Relating the master surgery schedule to the workload at the nursing wards

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Summary

Introduction

This master thesis has been conducted from February through September 2011 at the Isala Klinieken Zwolle. The goal of the research was to reduce the variability of the workload on the nursing wards.

The study shows that stream of elective surgery patients is responsible for most of the erratic behaviour at the nursing wards. High variability of workload in the nursing wards results in many unfavourable consequences: peak workloads, cancellation of patients, empty beds, the allocation of patients to wards that are non-optimal for their healing process, difficulties handling emergency patients, higher risk of mortality, higher failure to rescue rates, lower job satisfaction and higher likelihood of nurse burn-out.

The study proposes a decision tool that quantifies the required bed demand for the current master surgery schedule and offers alternative MSSs that are expected to perform substantially better.

Research approach

To conduct this research, we use Vanberkel's model to relate recovering surgical patient workload to the Master Surgery Schedule. The model is used to evaluate variants of the current MSS. In this research the term OR-block is defined as a shift (morning or afternoon) in any of the operating rooms on any of the 10 days within an MSS-cycle (De Weezenlanden there are 10 (ORs) times 2 (shifts per day) times 10 (Days) = 200 OR-blocks). The heuristic developed in this research swaps OR-blocks and compares the calculated expected patient workload.

The performance of an MSS is defined along three dimensions: the variability of the expected bed demand per day, of the expected number of admissions per day, and of the expected number of discharges per day. The model records the best possible swaps. After implementing the change the model can be rerun. We refer to a rerun as an iteration.

Results

Two interventions are tested: restricting the amount of patients that are allowed to be operated during one OR-block, and altering the MSS. The first intervention yields no consistent results. The later, however, shows considerable improvements. The interventions are tested for both of the hospital's major locations, De Weezenlanden (WL) and Sophia (SZ).

For De Weezenlanden, the workload performance measure has been reduced by about 50 percent after five iterations. The total bed demand for the location is reduced from 137 to 131 beds after five iterations. For the Sophia location, the workload performance measure is reduced by about 60 percent after four iterations, and the bed demand is reduced by 3 beds.

Ward specific distributions

The situation of individual wards as a result of the changes is explored as well. It turns out that for the Weezenlanden location the performance for the specific wards improves as well. For the Sophia location the net workload for the individual wards is about the same.

Conclusions

The best swaps for the Weezenlanden location are: swapping urology from the first Wednesday to the last Friday afternoon, then swapping urology from the second Wednesday to the last Friday of the cycle, then swapping ear, nose and throat surgery from the first Thursday for orthopaedics from the second Monday, then ear, nose and throat surgery from the first Friday for orthopaedics from the first Monday. Table 5.5 and 5.6 give an overview of the best swaps.

The best swaps for the Sophia location are: swapping neurosurgery from the first Monday with plastic surgery from the last Friday, then swapping neurosurgery from the second Monday with plastic surgery from the first Friday, then neurosurgery from the second Monday with general surgery from the last Friday, then neurosurgery from the first Monday with general surgery from the second Monday. A complete overview of the best swaps can be found in the Appendix.

The heuristic is flexible. The performance measure can be adapted to minimize variance over all days (both week and weekend days), or to minimize total bed demand, or give different weights to either the variance of bed demand during the week and the variance of bed demand during the weekend. It is also possible to swap OR-days instead of OR-blocks.

The workload is reduced considerably for the hospital in general, but further investigation shows that we need to be aware of changes at specific wards. As a consequence of the reduction in workload some wards perform better as well. There are some wards that perform worse after the intervention however, and it is important to be aware of this.

Recommendations

The implementation of this research is a delicate matter. The recommendations regarding the implementation should be followed. Because the MSS for the new location is not decided upon yet, it is a huge opportunity to get rid of inefficiencies in the schedule. It is recommended to carefully structure the new MSS. Strictly speaking the hospital can start with a completely new MSS. Building an MSS from the bottom up allows for improvements compared to the current schedule and it is recommended that this opportunity is used wisely.

Depending on the management's goal for the new hospital, the heuristic for optimization may or may not lead to a desired MSS. If capacity becomes an issue and the hospital's management decides to increase the number of patients in the weekends in order to decrease the workload throughout the week the one-step-swaps may not be the most effective modus operandi. Traditionally the Friday has been a relatively quiet day for the operating rooms. If bed occupancy needs to be raised in the weekends one might consider more drastic approaches to altering the MSS.

When workload of a specific ward is expected to increase measures must be taken. Our model predicts when this will happen, so we can anticipate on this. Possible measures include exchanging nurses between different wards.

It is possible to optimize the model over all wards individually as well, but we need to be careful about how we want to measure performance. A great deal of experimenting is not possible due to the expected runtime of about 12 hours (calculating the performance of an MSS on the ward-level takes about 60 seconds, so going through some 900 configurations will take about 15 hours).

Management Samenvatting (Dutch)

Introductie

Deze master thesis is uitgevoerd in februari tot en met augustus 2011 in de Isala Klinieken Zwolle. Het doel van het onderzoek was de patiëntlogistiek te verbeteren, met name de variabiliteit met betrekking tot de werklast op de verpleegafdelingen te verminderen.

De studie toont aan dat de patiëntstroom die verantwoordelijk is voor het grootste deel van het grillige gedrag op de verpleegafdelingen de electieve OK-patiënten zijn. Hoge variabiliteit op de verpleegafdelingen resulteert in een hele reeks van ongunstige gevolgen: pieken in de werklast, de annulering van patiënten, de toewijzing van patiënten aan afdelingen die niet optimaal is voor hun herstel, lege bedden, moeilijkheden met het verwerken van spoedeisende patiënten, een hoger risico op sterfte, hogere failure-to-rescure rates, een lagere werktevredenheid en een hogere kans op burn-out van verpleegkundigen.

De studie levert een beslissingsinstrument aan dat de vereiste bedvraag ten gevolge van het huidige master surgery schedule kwantificeert en stelt alternatieve MSS-en voor die naar verwachting aanzienlijk beter presteren.

Onderzoeksaanpak

Voor het uitvoeren van dit onderzoek is Vanberkel's model gebruikt dat het verband legt tussen de werklast die gemoeid gaat met herstellende chirurgische patiënten en het master surgery schedule.

In dit onderzoek wordt de term OR-block (OK-blok) gedefinieerd als een shift (ochtend of middag) in een van de operatiekamers op een van de 10 dagen binnen een MSS-cyclus (dus voor De Weezenlanden zijn er 10 (OK's) keer twee (verschuivingen per dag) maal 10 (dagen) = 200 OK-blokken. De heuristiek zoals ontwikkeld in dit onderzoek wisselt alle mogelijke paren OK-blokken en vergelijkt de berekende verwachte werklast.

De prestaties van een MSS wordt bepaald op drie dimensies, die elk wordt beschouwd als een belangrijk onderdeel van de werklast: de variabiliteit van de verwachte vraag naar bedden, die van het verwachte aantal opnames, en van het verwachte aantal ontslagen.Het model legt de best mogelijke wisselingen vast. Na de implementatie van een verandering kan het proces herhaald worden. Elke herhaling wordt gedefinieerd als een iteratie.

Resultaten

Twee interventies worden getest: het beperken van de hoeveelheid patiënten die geopereerd mogen worden tijdens een OK-blok, en het veranderen van het MSS. Beperking van de hoeveelheid operaties per OK-blok levert geen consistente resultaten op. Het wijzigen van het MSS levert wel aanzienlijke verbeteringen op. Het model is toegepast op de twee ziekenhuislocaties van de Isala Klinieken, te weten: De Weezenlanden (WL) en Sophia (SZ).

Voor de Weezenlanden is de performance measure voor de variabiliteit van de werkdruk verminderd met ongeveer 50 procent na vijf iteraties. De totale bedvraag naar het beddenhuis wordt teruggebracht 137 tot 131 bedden na vijf iteraties. Voor de locatie Sophia is de variabiliteit van de werkdruk verminderd met ongeveer 50 procent. Na vier iteraties wordt de bedvraag verlaagd met 3 bedden.

Resultaten op het niveau van individuele verpleegafdelingen

De situatie op de individuele afdelingen als gevolg van de veranderingen is ook onderzocht. Het blijkt dat voor de locatie Weezenlanden de prestaties voor de specifieke afdelingen verbetert. Voor de locatie Sophia is de netto werklast voor de individuele afdelingen is ongeveer hetzelfde als voor de interventie.

Conclusies

De beste swaps voor de Weezenlanden locatie zijn: het omwisselen van urologie van de eerste woensdag met een lege OK-dag op de laatste vrijdag, daarna het wisselen urologie van de tweede woensdag met een lege OK-dag op de laatste vrijdag van de cyclus, dan het wisselen van KNO vanaf de eerste donderdag met orthopedie van de tweede maandag, dan KNO vanaf de eerste vrijdag met orthopedie vanaf de eerste maandag. Tabellen 5.5 en 5.6 bevatten een compleet overzicht van de beste swaps.

De beste swaps voor de Sophia locatie zijn: het wisselen van neurochirurgie vanaf de eerste maandag met plastische chirurgie van de laatste vrijdag, dan het wisselen van neurochirurgie vanaf de tweede maandag met plastische chirurgie vanaf de eerste vrijdag, dan neurochirurgie vanaf de tweede maandag met algemene chirurgie van de laatste Vrijdag, dan neurochirurgie vanaf de eerste maandag met algemene chirurgie vanaf de tweede maandag. Tabel 5.9 bevat een compleet overzicht.

De optimalisatie-doelfunctie kan worden aangepast. Voorbeelden zijn het minimaliseren van de variantie over alle dagen (zowel week-en weekenddagen), of om de maximale bedvraag te minimaliseren, of het verschillend wegen van de verschillende onderdelen van werklast .

