00
05:00	7.66	3.00	11.00	7.66	8.00
06:00	7.63	3.00	11.00	7.63	8.00
07:00	7.71	4.00	11.00	7.71	8.00
08:00	7.76	4.00	12.00	7.76	8.00
09:00	7.76	4.00	12.00	7.76	8.00
10:00	7.70	4.00	12.00	7.70	8.00
11:00	7.74	4.00	12.00	7.74	8.00
12:00	7.75	4.00	12.00	7.75	8.00
13:00	7.67	4.00	11.00	7.67	8.00
14:00	7.67	4.00	11.00	7.67	8.00
15:00	7.66	4.00	11.00	7.66	8.00
16:00	7.60	4.00	11.00	7.60	8.00
17:00	7.57	4.00	11.00	7.57	8.00
18:00	7.53	3.00	11.00	7.53	8.00
19:00	7.51	3.00	11.00	7.51	8.00
20:00	7.51	3.00	11.00	7.51	8.00
21:00	7.51	3.00	11.00	7.51	8.00
22:00	7.51	3.00	11.00	7.51	8.00
23:00	7.52	3.00	11.00	7.52	8.00

Figure Appendix F - 7 Descriptive statistics bed occupancy intervention option 2 per hour

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
Monday	1.55	5.00	11.00	8.09	8.00
Tuesday	1.39	6.00	11.00	8.65	9.00
Wednesday	1.54	5.00	12.00	8.51	9.00
Thursday	1.67	4.00	11.00	8.42	9.00
Friday	1.62	4.00	10.00	7.41	8.00
Saturday	1.06	3.00	8.00	6.12	6.00
Sunday	1.24	3.00	9.00	6.39	6.00

Figure Appendix F - 8 Descriptive statistics bed occupancy intervention option 2 per day

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
February	1.83	5.00	12.00	8.05	8.00
March	1.35	6.00	10.00	7.89	8.00
April	1.82	3.00	10.00	6.90	7.00

Figure Appendix F - 9 Descriptive statistics bed occupancy intervention option 2 per month

Intervention option 3

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
00:00	1.54	5.00	11.00	7.65	8.00
01:00	1.55	5.00	11.00	7.70	8.00
02:00	1.54	5.00	11.00	7.70	8.00
03:00	1.60	5.00	11.00	7.75	8.00
04:00	1.65	5.00	11.00	7.81	8.00
05:00	1.65	5.00	11.00	7.83	8.00
06:00	1.64	5.00	11.00	7.79	8.00
07:00	1.66	5.00	11.00	7.81	8.00
08:00	1.65	5.00	11.00	7.88	8.00
09:00	1.62	5.00	11.00	7.80	8.00
10:00	1.59	5.00	11.00	7.80	8.00
11:00	1.62	5.00	11.00	7.80	8.00
12:00	1.59	5.00	11.00	7.73	8.00
13:00	1.59	5.00	11.00	7.74	8.00
14:00	1.59	5.00	11.00	7.72	8.00
15:00	1.62	5.00	11.00	7.73	8.00
16:00	1.55	5.00	11.00	7.67	8.00
17:00	1.57	5.00	11.00	7.67	8.00
18:00	1.55	5.00	11.00	7.60	8.00
19:00	1.55	5.00	11.00	7.60	8.00
20:00	1.54	5.00	11.00	7.63	8.00
21:00	1.54	5.00	11.00	7.63	8.00
22:00	1.54	5.00	11.00	7.63	8.00
23:00	1.54	5.00	11.00	7.63	8.00

Figure Appendix F - 10 Descriptive statistics bed occupancy intervention option 3 per hour

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
Monday	1.61	5.00	11.00	7.63	7.00
Tuesday	1.63	5.00	11.00	8.19	8.00
Wednesday	1.50	5.00	11.00	8.25	8.50
Thursday	1.38	5.00	11.00	8.55	9.00
Friday	1.47	5.00	10.00	8.08	8.00
Saturday	1.29	5.00	9.00	6.88	7.00
Sunday	1.06	5.00	9.00	6.63	6.00

Figure Appendix F - 11 Descriptive statistics bed occupancy intervention option 3 per day

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
February	1.88	5.00	11.00	7.66	8.00
March	1.27	5.00	10.00	7.85	8.00
April	1.55	5.00	11.00	7.61	7.00

Figure Appendix F - 12 Descriptive statistics bed occupancy intervention option 3 per month

MSS current situation

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
00:00	2.40	12.00	23.00	18.44	19.00
01:00	2.42	12.00	23.00	18.48	19.00
02:00	2.42	12.00	23.00	18.45	19.00
03:00	2.47	12.00	23.00	18.53	19.00
04:00	2.50	12.00	23.00	18.61	19.00
05:00	2.49	12.00	23.00	18.63	19.00
06:00	2.47	12.00	23.00	18.61	19.00
07:00	2.50	12.00	23.00	18.72	19.00
08:00	2.23	13.00	23.00	18.95	19.00
09:00	2.04	14.00	23.00	18.85	19.00
10:00	2.05	14.00	22.00	18.83	19.00
11:00	2.14	14.00	22.00	18.88	19.00
12:00	2.01	14.00	22.00	19.03	19.00
13:00	2.03	13.00	22.00	18.84	19.00
14:00	2.15	13.00	23.00	18.68	19.00
15:00	2.30	13.00	23.00	18.72	19.00
16:00	2.44	12.00	23.00	18.65	19.00
17:00	2.40	12.00	23.00	18.57	19.00
18:00	2.39	12.00	23.00	18.44	19.00
19:00	2.39	12.00	23.00	18.42	19.00
20:00	2.43	12.00	23.00	18.48	19.00
21:00	2.41	12.00	23.00	18.44	19.00
22:00	2.38	12.00	23.00	18.41	19.00
23:00	2.38	12.00	23.00	18.40	19.00

Figure Appendix F - 13 Descriptive statistics bed occupancy MSS original per hour

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
Monday	1.14	14.00	19.00	17.43	21.00
Tuesday	1.53	16.00	23.00	21.01	21.00
Wednesday	1.24	12.00	18.00	15.77	19.00
Thursday	2.22	12.00	20.00	17.24	19.00
Friday	0.83	16.00	20.00	18.67	17.00
Saturday	1.31	18.00	23.00	21.18	16.00
Sunday	0.84	17.00	21.00	19.33	18.00

Figure Appendix F - 14 Descriptive statistics bed occupancy MSS original per day

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
February	2.21	14.00	23.00	18.91	19.00
March	2.20	15.00	23.00	18.98	19.00
April	2.43	12.00	22.00	17.98	18.00

Figure Appendix F - 15 Descriptive statistics bed occupancy MSS original per month

MSS intervention option 1

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
00:00	2.41	12.00	23.00	18.44	19.00
01:00	2.42	12.00	23.00	18.45	19.00
02:00	2.44	12.00	23.00	18.47	19.00
03:00	2.46	12.00	23.00	18.51	19.00
04:00	2.46	12.00	23.00	18.52	19.00
05:00	2.41	12.00	23.00	18.56	19.00
06:00	2.40	12.00	23.00	18.56	19.00
07:00	2.48	12.00	23.00	18.72	19.00
08:00	2.34	13.00	23.00	18.98	19.00
09:00	2.07	14.00	23.00	18.92	19.00
10:00	1.98	14.00	22.00	18.83	19.00
11:00	2.03	14.00	22.00	18.88	19.00
12:00	2.00	14.00	22.00	18.99	19.00
13:00	1.98	13.00	22.00	18.84	19.00
14:00	2.05	13.00	22.00	18.80	19.00
15:00	2.21	13.00	23.00	18.73	19.00
16:00	2.24	12.00	23.00	18.58	19.00
17:00	2.26	12.00	23.00	18.48	19.00
18:00	2.41	12.00	23.00	18.42	19.00
19:00	2.41	12.00	23.00	18.43	19.00
20:00	2.42	12.00	23.00	18.45	19.00
21:00	2.42	12.00	23.00	18.45	19.00
22:00	2.41	12.00	23.00	18.42	19.00
23:00	2.42	12.00	23.00	18.44	19.00

Figure Appendix F - 16 Descriptive statistics bed occupancy MSS option 1 per hour

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
Monday	1.16	19.00	23.00	21.11	21.00
Tuesday	1.32	18.00	23.00	21.13	21.00
Wednesday	0.85	17.00	21.00	19.29	19.00
Thursday	0.84	16.00	20.00	18.82	19.00
Friday	1.15	14.00	19.00	17.77	18.00
Saturday	1.37	12.00	18.00	15.79	16.00
Sunday	2.22	12.00	20.00	16.98	17.00