Het is ook mogelijk om te wisselen niet OK-blokken te verwisselen in plaats van OK-dagen.

De werkdruk is aanzienlijk verminderd voor het ziekenhuis in het algemeen, maar nader onderzoek laat zien dat het nodig is om bewust te zijn van veranderingen op specifieke afdelingen. Als gevolg van de vermindering van de werklast presteren sommige afdelingen beter. Er zijn echter een aantal afdelingen die slechter presteren na de interventie, en het is belangrijk om hiervan bewust te zijn.

Aanbevelingen

Het invoeren van de door het model gesuggereerde veranderingen is een delicate zaak. De aanbevelingen ten aanzien van de invoering moeten worden gevolgd. Omdat het MSS voor de nieuwe locatie nog niet vaststaat, is het een enorme kans voor het ziekenhuis om zich te ontdoen van inefficiënties in de planning. Het is aan te bevelen om zorgvuldig de structuur van het nieuwe MSS te bepalen.

Afhankelijk van de doelstelling van de directie voor het nieuwe ziekenhuis zal de heuristiek voor optimalisatie wel of niet leiden tot een gewenst MSS. Als de capaciteit een probleem wordt en het ziekenhuismanagement beslist om het aantal patiënten in de weekenden te verhogen om vermindering van de werkdruk gedurende de week te bewerkstelligen dan zijn de een-stap-wisselingen misschien niet de meest effectieve manier. Traditioneel is de vrijdag een relatief rustige dag voor de operatiekamers. Als bed bezetting moet worden verhoogd in het weekend dan kan men een meer drastische aanpak van het veranderen van de MSS overwegen.

Wanneer de werklast op een specifieke afdeling naar verwachting zal toenemen is het belangrijk om maatregelen te nemen. Het model voorspelt wanneer excessen te verwachten zijn, zodat we hierop goed kunnen anticiperen. Mogelijke maatregelen zijn het uitwisselen van verpleegkundigen tussen de verschillende afdelingen.

Het is mogelijk om het model te optimaliseren over alle afdeling individueel, maar we moeten voorzichtig zijn met hoe we de prestaties meten. Experimenteren met hoe de performance te meten is lastig vanwege de verwachte rekentijd van ongeveer 12 uur (het berekenen van de prestaties van een MSS op de afdeling-niveau duurt ongeveer 60 seconden duren, omdat er zo'n 900 configuraties doorgerekend dienen te worden is de verwachte rekentijd ongeveer 15 uur).

Word of thanks

This research would not have been possible without several persons and I want to take the time to thank them.

First of all I want to extend my gratitude to my supervisor Bernd van den Akker, whose clear perspective has always been of great help. He held the reins but I barely noticed it even if I were paying close attention. As a result I could completely plan my assignment and make major decisions on my own (or so I thought). Still, conversing about bigger issues (the state of health care in the Netherlands, soccer, religion, economics, etc.) or even greater matters (life and amazement about it) was where I derived the most pleasure from.

It has also been a great honour for me to have Erwin Hans as my supervisor. He has been able to solve problems I wasn't even experiencing yet. His advice would always surprise me because I never see problems coming if they are still 6 months in the future. His advice has allowed me to swiftly avoid pitfalls long before they presented themselves. His wisdom, intelligence and humour were of great aid during the process.

I would like to thank Ingrid Vliegen as well, whose late entrance did not restrain her from urging me to take strides in improving my research.

Furthermore, I could never repay my colleagues at the Isala Klinieken. Numerous lunch breaks, conversations, jokes and stories have been shared. The occasional vrijdag-patat-met will be a pleasant memory I will not forget.

The Kwaliteit & Veiligheid section has made me feel very welcome indeed, always inviting me to their shared activities (meetings, presentations, lunches and drinks). For this I would like to thank them.

Additionally I would like to thank my family for everything they have done for me. And last but very definitely not least, I want to thank my sweet girlfriend. Her love, support and understanding have been crucial for this project. Without her I could have never achieved what I have.

Many more have been conducive for my research. I will not mention you here, but you know who you are. If I can ever return the favour, you know where to find me.

Ronald Vlijm

Zwolle, 3-11-2011

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1 Introduction

Patients that undergo surgery at one of the operating rooms (OR) at the Isala Klinieken Zwolle have to spend some time at the wards to receive care. The recovery of these patients takes place on the intensive care (IC) and the nursing wards. The nursing wards face a high variability in bed occupancy and hence workload. This variability is partly caused by the OR-planning. The surgeries that take place in operating rooms are governed by the biweekly master surgery schedule (MSS). The MSS prescribes which surgical specialties are operating in particular operating rooms on particular days.

Isala Klinieken Zwolle is on the brink of a new era. In 2013 the hospital is moving to a new location, where the two main locations will merge and move into one building. In this new hospital there will be fewer operating rooms and fewer beds.

Other interesting developments are taking place in the health care sector in the Netherlands. The Dutch population is rapidly ageing, health expenditures are rising, waiting lists are still long, and public opinion with regard to health care is changing. Also, in recent years the Dutch Government decided that reductions in health care costs are necessary, and has consequently implemented changes that would facilitate the intended cost reductions. All of a sudden hospitals compete with one another.

Even though the budgets are tightened, hospitals in general are faced with a growing demand for better care. Patients are getting more knowledgeable and stronger opined. More and more factors such as quality and safety start playing a role. The rules and regulations with regard to these aspects are being updated constantly, thus getting harder and more expensive to adhere to.

In fact, during the years, many constraints have been added to the realm of providing health care, and this has only made delivering proper care tougher. It is for these reasons that health care optimization has never been more relevant.

Section 1.1 introduces the Isala Klinieken, Section 1.2 gives a problem definition and Section 1.3 poses the research objective and research questions.

1.1 Isala Klinieken Zwolle

Isala Klinieken Zwolle is one of the biggest hospitals and the biggest non-academic hospital in the Netherlands. Currently, Isala Klinieken Zwolle has two locations, De Weezenlanden and Sophia, both located in Zwolle. Isala Klinieken has two additional outpatient clinics, one in Kampen and in one in Heerde. Isala has two laboratory locations in Zwolle, one for pathology, and one for microbiology and infection illnesses.

Isala Klinieken has approximately 6000 employees and some 1000 beds available. The annual turnover is about 400 million euros. The number of outpatients amounted to over half a million and almost 90.000 inpatients visited the hospital. Patients are operated in one of the 22 operating rooms which include 4 that are dedicated to day care. The catchment area of Isala clinic reaches from Groningen to Utrecht and to Nijmegen (www.isala.nl, 2010). Table 1.1.gives some more facts and figures about Isala.

Table 1.1: Isala Klinieken: Facts and figures
Source: Annual reports Isala Klinieken

	2007	2008	2009
Nursing days	263.765	267.078	279.238
Inpatient	42.339	44.334	46.060
Outpatient	471.609	502.294	522.342
Employees	5691	5275	5407
Medical specialists	236	238	250
Turnover	333.146	365.180	401.650
Beds	931	964	994

In addition to the impending migration, the organizational structure is currently being updated. Heading the new organizational structure is the Board of Directors, which forms the Team of Directors together with three Operational Directors. Each of the Operational Directors will be assigned a number of Resultaat Verantwoordelijke Eenheden (RVEs), which are clustered specialities. Each of these RVEs has an RVE-manager who reports to their respective Operational Director.

1.2 Problem

In Section 1.2.1 it is explained why the research was initiated. In Section 1.2.2 the research context and its relevance are explained. In Section 1.2.3 the problem is defined in both qualitative and quantitative terms. In 1.2.4 the problem is put in perspective in order to understand on what level is being operated.

1.2.1 Motivation and goal

Currently there is a suspicion that the performance with regard to bed capacity is not optimal. There is a lot of variability in the amount of patients on the wards on different weekdays. In addition to this, there is a lot of variability in the amount of patient admissions and patients discharged on different days of the week. The fluctuating nature of the amount of patients and amount of work to be done at the wards leads to sub-optimal care. When nurses have too much work on their hands individual care is of a lower quality. On the other hand, on days where too many personnel are present, personnel is not being used effectively. Recent studies show that patient safety is compromised in cases where the workload is either too high or too low (Kc & Terwiesch, 2009). Other studies find that high workload leads to a higher risk of mortality and higher failure-to-rescue rates and that it is likely to cause nurse burn-out and job dissatisfaction (Aiken et al., 2002).

It all boils down to this: because the workload is erratic and predictability is low it is impossible to have excellent personnel planning. The department of Patient Logistics has developed a tool to predict workload more accurately (Vlijm, 2011a). This tool takes the patients that are planned for surgery as input and determines the amount of care individual patients is expected to generate. This allows OR-planners and ward managers to understand the impact of adding a patient to an OR-block. It also makes it easier to plan personnel accordingly. This model is a great example of a tool that works on the operational level. The model proposed in this research operates on the tactical level. Ideally the flow of patients is more stable in order to improve scheduling, performance and the quality of care.

1.2.2 Research context

This research is being carried out in collaboration with the division Patient Logistics of the Isala Klinieken. The department concerns itself with the patient flow through the hospital. Several researchers have been investigating factors concerning patient logistics. Vanberkel et al. (2010), concluded that there is a relationship between variability and the operating room schedule, and thus that the variability can be reduced by altering the OR schedule. Vanberkel also acknowledges that when altering the schedule individual characteristics of specialists should be taken into account.

Lastly, Vanberkel asserts that the length of stay (LOS) of patients can be predicted as soon as the patient is being diagnosed. It is his impression that this knowledge can be used to the hospitals' advantage.