Figure Appendix F - 17 Descriptive statistics bed occupancy MSS option 1 per day

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
February	2.19	14.00	23.00	18.90	19.00
March	2.19	14.00	23.00	18.97	19.00
April	2.37	12.00	22.00	17.97	18.00

Figure Appendix F - 18 Descriptive statistics bed occupancy MSS option 1 per month

MSS intervention option 2

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
00:00	2.37	11.00	22.00	18.54	19.00
01:00	2.38	11.00	22.00	18.56	19.00
02:00	2.38	11.00	22.00	18.55	19.00
03:00	2.40	11.00	22.00	18.63	19.00
04:00	2.43	11.00	22.00	18.70	20.00
05:00	2.41	12.00	22.00	18.74	20.00
06:00	2.38	12.00	22.00	18.76	20.00
07:00	2.37	12.00	22.00	18.81	20.00
08:00	2.16	13.00	22.00	19.01	20.00
09:00	2.10	13.00	22.00	18.92	20.00
10:00	2.04	13.00	22.00	18.88	20.00
11:00	2.04	14.00	22.00	18.99	20.00
12:00	1.99	13.00	22.00	19.08	19.00
13:00	2.07	13.00	22.00	18.85	19.00
14:00	2.11	12.00	22.00	18.75	19.00
15:00	2.19	12.00	22.00	18.77	19.00
16:00	2.31	12.00	22.00	18.72	19.00
17:00	2.33	12.00	22.00	18.63	19.00
18:00	2.33	12.00	22.00	18.51	19.00
19:00	2.37	11.00	22.00	18.50	19.00
20:00	2.37	11.00	22.00	18.50	19.00
21:00	2.37	11.00	22.00	18.51	19.00
22:00	2.37	11.00	22.00	18.49	19.00
23:00	2.37	11.00	22.00	18.50	19.00

Figure Appendix F - 19 Descriptive statistics bed occupancy MSS option 2 per hour

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
Monday	1.48	14.00	20.00	18.15	20.00
Tuesday	1.42	16.00	22.00	20.30	21.00
Wednesday	1.40	11.00	18.00	15.67	20.00
Thursday	2.16	11.00	20.00	16.79	20.00
Friday	0.85	17.00	21.00	19.56	18.00
Saturday	0.98	17.00	22.00	20.82	16.00
Sunday	0.89	17.00	21.00	19.95	17.00

Figure Appendix F - 20 Descriptive statistics bed occupancy MSS option 2 per day

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
February	2.12	14.00	22.00	19.12	20.00
March	2.16	14.00	22.00	19.05	20.00
April	2.34	11.00	22.00	17.93	19.00

Figure Appendix F - 21 Descriptive statistics bed occupancy MSS option 2 per month

MSS intervention option 3

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
00:00	1.91	12.00	22.00	18.40	19.00
01:00	1.91	12.00	22.00	18.47	19.00
02:00	1.90	12.00	22.00	18.44	19.00
03:00	1.98	12.00	22.00	18.56	19.00
04:00	2.00	12.00	22.00	18.59	19.00
05:00	1.98	12.00	22.00	18.64	19.00
06:00	1.96	12.00	22.00	18.66	19.00
07:00	1.98	12.00	22.00	18.72	19.00
08:00	1.75	13.00	22.00	18.99	19.00
09:00	1.63	13.00	22.00	18.95	19.00
10:00	1.60	13.00	22.00	18.92	19.00
11:00	1.57	13.00	21.00	18.91	19.00
12:00	1.60	14.00	21.00	18.98	19.00
13:00	1.56	14.00	21.00	18.78	19.00
14:00	1.68	13.00	21.00	18.61	19.00
15:00	1.75	13.00	22.00	18.68	19.00
16:00	1.78	13.00	22.00	18.59	19.00
17:00	1.89	12.00	22.00	18.51	19.00
18:00	1.91	12.00	22.00	18.45	19.00
19:00	1.88	12.00	22.00	18.42	19.00
20:00	1.92	12.00	22.00	18.45	19.00
21:00	1.94	12.00	22.00	18.44	19.00
22:00	1.92	12.00	22.00	18.41	19.00
23:00	1.92	12.00	22.00	18.41	19.00

Figure Appendix F - 22 Descriptive statistics bed occupancy MSS option 3 per hour

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
Monday	1.79	14.00	22.00	19.15	19.00
Tuesday	1.16	15.00	22.00	19.74	20.00
Wednesday	0.76	17.00	20.00	18.89	19.00
Thursday	1.07	17.00	21.00	19.36	19.00
Friday	1.51	15.00	22.00	19.29	20.00
Saturday	1.90	12.00	20.00	17.13	17.00
Sunday	1.87	12.00	20.00	16.96	17.00

Figure Appendix F - 23 Descriptive statistics bed occupancy MSS option 3 per day

	ST. DEV expected value	MIN expected value	MAX expected value	Average expected value	Median expected value
February	1.64	15.00	22.00	18.96	19.00
March	1.61	15.00	22.00	19.03	19.00
April	2.00	12.00	21.00	17.87	18.00

Figure Appendix F - 24 Descriptive statistics bed occupancy MSS option 3 per month

Appendix G –Realization 1, 2, and 3

Figure Appendix G - 1 gives an overview of the realization of the bed occupancy of dataset R-1. This dataset has 1,118 unique sessions over the period February 2, 2018 to April 30, 2019. All emergencies are included in this dataset. On the Y-axis the realization of the bed occupancy is given. The period in January 2018 is a warming-up period. The peak in bed demand is on May 23, 2018 at 10:00 a.m. The realization of the bed occupancy at that moment is 78 beds. There is an off-peak load on December 28 at 12:00 a.m. The realization at that moment is 15 beds. The aforementioned peak and off-peak load are shown in Appendix G –Realization 1, 2, and 3- Peak and off-peak load realization 1. The off-peak loads for the entire period take place during weekends. In addition, patterns can be recognized during the summer and Christmas holidays. During this period there are generally fewer beds occupied.

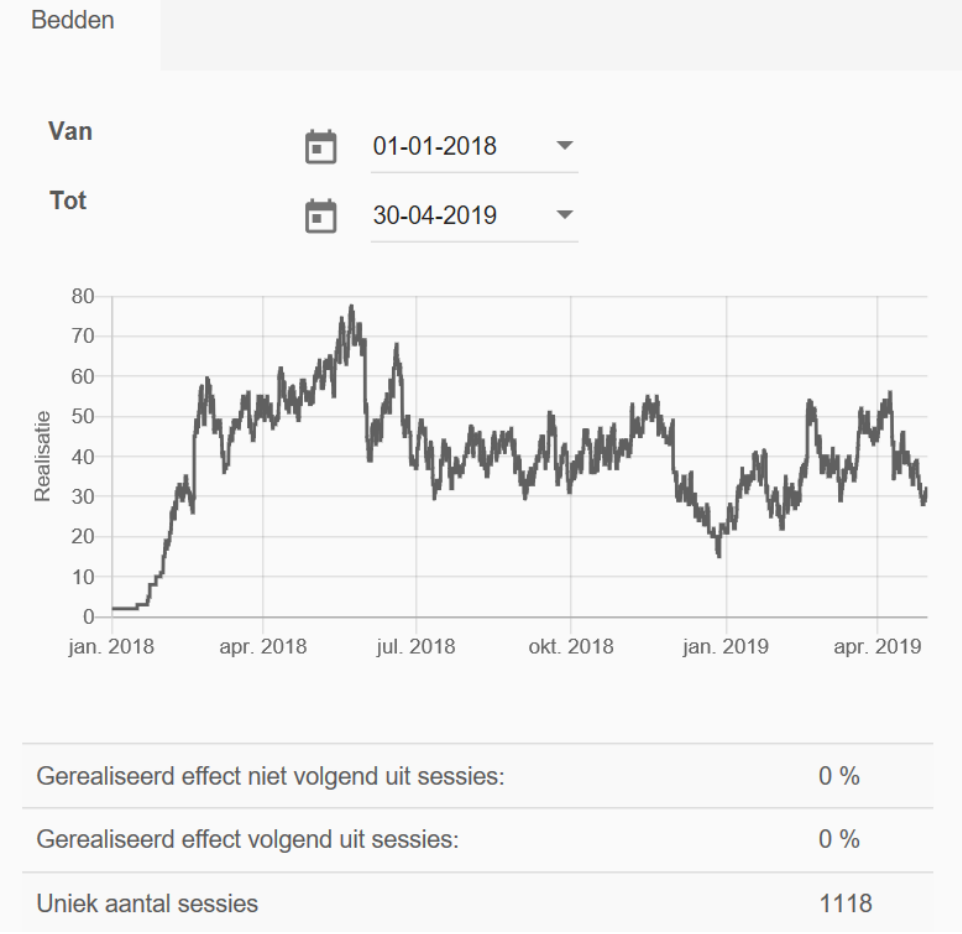

Figure Appendix G - 1 Realization bed occupancy dataset R-1 HOH (n=1,118, PFF Rhythm, 2018-2019)