Presently, when planning the OR the LOS of patients is generally not considered, i.e. nursing wards are ignored. This results in highly variable numbers of patients in the wards on different days of the week. The current variability of the operating rooms is detrimental to the performance of down ward departments, in this case the IC and the nursing wards (Hopp, W.J. & Spearman, M.L., 2008).

1.2.3 Problem definition

To get insight in the nature of the problems some issues with current bed planning are listed. These are concerns that bother ward managers.

- Ward managers feel that there are too few beds available, and they feel that this might be because OR planning does not explicitly consider availability of beds on the wards.
- Last minute alterations in the OR-schedule lead to a high influx of patients at inappropriate times
- On some days many patients from one specialty arrive, at other days only a few. This results in peak workloads at some times and to overcapacity of personnel at other times.
- Emergency patients are not considered in the process of ward planning, which leads to cancellations of elective patients.

The first concern leads to believe that variability on the wards is not leveled, because otherwise this situation would not occur on a regular basis. The second issue suggests that it is possible to operate a lot of patients that need small interventions without notice, causing an unexpected influx of patients to the wards. The third bullet stresses the importance of admissions as being an import consideration in establishing the level of workload on a ward at a given time. The fourth bullet could very well be a consequence of the fact that the elective patient stream is not leveled, because if it were, it would be easier to accommodate emergency patients.

These problems point in the same direction: apparently there is a lack of predictability and an excess of variability for the nursing wards. In this chapter we conduct an initial data analysis to quantify the concerns.

We must consider two types of patients: the first category consists of patients that require surgery, the second one does not. These two types of patients occur in two categories, elective patients (patients that allow planning) and emergency patients.

Non-surgery patients arrive at a stable rate, which is shown in Figure 1.1. In this figure the columns are the average total numbers of non-surgery patients on the different weekdays. The dark-blue part of the columns are the emergency patients and the light blue area comprise elective patients. The lines show the mean plus / minus the standard deviation, and the blue dots the maximum number of patients that occurred during the year.

This figure shows that both emergency patients and elective patients have similar average numbers on weekdays. In weekends there are fewer admissions, but again the two days have similar characteristics. This observation does raise the question why the number of emergency patients is much higher on week days than on weekend days. It seems the definition of emergency patients is partly dependent on the day of the week.

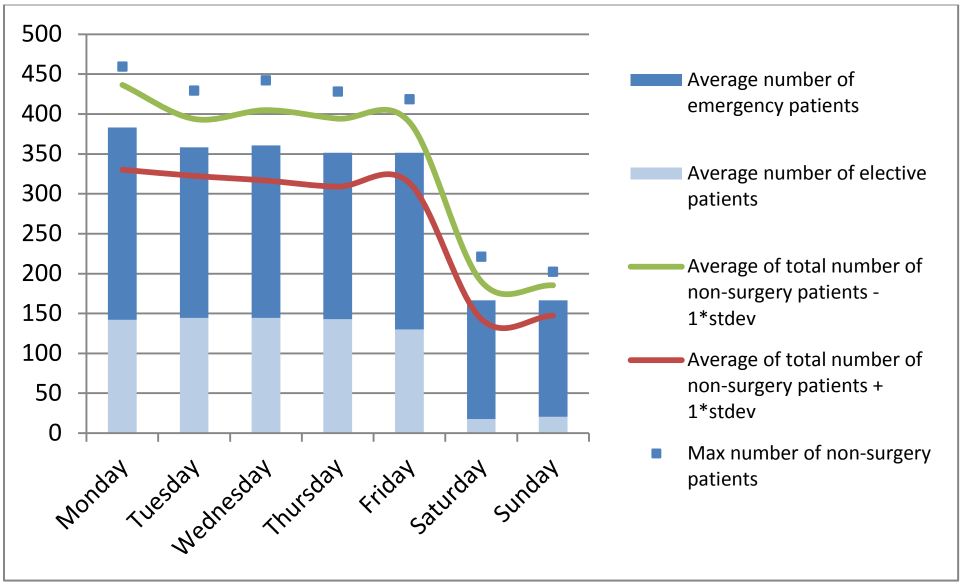

Figure 1.1: Average number of non-surgery patients per day
Source: iZis, 2010, n = 72853

The second category of patients are the surgery patients. Figure 1.2 show that these show more variability and larger standard deviations from the mean. Note however that large fluctuations in emergency patients do not occur (safe from the fact that less emergency patients arrive in the weekend compared to week days).

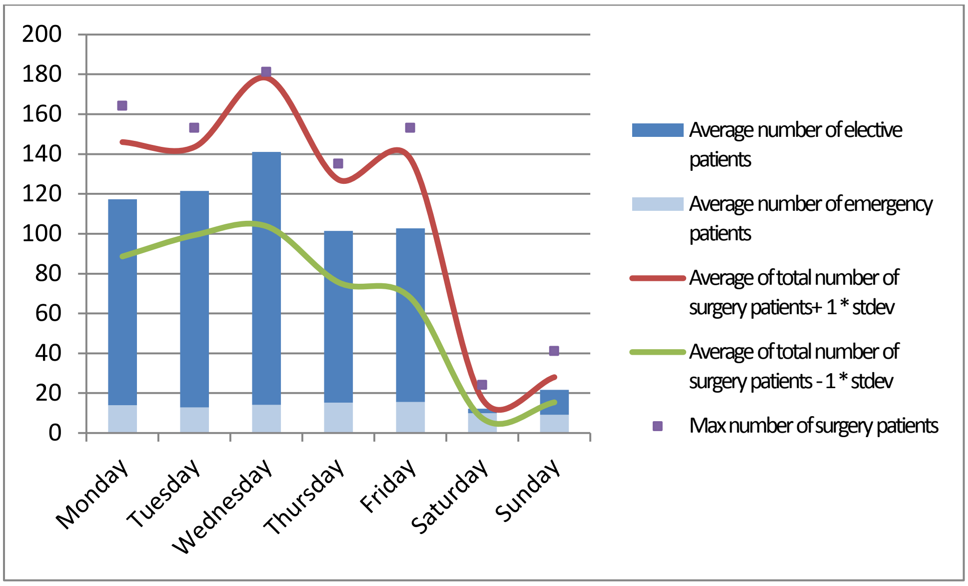

Figure 1.2: Average number of surgery patients per day
Source: iZis, 2010, n = 32225

So far four streams of patients have been analysed. The figures show how there is only one of these that shows high variability, which happens to be the elective surgery patients.. Literature hastens to suggest that in production processes a stable arrival process is favoured over highly variable streams (Hopp, W.J. & Spearman, M.L., 2000). Highly variable arrival streams result in congestion and peak workloads at the nursing wards.

The admission of elective patients is a direct result of the MSS. It is not surprising that empty beds at some times alternate times of high workloads and cancellations of patients. This research focuses on leveling this particular stream by modifying the MSS and adding planning rules to the process of planning elective patients. In other words, we investigate whether altering the MSS results in lower workload variability, and also whether limiting the amount of patients operated in an OR-block achieves this result.

1.2.4 Theoretical framework

After investigation of the problems, the model from Hans et al. (2011) is used to position the area of interest. The authors distinguish four areas of interest and four levels of control (see Table 1.2). The levels are the strategic (long-term), tactical (medium term), and the operational (short term) level. On the operational level a further distinction is made between the offline and online level. The strategic level is the meta-level where the hospital- encompassing, long term decisions are made, such as which costumer groups to cater to, which facilities should be expanded and so on.

On the tactical level the production targets should be translated into OR time. Each specialty gets assigned OR time so that their demand is met and the hospital's production targets are realized. The third level, the offline operational planning deals with the elective patients in specific OR-blocks. The number of patients and the order in which they are planned take place on this level. The lowest level, the online operational planning concerns ad-hoc changes. If an emergency patient arrives the planning has to be altered in order to allow the emergency patient to be operated. This research is concerned with the tactical level, because the MSS is evaluated and iteratively altered.

Table 1.2: Framework for hospital planning and control

	Medical Planning	**Resource capacity planning**	Materials planning	Financial planning
Strategic	Research, development of medical protocols	Case mix planning, capacity dimensioning, workforce planning	Supply chain and warehouse design	Investment plans, contracting with insurance companies
Tactical	Treatment selection, protocol selection	**Block planning, staffing, admission planning**	Supplier selection, tendering	Budget and cost allocation
Offline	Diagnosis and planning of an individual treatment	Appointment scheduling, workforce scheduling	Purchasing, determining order sizes	DRG billing, cash flow analysis
Online	Triage, diagnosing emergencies and complications	Monitoring, emergency coordination	Rush ordering, inventory replenishing	Billing complications and changes

There are four managerial levels to consider: medical planning, resource capacity planning, materials planning and financial planning. The medical planning is concerned with medical protocols, treatments diagnoses and the development of new treatment methods. Resource capacity planning deals with the dimensioning, planning and scheduling, monitoring and control of equipment, facilities and staff. Thirdly, materials planning deals with the acquisition, storage, distribution of consumable materials such as blood, bandages, food and medicine. Lastly, financial planning addresses how the organization should manage its costs and revenues to achieve its objectives under its current and future organizational and economic circumstances. Of the four managerial areas we are specifically concerned with resource capacity planning.

1.3 Research questions and approach

In this paragraph the research question and the accompanying research questions are detailed. The research objective is the following:

> *Create a decision tool that is able to predict the effects of alterations in the master surgery schedule on the bed demand of the nursing wards. Using this model we are able to recommend alternative configurations of the MSS that perform better.*

In order to reach the objective the following research questions will be answered.

1. How is the hospital organized and how does planning take place?

This question is answered in chapter 2. The first part of the question is concerned with the system. It includes a description of the hospital in general, the operating rooms and the nursing wards. The second part of the question deals with the planning of the different departments.

2. What are indicators for the workload and what is the current performance of the hospital?

Section 2.4 gives indicators for workload. To determine the properties of the workload a data analysis is carried out.

3. How can we connect OR planning to ward planning in order to improve performance?

We answer this question in Chapter 3, where literature hands us ideas for interventions we may apply to improve the MSS.

4. How can we model the relationship between the OR and the wards and how do we construct alternative OR-schedules?

In Chapter 4 we deal with the issue of modelling the relationship between the OR-department and the workload at the wards. We will also discuss how we generate alternative configurations.

5. How can we evaluate the performance of a master surgery schedule?

In Chapter 5 we formulate an objective function to aid in evaluating the performance and we analyse the results of the model.

6. How would the hospital perform after implementing the alternative solutions?

After generating new master surgery schedules and constructing performance measures we evaluate the proposed schedules in Chapter 5.

7. What are the main findings and the implications of the research in practice?

Chapter 6 addresses details concerning the implementation of the research.

2 Process analyses: OR-planning versus ward planning and its measurement

In Section 2.1 the system and its characteristics are analysed. In Section 2.2 we discuss the OR-planning and the ward planning. In Section 2.3 we discuss the master surgery schedule and in Section 2.4 we consider the performance of the wards.

2.1 System characteristics

2.1.1 Weezenlanden

Weezenlanden has twelve operating rooms available, of which ten are general and two are day care operating rooms. The operating rooms are similar in size and composition. Approximately half of the operating rooms are dedicated ORs. The others are divided over several specialties and are used as is specified in the master surgery schedule.

The following specialties are available at Weezenlanden: orthopaedics, urology, ear, nose and throat surgery, dental surgery, thorax surgery, jaw surgery, eye surgery, cardiology, pulmonology, neurology, and neurosurgery. The wards that are available in the Weezenlanden are located in two separate wings and are of different sizes. The capacity of the wards is given in Table 2.1.

In Figure 2.1 and Figure 2.2 the MSS of the Weezenlanden location is given. The figure shows for the ten ORs how the OR-blocks are divided over the specialties during a typical cycle of two weeks.

The numbering of specialties is as follows:

- Two / green / ORT: Orthopaedics
- Four / pink / DS: Jaw surgery
- Eight / yellow / URO: Urology
- Fourteen / brown / ENT: Ear nose throat surgery
- Fifteen / red / AN: Anaesthetics
- Twenty / blue / THO: Thorax surgery
- Twenty-two / purple / JAW: Dental surgery
- Forty-two / white: empty / flexible slots

Table 2.1: Weezenlanden: Wards and bed counts
Source: Cognos, 2010

Wards A-wing	Number of beds	Wards B-Wing	Number of beds
A2	39	B1	12
A4	41	B2	24
A5	44	B3	39
A6	33	B4	42
A7	36	B5	39
		B6	39

WEEZENLANDEN	OR 1		OR 2		OR 4		OR 5		OR 6	
	M	A	M	A	M	A	M	A	M	A
Monday	ORT	ORT	ORT	ORT	URO	URO	ENT	ENT	ORT	ORT
Tuesday	ORT	ORT	ORT	ORT	URO	URO	ENT	ENT	ORT	ORT
Wednesday	ORT	ORT	ORT	ORT	URO	URO	ENT	ENT	URO	URO
Thursday	ORT	ORT	ORT	ORT	URO	URO	ENT	ENT	DS	DS
Friday	ORT	ORT			URO	URO	ENT	ENT		
Saturday										
Sunday										
Monday	ORT	ORT	ORT	ORT	URO	URO	ENT	ENT	ORT	ORT
Tuesday	ORT	ORT	ORT	ORT	URO	URO	ENT	ENT	ORT	ORT
Wednesday	ORT	ORT	ORT	ORT	URO	URO	ENT	ENT	ORT	ORT
Thursday	ORT	ORT	ORT	ORT	URO	URO	ENT	ENT	URO	
Friday					URO		ENT	ENT		
Saturday										
Sunday										

Figure 2.1: The current MSS for the Weezenlanden (a), 2011

WEEZENLANDEN	OR 7		OR 8		OR 9		OR 10		OR 11	
	M	A	M	A	M	A	M	A	M	A
Monday	DS	DS	AN	THO	THO	THO	THO	THO	THO	THO
Tuesday	JAW	JAW	THO	THO	THO	THO	THO	THO	THO	THO
Wednesday	JAW	JAW	THO	THO	THO	THO	THO	THO	THO	THO
Thursday	JAW	JAW	THO	THO	THO	THO	THO	THO	THO	THO
Friday	JAW	JAW			THO	THO	THO	THO	THO	THO
Saturday										
Sunday										
Monday	JAW		AN	THO	THO	THO	THO	THO	THO	THO
Tuesday	JAW	JAW	THO	THO	THO	THO	THO	THO	THO	THO
Wednesday	URO	URO	THO	THO	THO	THO	THO	THO	THO	THO
Thursday	JAW	JAW	THO	THO	THO	THO	THO	THO	THO	THO
Friday	JAW	JAW			THO	THO	THO	THO	THO	THO
Saturday										
Sunday										

Figure 2.2: The current MSS for the Weezenlanden (b), 2011

2.1.2 Sophia

At the Sophia location of the Isala Klinieken there are ten operating rooms available, two of those are day care operating rooms and eight are general ORs.

The following specialties are hosted at the Sophia location of the Isala Klinieken: orthopaedics, ear nose throat surgery, general surgery, plastic surgery, gynaecology, gastroenterology, neurosurgery, psychiatry, paediatrics, and internal medicine. Table 2.2 and in Figure 2.3 show details with regard to the nursing wards and the MSS of Sophia.

The numbering of specialties in the Sophia MSS are as follows:

- One / yellow / GS: General surgery
- Three / purple / PS: Plastic surgery
- Nine / blue / GYN: Genealogy

- Eighteen / green / NEU: Neurosurgery
- Twente-three / pink / EM: Emergency OR
- Forty-two / white: empty / flexible slots

Table 2.2: Sophia: Wards and bed counts
Source: Cognos, 2010

Wards A-wing	Number of beds	Wards B-Wing	Number of beds	Wards	Number of beds
A1	10	B1	43	D3	30
A1P	15	B2	41	H0	27
A3	42	B3	44	K1B	16
A5	18	B4	44	K2	8
A5C	9	B5	13	K3	30
A6	17	B5G	17	M5	12
		B6	21	NEO	14

SOPHIA	OR 1		OR 2		OR 3		OR 4		OR 5		OR 6		OR 7		OR 8	
	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A
Monday	NEU	NEU	GS	GS	EM	EM	GS	GS	NEU	NEU	GS	GS	GYN	GYN	PS	PS
Tuesday	GS	GS	GS	GS	EM	EM	GS	GS	NEU	NEU	GYN	GYN	GYN	GYN	PS	PS
Wednesday	GS	GS	GS	GS	EM	EM	GS	GS	NEU	NEU	PS	PS	GYN	GYN	PS	PS
Thursday	NEU		GS	GS	EM	EM	GS	GS	NEU	NEU	GS	GS	GYN	GYN	GS	GS
Friday	GS	GS	GS	GS	EM	EM	PS	PS	NEU	NEU	EM	EM	GYN	GYN	PS	PS
Saturday																
Sunday																
Monday	NEU	NEU	GS	GS	EM	EM	GS	GS	NEU	NEU	1	1	GYN	GYN	PS	PS
Tuesday	GS	GS	GS	GS	EM	EM	GS	GS	NEU	NEU	GYN	GYN	GYN	GYN	PS	PS
Wednesday	GS	GS	GS	GS	EM	EM	GS	GS	NEU	NEU	PS	PS	GYN	GYN	PS	PS
Thursday	NEU		GS	GS	EM	EM	GS	GS	NEU	NEU	GS	GS	GYN	GYN	GS	GS
Friday	GS	GS	GS	GS	EM	EM	PS	PS	NEU	NEU	EM	EM	GYN	GYN	PS	PS
Saturday																
Sunday																

Figure 2.3: The current MSS for Sophia, 2011

2.1.3 The new hospital

A standard ward in the new hospital will have 24 beds twice. There are eight four-person rooms, one two-person room and fourteen one-person rooms in each nursing ward (Bureau Nieuwbouw, 2009). This amount totals to about 500 regular beds. Next to the regular beds there will be around 200 'heavy' beds (ICU, MCU, CCU etcetera). There are also about 200 day care beds and about 50 beds for psychiatry patients.

The new location will have 8 general operating rooms and 6 dedicated operating rooms. There will also be 4 day-care ORs. As of now the OR-schedules are empty ones. It is important to realize that filling an empty OR-schedule is a different matter than altering a current schedule. (Merely altering an existing master surgery schedule generates a far smaller solution space than comparing all possible solutions.)

2.1.4 Nursing wards process

In this section we discuss the patient flow of surgery patient types.

2.1.4.1 Elective patients

Elective patients typically enter the hospital after being directed there by a general practitioner. The patient then sees a specialist or a nurse practitioner that diagnoses the patient and finds a suitable treatment. If surgery is necessary the patient is send to pre-operative screening. When the patients is informed and deemed ready for surgery an appointment for surgery is planned. Patients that undergo surgery will be checked in the wards, at least two hours before surgery takes place. The patients are made ready for surgery, and then they are operated. Afterwards the patients can go to PACU if necessary and then to the nursing wards (either via the IC or directly).

After the operation, generally, the patients receive medication and treatment according to their needs. When the patient is ready to go home the patient6 is discharged from the hospital.