Figure Appendix G - 2 gives an overview of the realization of the bed occupancy of dataset R-2. This dataset has 768 unique sessions over the period February 2, 2018 to April 30, 2019. Dataset R-2 included all surgeries which were only conducted in the morning sessions and the afternoon sessions. On the Y-axis the realization of the bed occupancy is given. The period in January 2018 is a warming-up period. The peak in bed demand is on May 23, 2018 at 10:00 a.m. The realization of the bed occupancy at that moment is 53 beds. There is an off-peak load on December 28 at 12:00 a.m. The realization at that moment is 10 beds. The aforementioned peak and off-peak load are shown in Appendix G –Realization 1, 2, and 3 - Peak and off-peak load realization 2. The off-peak loads for the entire period take place during weekends. In addition, patterns can be recognized during the summer and Christmas holidays. During this period there are generally fewer beds occupied.

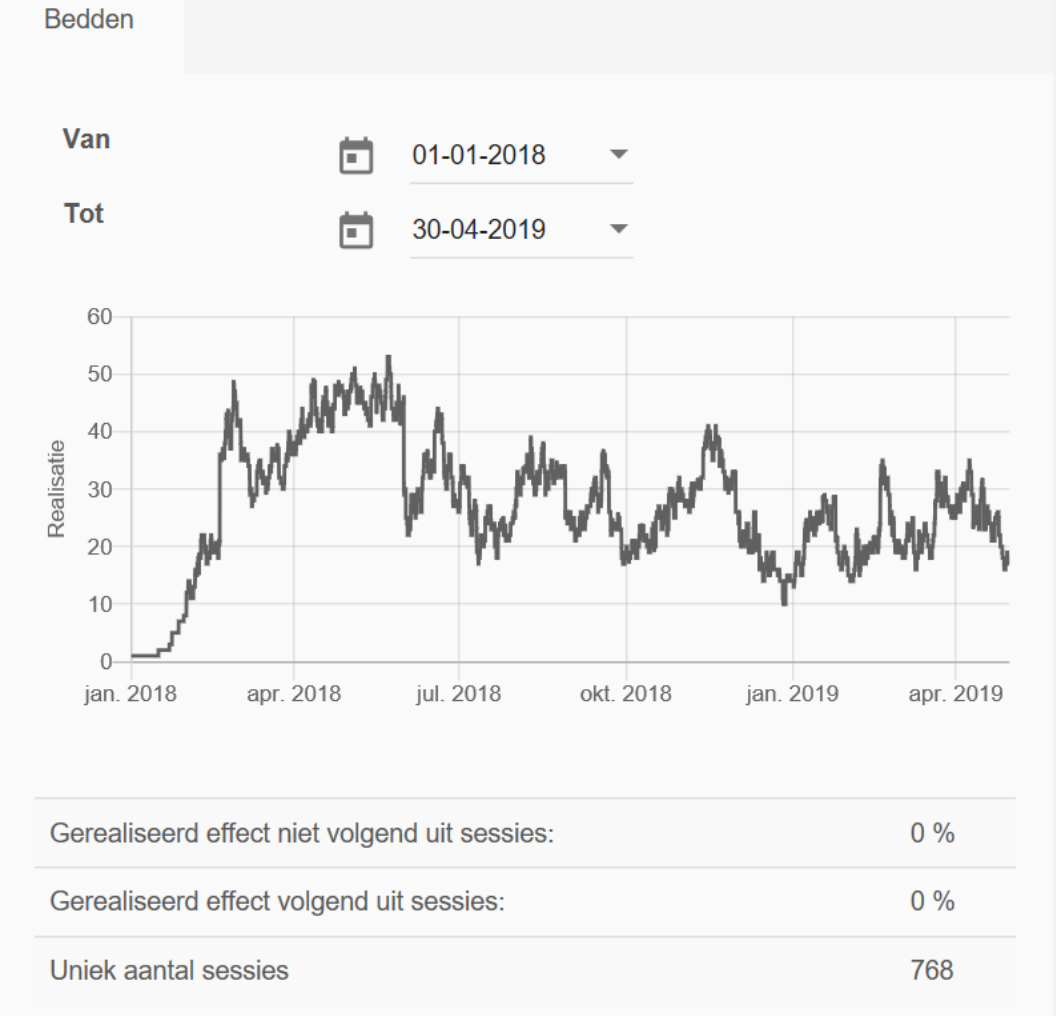

Figure Appendix G - 2 Realization bed occupancy dataset R-2 HOH (n=768, PFF Rhythm, 2018-2019)

Figure Appendix G - 3 gives an overview of the realization of the bed occupancy of dataset R-3. This dataset has 437 unique sessions over the period February 2, 2018 to April 30, 2019. Dataset R-3 included all surgeries which were only conducted in the morning sessions and the afternoon sessions and which were planned for general surgery. On the Y-axis the realization of the bed occupancy is given. The period in January 2018 is a warming-up period. There are two peaks in bed demand. The first peak is on April 12, 2018 at 1:00 p.m. The realization at that moment is 24 beds. The second peak is June 19, 2018 at 12:00 p.m. The realization at that moment is 24 beds. There is an off-peak load on December 28, 2018 at 12:00 a.m. The realization at that moment is two beds. The aforementioned peaks and off-peak load are shown in Appendix G –Realization 1,

2, and 3Peak and off-peak load realization 3. The off-peak loads for the entire period take place during weekends.

In addition, patterns can be recognized during the summer and Christmas holidays. During this period there are generally fewer beds occupied.

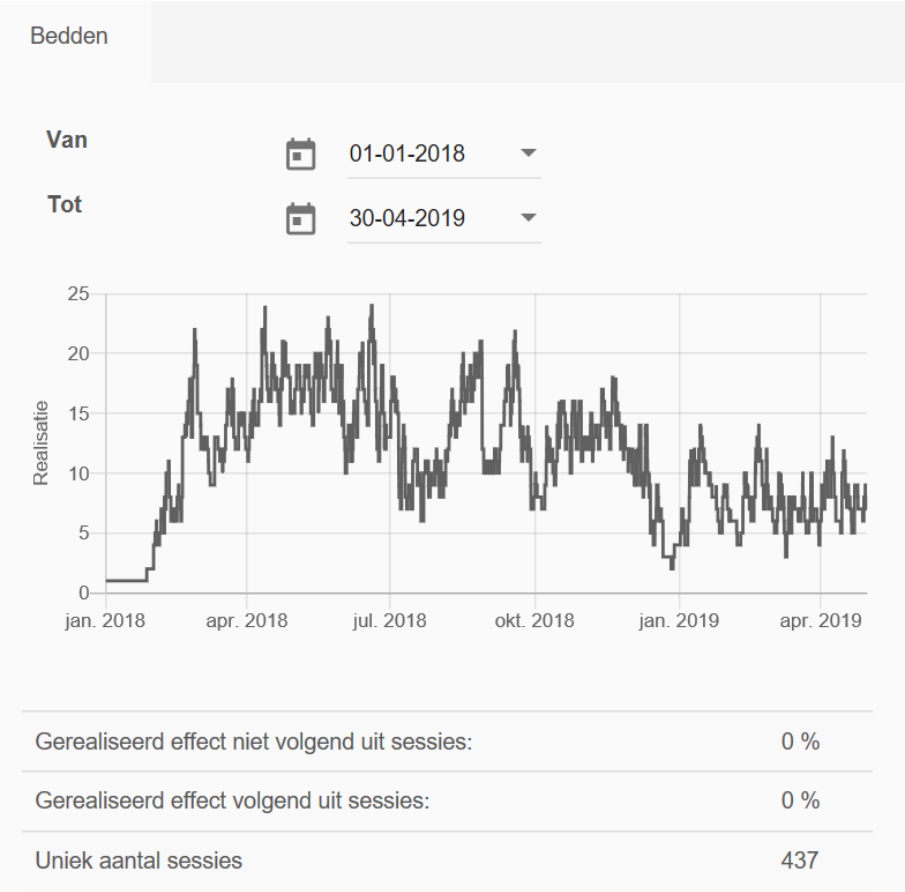

Figure Appendix G - 3 Realization bed occupancy dataset R-3 HOH (n=437, PFF Rhythm, 2018-2019)

As described earlier in this research, many emergency surgeries occur within the morning and afternoon sessions, but also outside the morning and afternoon sessions. 50% of the emergency surgeries that take place outside the morning and afternoon sessions are performed by general surgery. The various realizations show that emergencies do have an influence on the bed demand for general surgery. There is a large difference in bed demand between the realizations of the three datasets. The patterns remain the same for all three datasets. During the holidays and in

the weekend, there is an off-peak load. Another pattern is the decrease in the amount of surgeries per October 2018. The employees of HOH do not have a reason for this decrease.