2.1.4.2 Emergency patients

Emergency patients arrive either by ambulance or, in some cases, report at the outpatient clinic. Emergency patients that do not require immediate surgery go to the patient wards. Other emergency patients may go to the Intensive Care or to an OR. If required the patient goes from the OR to either the PACU or the IC and then to the nursing wards. When the patients are done receiving hospital care they can be discharged.

2.2 Planning methodology

2.2.1 OR-planning and surgery planning

In the strategic assignment the case-mix planning is defined. In this phase it should be estimated how much OR-time each specialty needs. However, at the Isala Klinieken the case-mix planning has not been altered for years. RVE's are hard-pressed to accept a lower amount of OR-time, even when prognosis dictates they should be able to do with less. Should they ever meet an increasing influx of patients they are afraid they will not be reassigned the necessary OR-time (Vlijm, 2011b).

On the tactical level the specific OR-blocks need to be assigned to specific specialties. The result of this is the master surgery schedule. Section 2.3 describes which factors play a role in designing an MSS. In the operational level of OR-planning specific patients are planned in the OR-blocks. We can distinguish between two types of planning required for two types of patients. The planning of elective patients is called offline planning of patients, whereas the planning of emergency patients is called online planning.

2.2.2 Hospitalization planning

Now that patients are planned in the specific time-slots they are being hospitalized. The elective patients are asked to check in at a certain time and date and are also inserted in the hospital information system iZIS, according to their diagnosis / treatment relation. The ward planners get the required information from this system and make the ward planning. The information is often only available one day before actual hospitalization takes place.

Should bed demand be higher than the actual amount of available beds, then the ward planners have to decide how to handle the extra patients. It is possible to make phone calls to other wards and ask if they could handle the extra patients. This process is tiresome as other wards might not be particularly interested in having patients on their turf which do not belong to their area of expertise. It is detrimental to patient safety and the effectiveness of treatment when patients are not nursed on the ward(s) of preference.

Another reason why ward managers are not happy to accept patients from other specialties is that they simply occupy their own scarce resources. For these reasons it is beneficial to keep the number of patients being nursed at a ward different than their preferred nursing ward to a bare minimum.

2.3 Restrictions for altering MSS

The master surgery schedule is the cyclic OR-block plan for a hospital. The MSS is reviewed every three months and is organized according to current demand. In practice this means that for the most part the previous MSS are copied without too much ado. Sessions are planned (i.e. specialties are planned in OR-blocks) and finally specific patients are planned in the operational phase.

2.3.1 Level of control

In the Isala Klinieken Zwolle a biweekly master surgery schedule exists. The MSS repeats itself every two weeks, bar periods where fewer personnel are available. In the latter case a reduced MSS is made available. The design of a MSS is a complex matter since many RVE's are competing for the same resources. Also, different specialists might only be available part of the time, because they may have responsibilities elsewhere.

2.3.2 Performance of an MSS

It is difficult to actually asses the quality of the performance of an MSS. The performance is often measured using performance measures such as patient waiting time, utilization, leveling, makespan, patient deferrals and so on (Cardoen et al., 2010).

An MSS can be optimized locally on some of these performance measures (i.e. without considering downward departments such as the intensive care and the nursing wards), using mathematical programming for instance. The fact is, that many additional constraints are introduced, e.c. some operations may not be allowed to be planned on consecutive days because the cleaning of certain crucial equipment may preferably not be done overnight, but during office hours.

2.3.3 Optimization constraints

When optimizing an MSS many constraints enter the equation. Examples of these types of constraints are: physicians may not be able for operating on some days, materials may not be present on certain days, and there are not enough IC beds available for certain operations and so on. A benefit of omitting constraints is that they can be removed once they are spotted, e.g. if a certain sequence of OR-blocks is impossible because the IC-department is unable to meet the increased demand, one can compare the costs of increasing capacity at the IC-department and compare these to the expected reward of the suggested OR-block sequence.

2.4 Workload at nursing wards

2.4.1 Admission of patients

First we examine the average number of admissions for surgery patients. In the first chapter the capriciousness of the average admissions was already mentioned. In this paragraph the numbers are put under closer inspection.

Figure 2.4 displays the number of admissions of surgery patients through a typical month for the Isala Klinieken, i.e. a month where no reduced MSSs are applied. It shows how erratic admissions of patients in reality are. In weekends barely any patients have been admitted, because elective surgeries are typically not planned in the weekends. But even on the weekdays differences can be found between the numbers of admissions.

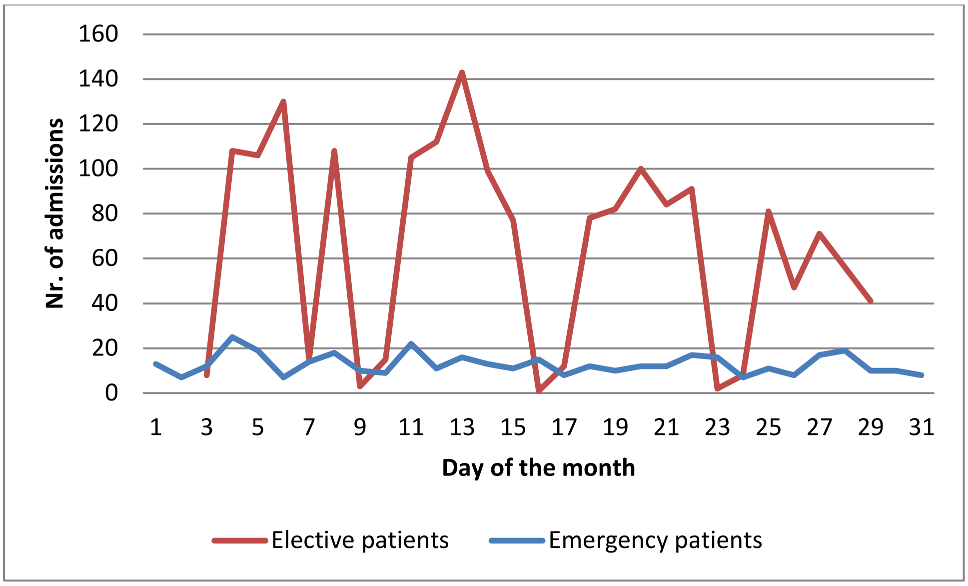

Figure 2.4: The number of admissions of surgery patients during a typical month
Source: iZIS, October (2010), n = 2590

The average admissions of patients are displayed in the Figure 1.2. In Figure 2.5 show the confidence intervals for the admission of emergency patients. The figure shows the confidence intervals of the admission of emergency patients on the weekdays and in the weekend. The arrivals during the week do not show significantly different results, as can be seen in Figure 2.6. However, during the weekend significantly fewer emergencies arrive.

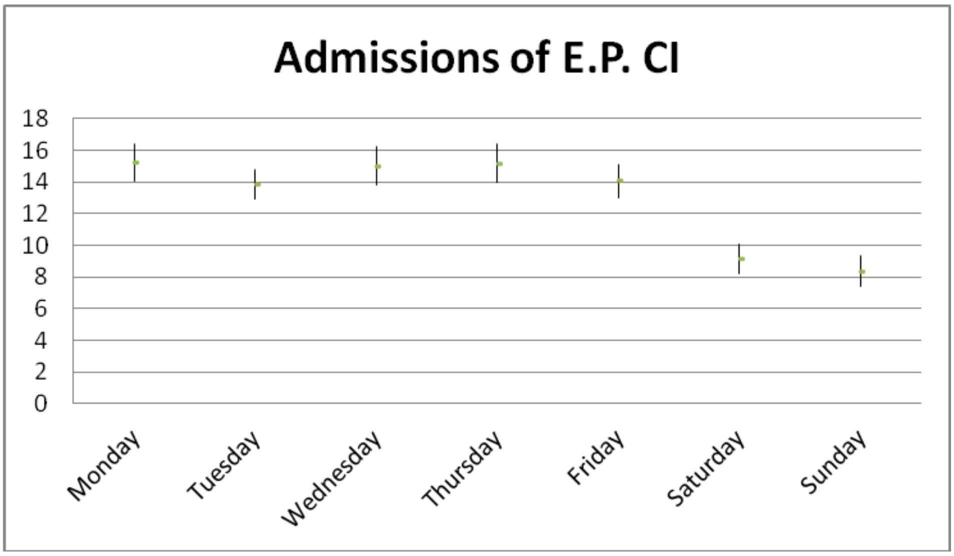

Figure 2.5: Confidence intervals of the admissions of emergency patients
Source: iZIS, 2010, n = 4734

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Monday		no	no	no	no	yes	yes
Tuesday			no	no	no	yes	yes
Wednesday				no	no	yes	yes
Thursday					no	yes	yes
Friday						yes	yes
Saturday							no
Sunday							

Figure 2.6: Statistically significant differences between days for emergency patients

Regarding the number of admissions of elective patients are inspected as well. Here we do find significant difference between working days, as is shown in Figures 2.7 and 2.8. The suspicion that the number of admissions for elective patients vary largely over the days can be deemed correct. This supports the qualitative concerns of head of wards and nursing personnel, which were discussed at an I-Lean workshop on 14 February 2011.