Peak and off-peak load realization 1

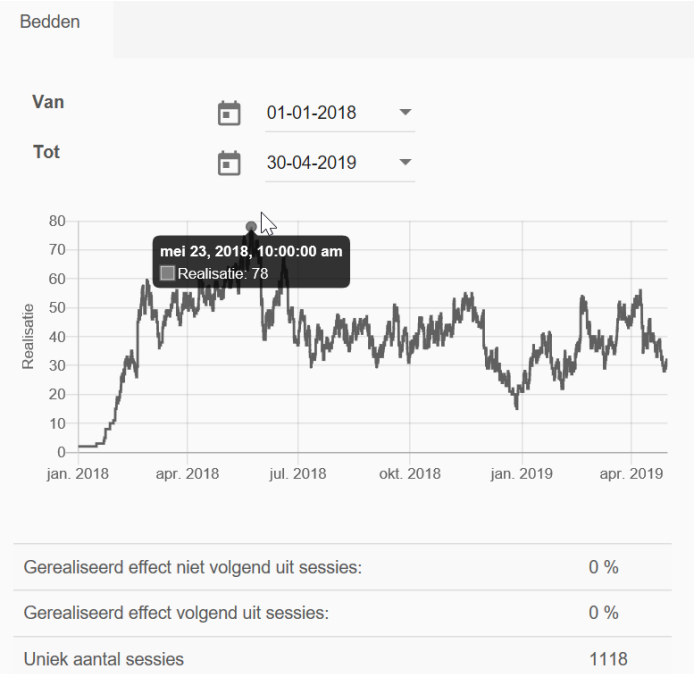

Figure Appendix G - 4 Peak realization dataset 1

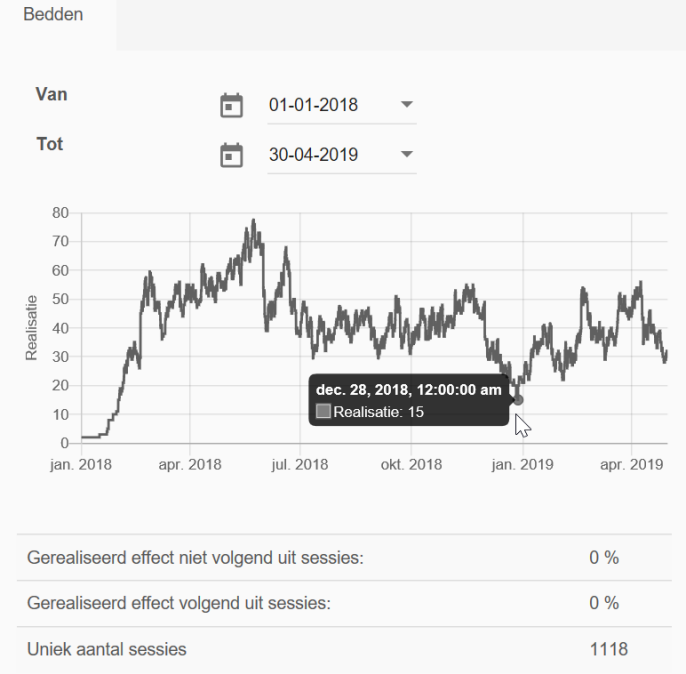

Figure Appendix G - 5 Off-peak load realization dataset 1

Peak and off-peak load realization 2

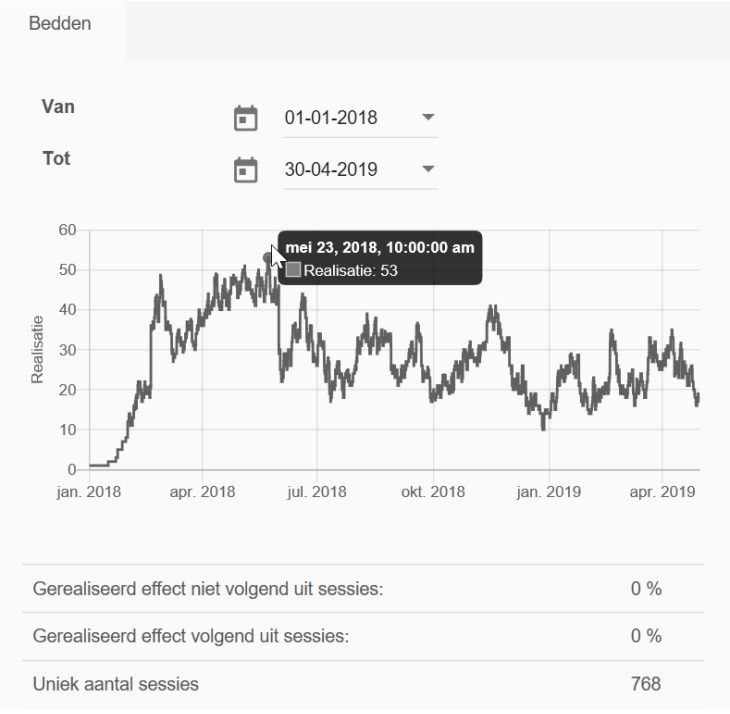

Figure Appendix G - 6 Peak realization dataset 2

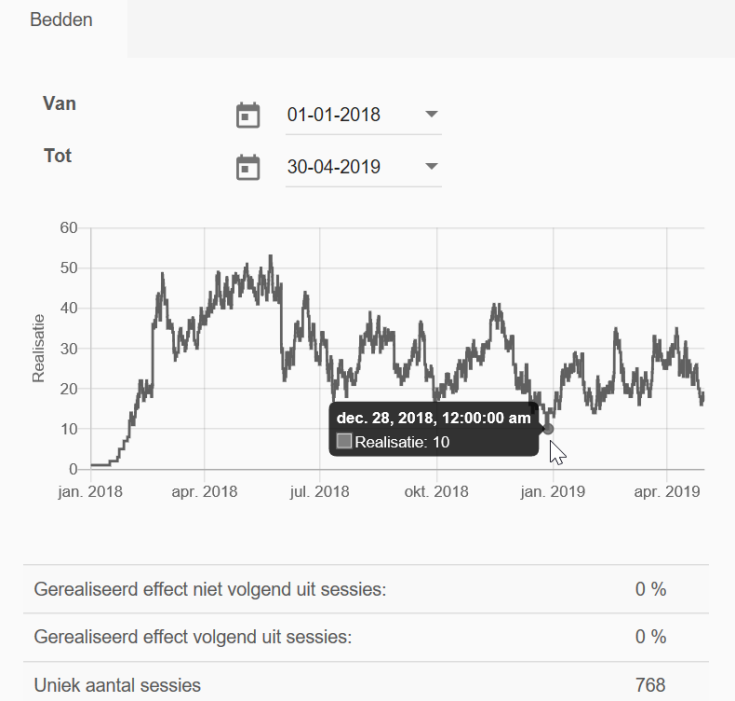

Figure Appendix G - 7 Off-peak load realization dataset 2

Peak and off-peak load realization 3

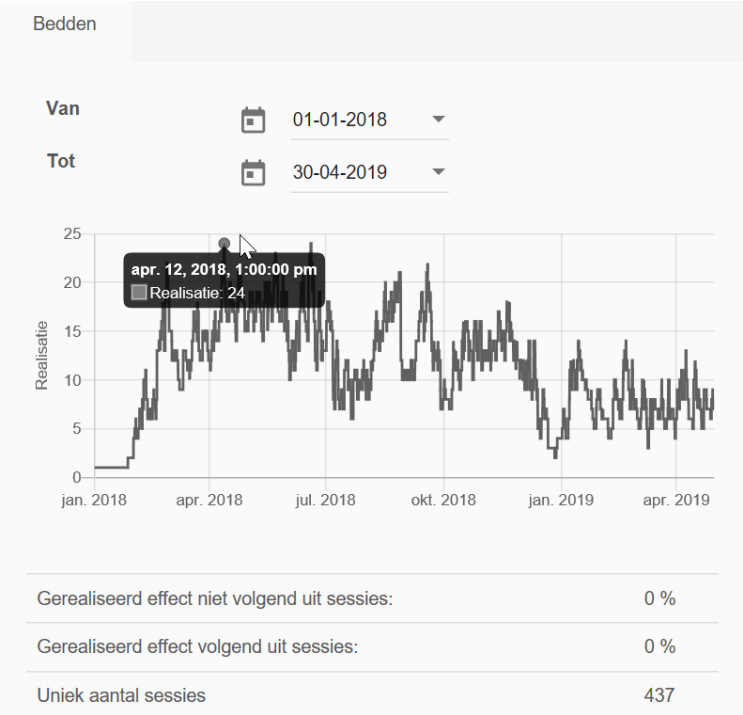

Figure Appendix G - 8 Peak 1 realization dataset 3

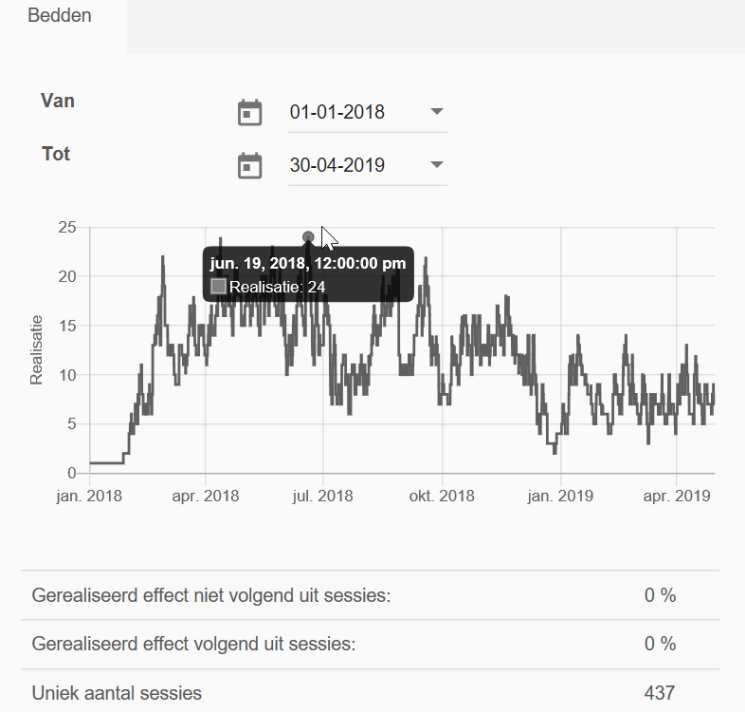

Figure Appendix G - 9 Peak 2 realization dataset 3

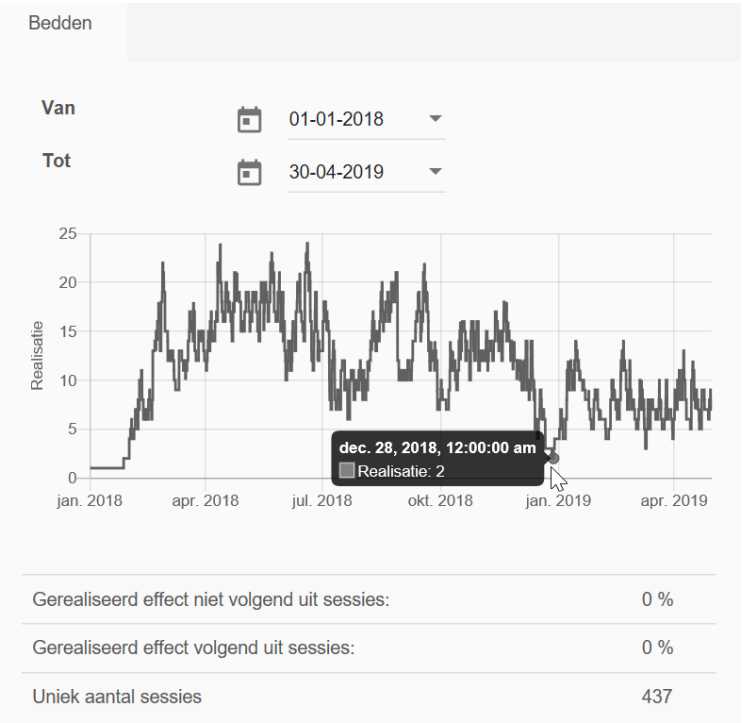

Figure Appendix G - 10 Off-peak load realization dataset 3

Appendix H – Intervention options 1, 2, and 3 of the realization

Intervention option 1

In order to optimize the OR session plan and to decrease the peak in bed demand at the surgical nursing wards, specialists from the specialism general surgery are exchanged. Option 1: General surgery E exchange with General surgery C.

Reason for the exchange of option 1:

The reason for this change is because the average LOS of General surgery E is shorter than the average LOS of General surgery C. The patients of General surgery C occupy a bed for about a week, so on average they will be discharged either on Sunday or on Monday. The expectation is that this change will increase the bed occupancy during the weekend. A disadvantage of this option is that General surgery E performed 30 surgeries, of which 21 on Monday.

The session load of the specialists is given in PFF. The session load calculates the expected value (y-axis) of the amount of occupied beds when specialist X conducts a surgery. The x-axis is in hours, where 0 is the start of the session. Table Appendix H - 1 gives an overview of the session load of General surgery E and General surgery C. For example: the expected value that a bed is occupied 24 hours after General surgery E has conduct a surgery is 1.111. The expected value that a bed is occupied 24 hours after General surgery C has conduct a surgery is 1.263. Figure Appendix H - 1 gives an overview of the session load of General surgery E. Figure Appendix H - 2 gives an overview of the session load of General surgery C.

Table Appendix H - 1 Overview session load General surgery E and General surgery C

Session load		
	General surgery E	General surgery C
24 hours	1.111	1.263
48 hours	0.778	0.702
72 hours	0.222	0.456
96 hours	0.222	0.368
120 hours	0.222	0.333

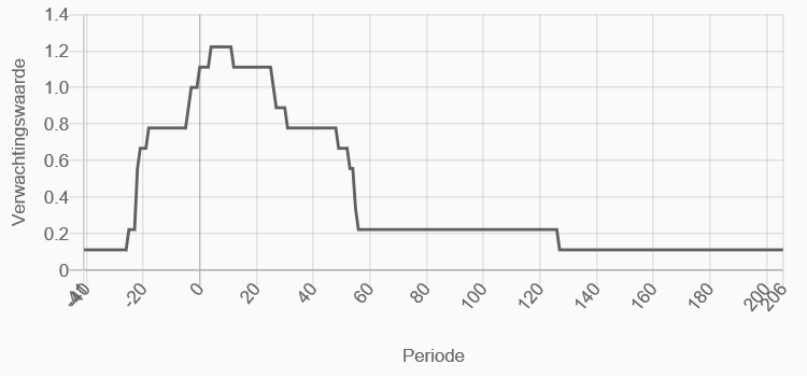

Figure Appendix H - 1 Session load of General surgery E (n=9, PFF Rhythm, 2018-2019)

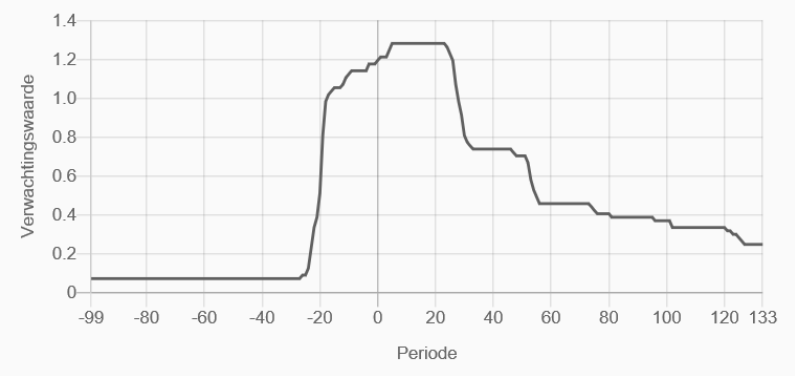

Figure Appendix H - 2 Session load of General surgery C (n=57, PFF Rhythm, 2018-2019)

The differences of session load between those two specialists is that the chance a bed is occupied is higher and longer for General surgery C then for General surgery E.