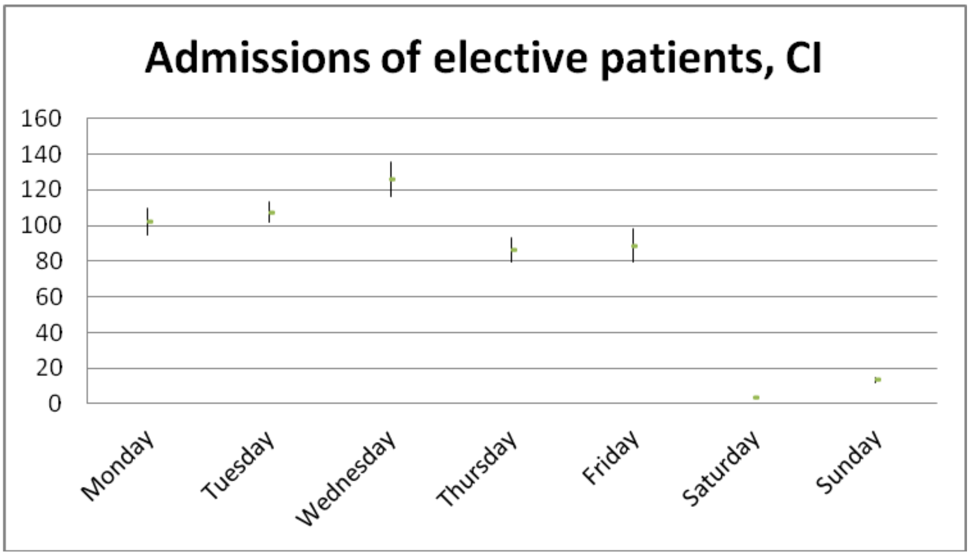

Figure 2.7: Confidence intervals of admissions of elective patients
Source: iZIS, 2010, n = 27491

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Monday		no	yes	yes	no	yes	yes
Tuesday			yes	yes	yes	yes	yes
Wednesday				yes	yes	yes	yes
Thursday					no	yes	yes
Friday						yes	yes
Saturday							yes
Sunday							

Figure 2.8: Statistically significant differences between days for elective patients

2.4.2 Discharges of patients

In this section we explore the discharges of patients. Just like patient admissions, patient discharges are labour intensive, they are a measure of workload. On the day of discharge, patients need to be visited, paperwork needs to be prepared, etc. Figure 2.9 shows the discharge statistics for all surgery patients.

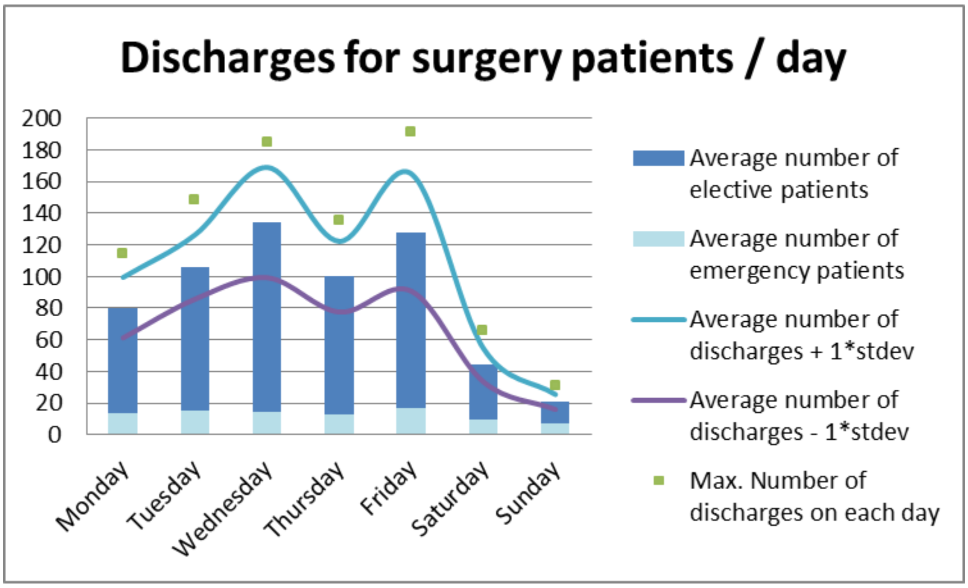

Figure 2.9: The discharges for all surgery patients on different week days
Source: iZIS, 2010, n = 32225

To examine the discharges we distinguish between emergency patients and elective patients. The goal of this exercise is to find out whether for different patient groups a significant difference exists between the different days.

The discharges of emergency patients seem to be spread evenly over the week. Figure 2.10 shows the confidence intervals for the different weekdays.

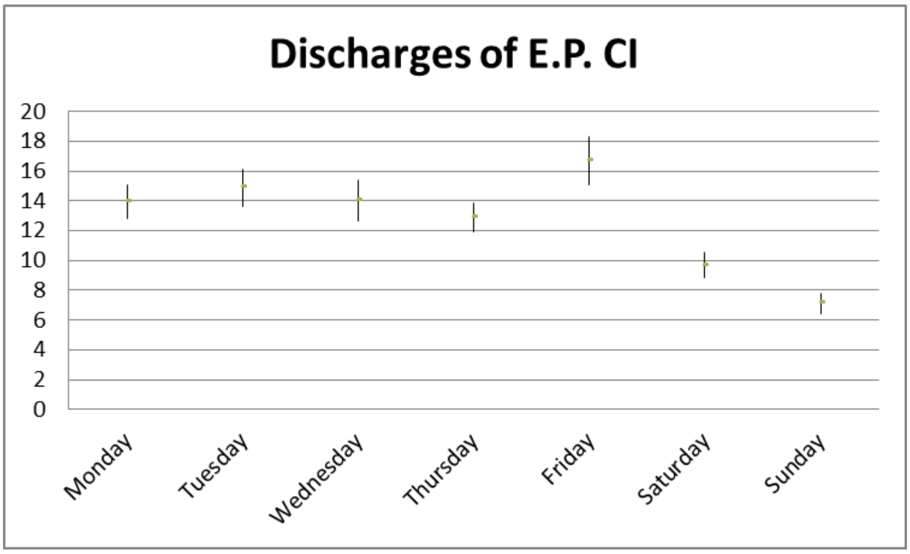

Figure 2.10: The confidence interval of the number of discharges of emergency patients
Source: iZIS, 2010, n = 4734

Here we can see that not all days have overlapping amounts of discharges. Figure 2.11 provides an overview of this phenomenon.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Monday		no	no	no	yes	yes	yes
Tuesday			no	no	no	yes	yes
Wednesday				no	no	yes	yes
Thursday					yes	yes	yes
Friday						yes	yes
Saturday							yes
Sunday							

Figure 2.11: Statistically significant differences between the numbers of discharges for emergency patients

Figure 2.12 shows that most notably on Friday significantly more emergency patients are discharged compared to Monday and Thursday. Why this is the case is something that should be addressed. It is plausible that emergency patients are sent home for the weekend to be taken care of by family if at all possible. It is also convenient for staff to have fewer patients in the nursing wards in the weekends.

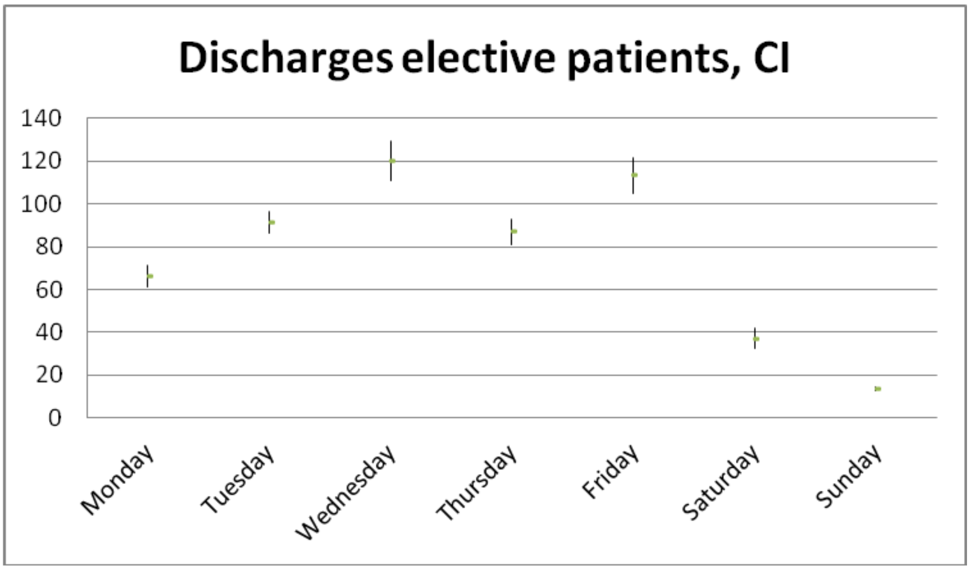

Figure 2.12: The confidence interval of the number of discharges of elective patients Source: iZIS, 2010, n = 27491

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Monday		yes	yes	yes	yes	yes	yes
Tuesday			yes	no	yes	yes	yes
Wednesday				yes	no	yes	yes
Thursday					yes	yes	yes
Friday						yes	yes
Saturday							yes
Sunday							

Figure 2.13: Statistically significant differences between the numbers of discharges of elective patients

There is a lot of variance for discharges for the patients in total. Especially on Wednesdays and Fridays a lot more discharges take place. It stands to reason that while on Wednesdays structurally more patients enter the system; it is also likely to be true that more patients exit the system. This is especially true when wards are full and old patients need to make room for newly arriving patients.

As is evident from Figure 2.12 and Figure 2.13 the number of discharges for elective patients are subject to a lot of variance. It is striking that more discharges occur on Fridays and fewer in weekends. The reason for this is the same as for the emergency patients.

2.4.3 Bed occupancy

The bed occupancy is also an important measure of workload. The bed occupancy as displayed in Figure 2.14 contains all elective surgery patients. Emergency patients are left out of the equation for two reasons. The first reason is that they are not a great source of variability. The second reason is that it is impossible to influence this patient stream. (However, the criteria for defining emergency patients can be debated. In some cases the term 'urgent' may be more appropriate.)

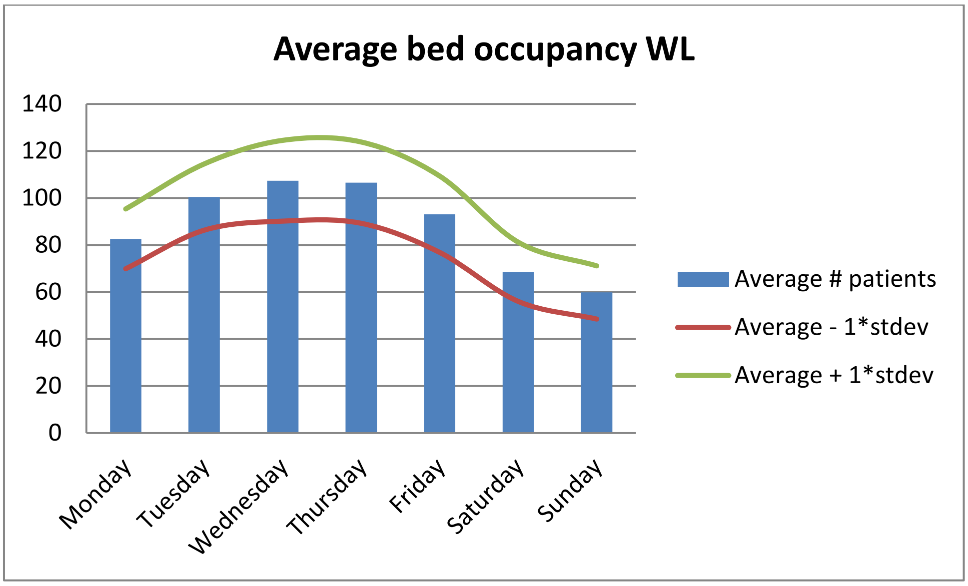

Figure 2.14: The average beds needed for elective surgery patients at the Weezenlanden Source: iZIS, 2010, n = 17318

As is evident from the figures the bed demand rises slowly through the week at the Weezenlanden location and decreases slowly when the weekend comes around. Essentially the wards start the week with low occupancy and then more and more patients are entering the system through the week. As Friday nears the hospital is emptied out to prepare for the weekend.

At the Sophia location there is a different trend. On Thursdays there is a dip in bed occupancy but the bed occupancies is relatively high. Still, a lot of patients leave the hospital on Fridays.

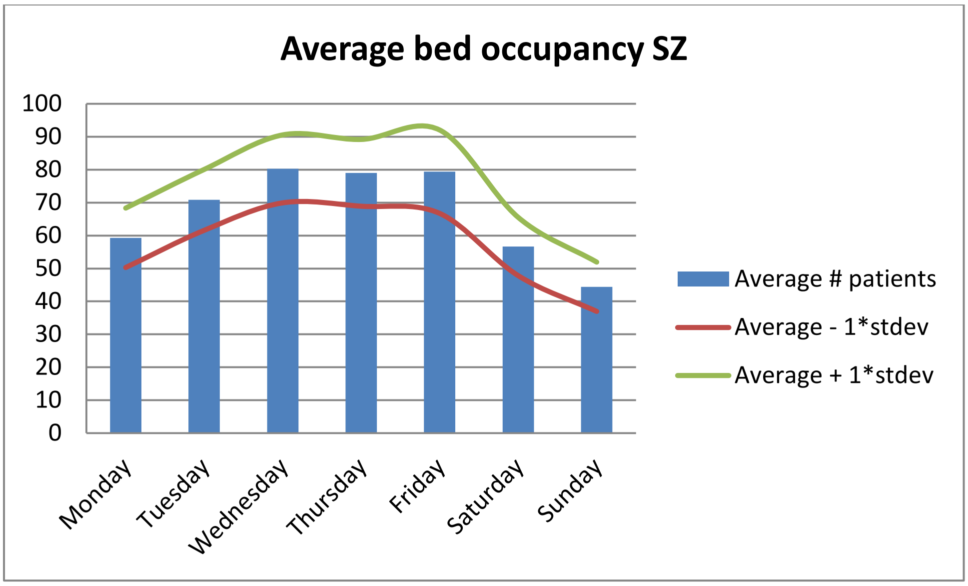

Figure 2.15: The average beds needed for surgery patients at the Sophia location Source: iZIS, 2010, n = 14904

2.4.4 Length of stay

Current planning ignores the length of stay of patients. Current planning even ignores the number of available beds at the wards. Even if wards are completely full online changes in the operating schedule might cause in influx of patients that have to be moved elsewhere. This is an example of operational, local decisions that cause problems at downward departments. We suggest that the solution to this problem lies in the tactical level. If the workload of elective patients is levelled the arrival of emergency patients can be handled / anticipated better.

The LOS of patients is dependent on several factors. It depends on which type of surgery the patient has undergone, which medication the patient receives, the patient's age, and the probabilities of having an infection and so on.

To determine the LOS per patient type iZIS is consulted. The LOSs are grouped by specialty. Some treatments have a better LOS prediction, which depends largely on standardisation and patient category.

2.4.5 Connecting OR-planning and the nursing wards

To get a clearer understanding of the system the number of operations per OR-block is inspected. If we want to use information with regard to the MSS to estimate the number of patients in the nursing wards, we need to know how many patients are operated in an OR-block. For every specialty there is a different distribution of patients. Since it is impossible to determine the real averages of numbers of patients per specialty the number is approximated by the distribution over the year 2010.

3 Desired situation

As is evident from the first chapters a large amount of the variability on the wards can be attributed to the planning of the ORs. In Section 3.1 we will consider the literature available on the subject. In Section 3.2 we will deal with the concept of master surgery schedule. In Section 3.3 we will determine which parts of the literature optimizes multiple hospital departments, focus on stochastic data and which performance measures can be used to measure performance. In Section 3.4 we will round up this chapter.

3.1 Available literature

Two recent literature reviews help us evaluate the literature available on OR-planning, more specifically OR-planning that acknowledges the actual relationship between OR-planning and ward planning. One of the literature reviews refers to over 120 articles (Cardoen, B. 2010). This literature review finds that 27 articles explicitly recognize the relationship between the OR planning and the ward planning. Of these 27 articles only seven strive to level workload at downward departments. Of these seven there are two that incorporate uncertainty in the sense that they define patient arrivals and the duration of operations to be stochastic variables.

A second literature review conducted by Vanberkel, P.T. et al. (2010) reviews quantitative health care models and examines to what extent the models consider multiple departments. They argue that a focus on single departments yield suboptimal results. Vanberkel et al. (2010) conclude that at the time of their writing 88 articles consider more than one hospital department. Most of these are included in the literature review of Cardoen et al. The researcher contributes to the OR-planning literature as well by developing a model that relates patient workload at the wards to the master surgical schedule.

Since these two literature reviews a couple of new papers have appeared that acknowledge the relation between the OR and the wards. An example would be (Tanfani, E., & Testi, A. 2010). This paper involves many more variables, like collective labour agreements, available OR equipment and the number of surgeons available. Another example is (Adan et al. 2011).

3.2 Master surgery schedule

A master surgery schedule is often mentioned in surgery planning and scheduling literature as a way to optimise OR-utilisation, level resource utilisation and create a robust schedule. An MSS is positioned on the framework of Hans et al. (2011) as resource capacity planning on a tactical level. There are several definitions of what to schedule in an MSS. Van Oostrum et al (2009) define an MSS as a cyclical schedule of recurrent surgery types, while Beliën and Demeulemeester (2007) define an MSS as a cyclical schedule of blocks of OR-time that are assigned to surgeons or specialisms. For the remainder of this report, we use the MSS definition of Van Oostrum et al. (2009). The cyclic execution of an MSS structures the workload of the OR department and the wards because they can better anticipate on demand. Van Houdenhoven et al. (2008) show that the effectiveness of the MSS approach depends on the case-mix of surgery types. Fewer surgery types can be scheduled within an MSS when a high percentage of surgery types occur infrequently. The percentage of surgeries that can be scheduled within an MSS also depends on how well the surgeries are clustered. In another of paper, Van Oostrum et al. (2008) propose an approach to cluster surgeries.

A disadvantage of the MSS approach is that it has little flexibility because it assumes the same resource capacity for each period. The MSS can be updated to account for these changes in resource capacity, but frequent changes contradict with the cyclical nature of an MSS.

3.3 Integrating bed-levelling into surgery scheduling

Many recent papers have focused on optimizing health care departments. Most have only focused on one department and have ignored other departments. This approach generally leads to suboptimal hospital solutions. Other authors stress the importance of considering more than one department, striving for an integral, holistic approach to deal with health care planning (Vanberkel, P.T. etal., 2010).

To accurately evaluate planning strategies for health care processes it is vital that the inherent uncertainty of health care processes is accounted for. Many models have ignored uncertainty and have opted for a deterministic approach, e.g. (Adan, I. & Vissers, J., 2002). Others have a big scope but do not account for the fact that the LOS of patients is specialty-specific, such as (Akcali, E. et al., 2006). Still others do consider the LOS to be dependent on (sub) specialty, but limit their efforts to only one specialty (Adan, I., 2007).

One approach that connects the OR to the nursing wards is developed by Beliën, J. & Demeulemeester, E. (2007). The authors propose a two-stage model that connects the operating theatre to the nursing wards. They say that the artificial variability that is introduced by the surgery schedules should be avoided if possible. The model uses stochastic arrival rates and procedure durations. Another approach developed by (Beliën, J. et al. 2009) presents a decision support system for cyclic master surgery scheduling and levels bed occupancy at the wards.

Van Oostrum et al., (2008) optimizes room utilization at the OR centre and levels the workload at the downstream departments, such as the IC and the nursing wards. The model generates cyclic MSSs within acceptable time bounds. Their two stage model assumes stochastic durations for surgery procedures but deterministic durations for the LOSs. Also, they only model elective procedures that occur frequently. This subsection of elective procedures accounts for around eighty percent of the patients.