Figure Appendix H - 3 shows an overview of March 5, 2019 to April 11, 2019 of the forecast of the bed occupancy of intervention option 1.

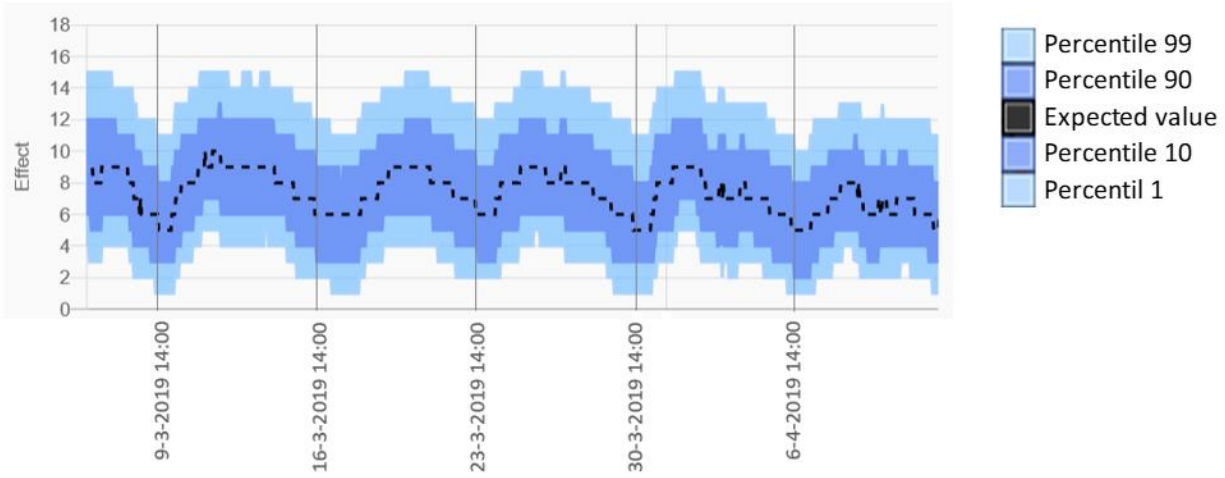

Figure Appendix H - 3 Forecast bed occupancy on Saturdays of intervention option 1 HOH (n=94, PFF Rhythm, 2018-2019)

Figure Appendix H - 3 shows a pattern during the weekends and weekdays. The data which is shown on the x-axis are Saturdays. In the weekends there is an off-peak load of the bed occupancy. The ultimate off-peak load is on Saturday, and it increases during the day on Sunday. The first peak has an expected value of ten beds. The second, third, and fourth peaks have an expected value of nine beds. The fifth peak has an expected value of eight beds. The first, fourth, and fifth off-peak load have an expected value of five beds. The second, and third off-peak load have an expected value of six beds. There is a difference of three, four, and five beds between the peaks and off-peaks load.

Table Appendix H - 2 gives an overview of the descriptive statistics of the bed occupancy for intervention option 1 of the months February, March, and April per hour. For example: the minimum bed occupancy for the expected value is 3. The standard deviation of the expected value is 1.66. This means that in 68.2% of the time the average bed occupancy is 7.16 +/- 1.66, under the assumption that the data is normally distributed. In Appendix F – Descriptive statistics of the bed occupancy - Intervention option 1 the descriptive statistics of the bed occupancy is given of the expected value per hour, per day, and per month for intervention option 1.

Table Appendix H - 2 Descriptive statistics of the bed occupancy for intervention option 1

	Percentile 1	Percentile 10	Expected value	Percentile 90	Percentile 99
STANDARD DEVIATION	1.38	1.53	1.66	1.78	1.87
MIN	0.00	1.00	3.00	6.00	8.00
MAX	6.00	8.00	11.00	15.00	18.00
AVERAGE	2.64	4.45	7.16	10.07	12.83
MEDIAN	3.00	5.00	7.00	10.00	13.00

Intervention option 2

In order to optimize the OR session planning and to decrease the peak in bed demand at the surgical nursing wards, specialists from the specialism general surgery are exchanged. Option 2: General surgery A exchange with General surgery C.

General surgery A performs surgeries on Mondays in OR1. The number of surgeries is: 179, of which 120 on Monday. The average LOS for this specialist is 4.3. The average LOS for this specialist on Monday is: 2.9.

General surgery C performs surgeries on Thursdays in OR3. The number of surgeries is: 123, of which 80 on Thursday. The average LOS for this specialist is: 7.1. The average LOS for this specialist on Thursday is 6.9.

The reason for this change is because the average LOS of General surgery A is shorter than the average LOS of General surgery C. The patients of General surgery C occupy a bed for about a week, so they will be discharged either on Sunday or on Monday. The expectation is that this will increase the bed occupancy during the weekend.

The session load of the specialists is given in PFF. The session load calculates the expected value (y-axis) of the amount of occupied beds when specialist X conducts a surgery. The x-axis is in hours, where 0 is the start of the session. Table Appendix H - 3 gives an overview of the session load of General surgery A and General surgery C. For example: the expected value that a bed is occupied 24 hours after General surgery A has conduct a surgery is 1.552. The expected value that a bed is occupied 24 hours after General surgery C has conduct a surgery is 1.263. Figure Appendix H - 4 gives an overview of the session load of General surgery A. Figure Appendix H - 5 gives an overview of the session load of General surgery C.

Table Appendix H - 3 Overview session load General surgery A and General surgery C

Session load		
	General surgery A	General surgery C
24 hours	1.552	1.263
48 hours	0.517	0.702
72 hours	0.259	0.456
96 hours	0.19	0.368
120 hours	0.155	0.333

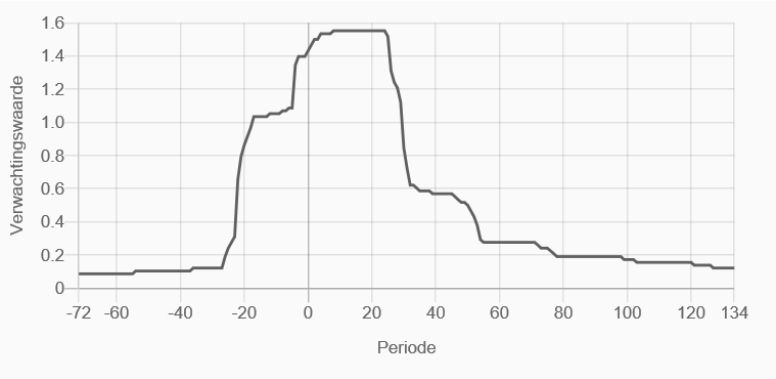

Figure Appendix H - 4 Session load of General surgery A (n=58, PFF Rhythm, 2-18-2019)

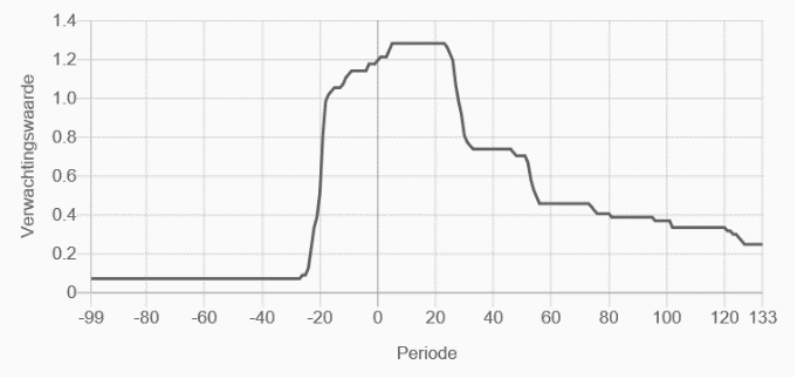

Figure Appendix H - 5 Session load of General surgery C (n=57, PFF Rhythm, 2018-2019)

The differences of session load between those two specialists is that the chance a bed is occupied is higher in the beginning for General surgery A, but eventually after 48 hours the chance a bed is occupied is lower for General surgery A.

Figure Appendix H - 6 shows an overview of March 5, 2019 to April 11, 2019 of the forecast of the bed occupancy of intervention option 2.

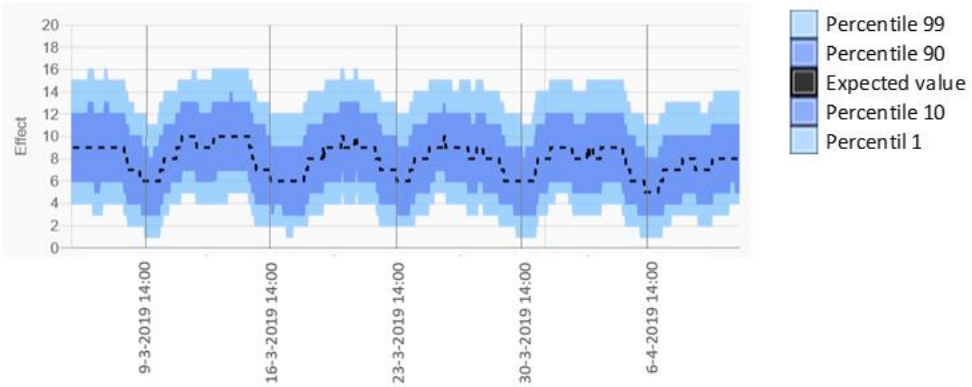

Figure Appendix H - 6 Forecast bed occupancy on Saturdays of intervention option 2 HOH (n=94, PFF Rhythm, 2018-2019)

Figure Appendix H - 6 shows a pattern during the weekends and weekdays. The data which is shown on the x-axis are Saturdays. In the weekends there is an off-peak load of the bed occupancy. The ultimate off-peak load is on Saturday, and it increases during the day on Sunday. The first, second, and third peak have an expected value of ten beds. The fourth peak has an expected value of nine beds. The first, second, third, and fourth off-peak loads have an expected value of six beds, the fifth off-peak load has an expected value of five beds. There is a difference of three and four beds between the peaks and off-peak loads.

Table Appendix H - 4 gives an overview of the descriptive statistics of the bed occupancy for intervention option 2 of the months February, March, and April per hour. For example: the minimum bed occupancy for the expected value is 3. The standard deviation of the expected value is 1.74. This means that in 68.2% of the time the average bed occupancy is 7.62 +/- 1.74, under the assumption that the data is normally distributed. In Appendix F – Descriptive statistics of the bed occupancy - Intervention option 2 the descriptive statistics of the bed occupancy is given of the expected value per hour, per day, and per month for intervention option 2.

Table Appendix H - 4 Descriptive statistics of the bed occupancy for intervention option 2

	Percentile 1	Percentile 10	Expected value	Percentile 90	Percentile 99
STANDARD DEVIATION	1.45	1.59	1.74	1.92	2.03
MIN	0.00	1.00	3.00	6.00	8.00
MAX	6.00	9.00	12.00	15.00	19.00
AVERAGE	2.89	4.77	7.62	10.66	13.48
MEDIAN	3.00	5.00	8.00	11.00	14.00

Intervention option 3

In order to optimize the OR session planning and to decrease the peak in bed demand at the surgical nursing wards, specialists from the specialism general surgery are exchanged. Option 3: move General surgery A from Monday to Friday.

General surgery A performs surgeries on Mondays in OR1. The number of surgeries is: 179, of which 120 on Monday. The average LOS for this specialist is: 3.6. The average LOS for this specialist on Monday is: 3.1. Employees of the OR and of the surgical nursing wards experience a high workload on Monday since there are three general surgeries performing surgeries. That is why the third option is a move in days, namely General surgery A from Monday to Friday.

Figure Appendix H - 7 shows an overview of March 5, 2019 to April 11, 2019 of the forecast of the bed occupancy of intervention option 3.

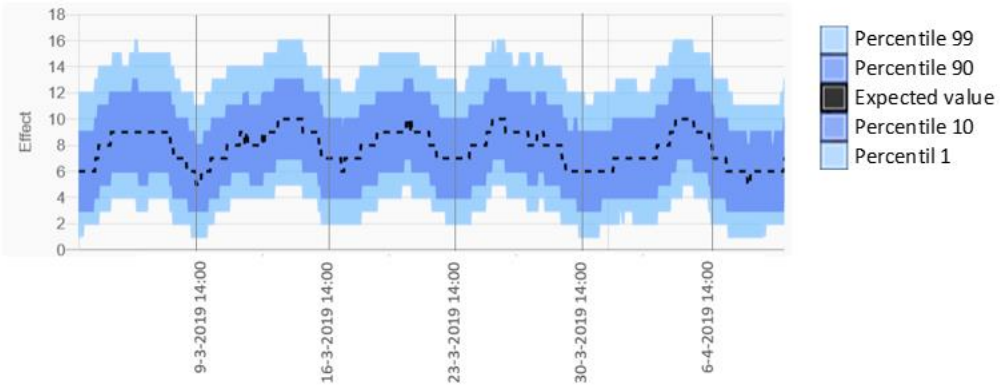

Figure Appendix H - 7 Forecast bed occupancy on Saturdays of intervention option 3 HOH (n=92, PFF Rhythm, 2018-2019)

Figure Appendix H - 7 shows a pattern during the weekends and weekdays. The data which is shown on the x-axis are Saturdays. In the weekends there is an off-peak load of the bed occupancy. The ultimate off-peak load is on Saturday, and it increases during the day on Sunday. The first peak has an expected value of nine beds, the other four peaks have an expected value of ten beds. The first and fifth off-peak loads have an expected value of five beds. The second, and fourth off-peak loads have an expected value of six beds.

The third off-peak load has an expected value of seven beds. There is a difference of three, four, and five beds between the peaks and off-peak loads.

Table Appendix H - 5 gives an overview of the descriptive statistics of the bed occupancy for intervention option 3 of the months February, March, and April per hour. For example: the minimum bed occupancy for the expected value is 5. The standard deviation of the expected value is 1.58. This means that in 68.2% of the time the average bed occupancy is 7.72 +/- 1.58, under the assumption that the data is normally distributed. In Appendix F – Descriptive statistics of the bed occupancy - Intervention option 3 the descriptive statistics of the bed occupancy is given of the expected value per hour, per day, and per month for intervention option 3.

Table Appendix H - 5 Descriptive statistics of the bed occupancy for intervention option 3

	Percentile 1	Percentile 10	Expected value	Percentile 90	Percentile 99
STANDARD DEVIATION	1.39	1.53	1.58	1.71	1.79
MIN	1.00	2.00	5.00	7.00	10.00
MAX	6.00	8.00	11.00	14.00	17.00
AVERAGE	2.99	4.85	7.72	10.72	13.45
MEDIAN	3.00	5.00	8.00	11.00	14.00

Appendix I – MSS intervention options 1, 2, and 3

MSS intervention option 1

In order to optimize the OR session plan and to decrease the peak in bed demand at the surgical nursing wards, specialists from the specialism general surgery are exchanged. In total three intervention options are analyzed with PFF. We assume that the planned sessions for specialist X are conducted by specialist X. The three intervention options for the MSS are the same options as for the realization. MSS intervention option 1 is described in this section. More information about this option is described in section 5.3.3.

Figure Appendix I - 1 shows an overview of March 5, 2019 to April 11, 2019 of the forecast of the bed occupancy of MSS intervention option 1.

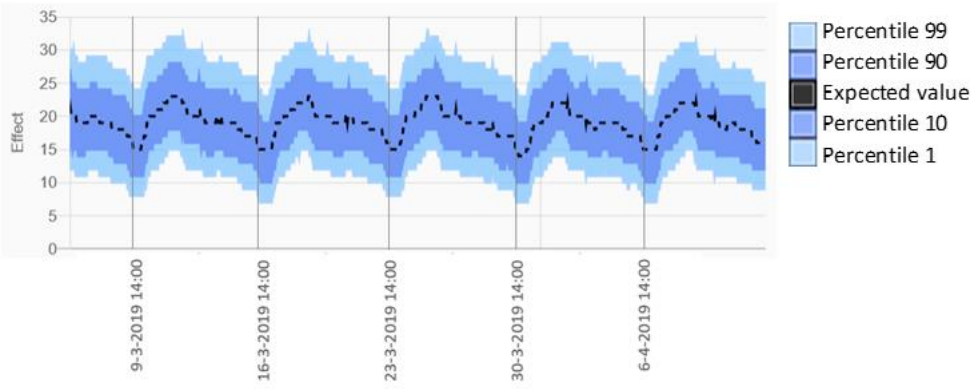

Figure Appendix I - 1 Forecast bed occupancy on Saturdays of MSS intervention option 1 HOH (n=229, PFF Rhythm, 2018-2019)

Figure Appendix I - 1 shows a pattern during the weekends and weekdays. The data which is shown on the x-axis are Saturdays. In the weekends there is an off-peak load of the bed occupancy. The ultimate off-peak load is on Saturday, and it increases during the day on Sunday. All the peaks have an expected value of 23 beds. The first, second, third, and fifth off-peak load have an expected value of 15 beds, the fourth off-peak load has an expected value of 14 beds. There is a difference of eight and nine beds between the peaks and off-peaks load.

TABLE X gives an overview of the descriptive statistics of the bed occupancy for MSS intervention option 1 of the months February, March, and April per hour. For example: the minimum bed occupancy for the expected value is 12. The standard deviation of the expected value is 2.30.

This means that in 68.2% of the time the average bed occupancy is 18.62 +/- 2.30, under the assumption that the data is normally distributed. In Appendix F – Descriptive statistics of the bed occupancy- MSS intervention option 1 the descriptive statistics of the bed occupancy is given of the expected value per hour, per day, and per month for MSS intervention option 1.

Table Appendix I - 1 Descriptive statistics of the bed occupancy for MSS intervention option 1

	Percentile 1	Percentile 10	Expected value	Percentile 90	Percentile 99
STANDARD DEVIATION	2.16	2.22	2.30	2.39	2.47
MIN	5.00	8.00	12.00	16.00	20.00
MAX	15.00	19.00	23.00	28.00	32.00
AVERAGE	10.83	14.11	18.62	23.30	27.47
MEDIAN	11.00	14.00	19.00	24.00	28.00

MSS intervention option 2

In order to optimize the OR session plan and to decrease the peak in bed demand at the surgical nursing wards, specialists from the specialism general surgery are exchanged. In total three intervention options are analyzed with PFF. We assume that the planned sessions for specialist X are conducted by specialist X. The three intervention options for the MSS are the same options as for the realization. MSS intervention option 2 is described in this section. More information about this option is described in section 5.3.3.

Figure Appendix I - 2 shows an overview of March 5, 2019 to April 11, 2019 of the forecast of the bed occupancy of MSS intervention option 2.

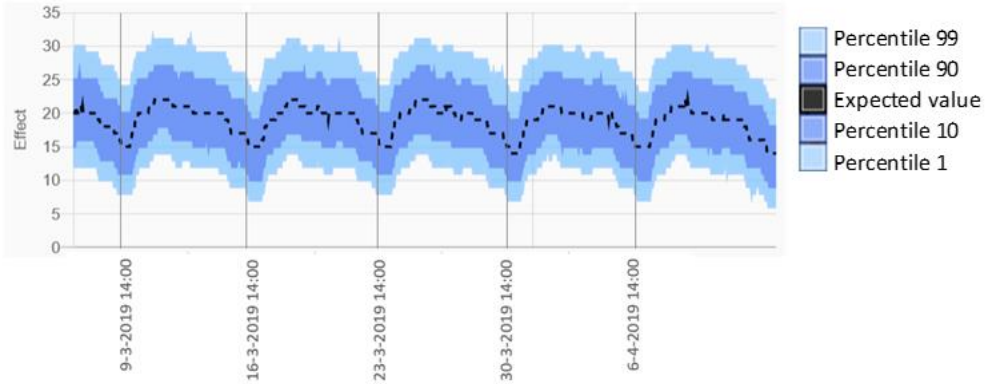

Figure Appendix I - 2 Forecast bed occupancy on Saturdays of MSS intervention option 2 (n=229, PFF Rhythm, 2018-2019)

Figure Appendix I - 2 shows a pattern during the weekends and weekdays. The data which is shown on the x-axis are Saturdays. In the weekends there is an off-peak load of the bed occupancy. The ultimate off-peak load is on Saturday, and it increases during the day on Sunday. The first, second, and third peak have an expected value of 22 beds, the fourth peak has an expected value of 21 beds, and the fifth peak has an expected value of 23 beds. The first, second, third, and fifth off-peak load have an expected value of 15 beds, the fourth off-peak load has an expected value of 14 beds. There is a difference of seven and eight beds between the peaks and off-peaks load.

Table Appendix I - 2 gives an overview of the descriptive statistics of the bed occupancy for MSS intervention option 2 of the months February, March, and April per hour. For example: the minimum bed occupancy for the expected value is 11. The standard deviation of the expected value is 2.28. This means that in 68.2% of the time the average bed occupancy is 18.70 +/- 2.28, under the assumption that the data is normally distributed. In Appendix F – Descriptive statistics of the bed occupancy– MSS intervention option 2 the descriptive statistics of the bed occupancy is given of the expected value per hour, per day, and per month for MSS intervention option 2.

Table Appendix I - 2 Descriptive statistics of the bed occupancy for MSS intervention option 2

	Percentile 1	Percentile 10	Expected value	Percentile 90	Percentile 99
STANDARD DEVIATION	2.06	2.17	2.28	2.41	2.50
MIN	5.00	7.00	11.00	16.00	19.00
MAX	14.00	18.00	22.00	27.00	31.00
AVERAGE	10.88	14.17	18.70	23.38	27.56
MEDIAN	11.00	15.00	19.00	24.00	28.00

MSS intervention option 3

In order to optimize the OR session plan and to decrease the peak in bed demand at the surgical nursing wards, specialists from the specialism general surgery are exchanged. In total three intervention options are analyzed with PFF. We assume that the planned sessions for specialist X are conducted by specialist X. The three intervention options for the MSS are the same options as for the realization. MSS intervention option 3 is described in this section. More information about this option is described in section 5.3.3.

Figure Appendix I - 3 shows an overview of March 5, 2019 to April 11, 2019 of the forecast of the bed occupancy of MSS intervention option 3.

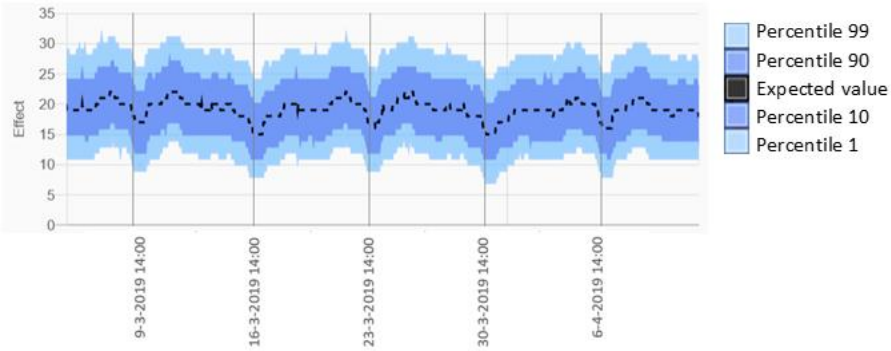

Figure Appendix I - 3 Forecast bed occupancy on Saturdays MSS intervention option 3 HOH (n=229, PFF Rhythm, 2018-2019)

Figure Appendix I - 3 shows a pattern during the weekends and weekdays. The data which is shown on the x-axis are Saturdays. In the weekends there is an off-peak load of the bed occupancy. The ultimate off-peak load is on Saturday, and it increases during the day on Sunday. The first, second, and third peak have an expected value of 22 beds, the fourth and fifth peak have an expected value of 21 beds. The first off-peak load has an expected value of 17 beds, the second and fourth off-peak load have an expected value of 15 beds, the third and fifth off-peak load have an expected value of 16 beds. There is a difference of five and six beds between the peaks and off-peak load.

Table Appendix I - 3 gives an overview of the descriptive statistics of the bed occupancy for MSS intervention option 3 of the months February, March, and April per hour.

For example: the minimum bed occupancy for the expected value is 12. The standard deviation of the expected value is 1.84. This means that in 68.2% of the time the average bed occupancy is 18.63 +/- 1.84, under the assumption that the data is normally distributed. In Appendix F – Descriptive statistics of the bed occupancy – MSS intervention option 3 the descriptive statistics of the bed occupancy is given of the expected value per hour, per day, and per month for MSS intervention option 3.

Table Appendix I - 3 Descriptive statistics of the bed occupancy for MSS intervention option 3

	Percentile 1	Percentile 10	Expected value	Percentile 90	Percentile 99
STANDARD DEVIATION	1.66	1.73	1.84	1.94	2.02
MIN	5.00	8.00	12.00	16.00	20.00
MAX	14.00	17.00	22.00	27.00	31.00
AVERAGE	10.80	14.09	18.63	23.28	27.43
MEDIAN	11.00	14.00	19.00	24.00	28.00