Vanberkel et al. developed a method to project the ward occupancy distributions that follow from the MSS, hence providing us with a method to evaluate minor alterations in the MSS (Vanberkel, P.T. et al., 2011).

3.3.1 Performance measures

In the literature review of Cardoen, Demeulemeester and Beliën, they distinguish between eight main performance measures. These performance measures include patient waiting times, throughput, utilization, leveling, makespan, patient deferrals, financial measures and preferences (Cardoen B., 2010).

3.4 Conclusion

Literature offers many single department models which provide suboptimal solutions, while only a few papers focus on multi-department optimization. Furthermore, to reduce complexity deterministic or partially stochastic data is used. The literature offers many simulation studies and little analytical models, but most papers use mathematical programming in combination with simulation study.

Vanberkel et al. (2009) propose a model that can be used to quickly evaluate proposed MSS solutions and is appropriate for both tactical (MSS) and operational level. In contrast to other models, it uses stochastic and actual data instead of deterministic data.

4 Testing interventions: model

4.1 The model: Surgery scheduling and nursing wards

To evaluate the performance of alternative MSSs a model for the tactical level is required. It is clear that the goal of this exercise is not necessarily to try and find an absolute optimal solution. Nevertheless, to evaluate different configurations there is a need for a model that is able to adequately analyse scenarios.

The most important performance measure is the leveling of workload. Workload consists of three factors: bed occupancy, number of admissions and number of discharges. Also, the scope of the model should reach beyond a single department, because it should incorporate the OR-planning and its result on the nursing wards. Furthermore, the model deals with stochastic data rather than deterministic data, in order to predict workload accurately. Vanberkel's model serves all these purposes and is the model of choice. In this chapter the model is fleshed out and altered to fit our purpose.

4.2 Model description

Vanberkel's model complete and detailed description can be found in (Vanberkel, P.T. et al., 2009). In this chapter the model is summarized. The model consists of three steps:

1. Distribution of recovering patients from specialty j following from a single OR block
2. Aggregate distribution of recovering patients following from a single MSS cycle
3. Steady-state distribution of recovering patients

The result of the three steps is a calculation of the number of beds needed on each day within an MSS. The steps are discussed in detail in this paragraph.

4.2.1 Step I: Distribution of recovering patients from specialty j following from a single OR block

In the first step the individual specialties will be considered and the MSS is ignored for now. During an OR-block a certain number of patients receive surgery. The amount of patients that undergo surgery in one OR-block differs and can be described by a probability distribution c^j. After surgery each patient still on the ward on day n has the probability d_n^j of being discharged that day. In the following we compute the probability $h_n^j(x)$ that n days after carrying out a block of specialty j, x patients of the block are still in the hospital. Note that $n \in \{0,1,\ldots,L^j\}$ and $x \in \{0,1,\ldots,C^j\}$ and that, for example $h_3^j(5) = 0.25$ means that for specialty j, 3 days after surgery there is a 25 percent chance that 5 patients are still recovering in the hospital.

Day n = 0 is defined as the day of surgery and it is assumed that patients occupy a bed all day on the day of surgery even though they may physically be in the OR. This is consistent with practice where patients have a bed reserved for them before surgery. As such the number of patients in the hospital from specialty j on day n = 0 is by definition the number of surgeries performed that day by specialty j. It follows that the distribution for the number of recovering patients on day n = 0 is $h_0^j = c^j$.

Note that on day n, each patient still in the hospital has a probability d_n^j of being discharged that day and $(1 - d_n^j)$ of staying. If there are k patients in the hospital on day n, then the probability of s patients in the hospital (where $s \leq k$) on day n + 1 is computed using the binomial distribution, (d_n^j) k–s $(1 - d_n^j)$ s. Since we know the probability distribution for the number of patients at the end of day n = 0 we can iteratively use this formula to compute the probability of k patients at the end of all days n > 0.

Summarizing, the distribution for the number of recovering patients on day n is recursively computed by:

$$\mathbb{P}(h_n^j = x) = \begin{cases} \mathbb{P}(c^j = x) & when\ n = 0 \\ \sum_{k=x}^{C^j} \binom{k}{x} (d_{n-1}^j)^{k-x} (1 - d_{n-1}^j)^x \mathbb{P}(h_{n-1}^j = k) & otherwise \end{cases}$$

So the inputs in this step are $c^j(x)$, which is the probability distribution of specialty j completing x surgeries in one OR-block and d_n^j which is the probability that a patient who is still present on day n will be discharged on that specific day, which is calculated from the length of stay per specialty using the following formula:

$$d_n^j = \frac{P^j(n)}{\sum_{n=k}^{L_j} P_j(k)}$$

The output of the first step of the algorithm is then $h_n^j(x)$ which is the probability distribution of x patients of a single OR-block of specialty j still present in the ward n days after surgery.

4.2.2 Step 2: Aggregate distribution of recovering patients following from a single MSS cycle

In this step we consider the previously computed probability distribution h_n^j and a given MSS as input. Although the MSS is cyclical and repeats after Q days, in this subsection we consider only a single MSS cycle in isolation. The MSS defines when each specialty is assigned an OR block and thus the days on which patients of specialty j arrive to the ward. Based on these, we compute the total number of patients in the hospital by means of discrete convolutions.

To calculate the overall distribution of recovering patients, we first identify for each block $b_{i,q}$ (where I ranges from 1 through I and q ranges from 1 through Q) the impact that this block has on the number of recovering patients in the hospital on days (q, q+1, …). If z denotes the specialty assigned to block $b_{i,q}$ which follows from the MSS, then the distribution $h_{i,q}^m$ for the number of recovering patients of block $b_{i,q}$ on day m ($m \in \{1,2,\dots,Q,Q+1,Q+2,\dots\}$) is given by:

$$\overline{h}_m^{i,q} = \begin{cases} h_{m-q}^z if\ q \leq m < L^z + q, \\ \mathbf{0} \quad otherwise \end{cases}$$

where $\mathbf{0}$ means $P(\overline{h}_m^{i,q} > 0) = 0$. Note that specialties index j is no longer needed as specialties are accounted for by their designated OR block(s).

Let H_M be a discrete distribution for the total number of recovering patients on day m resulting from a single MSS cycle. Since recovering patients do not interfere with each other we can simply iteratively add the distributions of all the blocks impacting day m to get H_M. Adding two independent discrete distributions is done by discrete convolutions which we indicate by *. Let A and B be two independent discrete distributions. Then C = A*B, is computed by:

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

Where τ is equal to the largest x value with a positive probability that can result from A*B. using this notations, H_M is computed by:

$$H_m(x) = \overline{h}_m^{1,1} * \overline{h}_m^{1,2} * \ldots * \overline{h}_m^{1,Q} * \overline{h}_m^{2,1} * \ldots * \overline{h}_m^{I,Q}$$

So in the second step two types of input are required, namely $h_n^j(x)$ which is the result from the first step and the current MSS which defines which specialty j operate in OR i on day q. The output of this step are $\overline{h}_m^{i,q}(x)$ which is the probability distribution of x patients from block $b_{i,q}$ being in the hospital on day m as a result of the MSS and $H_m(x)$ which is the probability function of x patients being in the hospital on day m as a result of a single MSS.

4.2.3 Step 3: Steady state distribution of recovering patients

In step 3 we consider a series of MSSs to compute the steady-state probability distribution of recovering patients. The cyclic structure of the MSS implies that patients receiving surgery during one cycle may overlap with patients from the next cycle. In the case of a small Q for example, patients from many different cycles can overlap.

In step 2 we have computed H_M for a single cycle of the MSS in isolation. Let M be the last day where there is still a positive probability that recovering patients is present as computed by H_M. Thus $M = max_j\{L^j + x^j\}$ (where x_j is the latest day q of a block assigned to specialty j) indicated the range of the MSS. To calculate the overall distribution of recovering patients when the MSS is repeatedly executed we must take into account $\lceil M/Q \rceil$consecutive cycle of the MSS (see Figure 4.1). Let H_q^{SS} denote the probability distribution of recovering patients on day q of the MSS cycle, resulting from$\lceil M/Q \rceil$consecutive MSS cycles. Since the MSS does not change from cycle to cycle, H_q^{SS} is the same for all MSS cycles. Using discrete convolutions HQSS is computed by:

$$H_q^{SS}(x) = H_q * H_{q+Q} * H_{q+2Q} * \ldots * H_{q+\lceil M/Q \rceil Q}$$

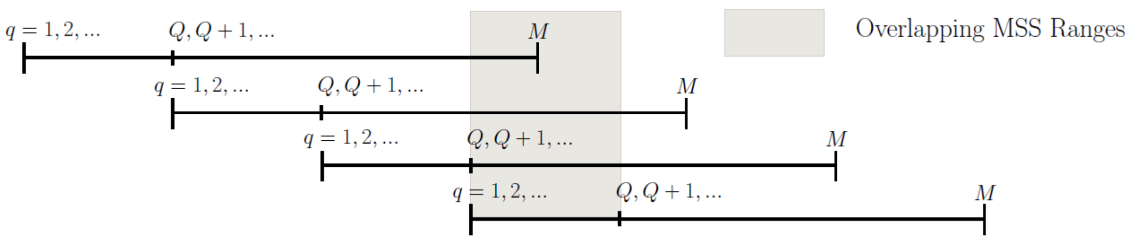

Figure 4.1: Demonstration of overlapping MSS ranges

So for the third step we use $H_m(x)$ from step II and the recurring MSSs as input and step III produces $H_q^{SS}(x)$ which is the steady state probability distribution of the recovering patients on day q as output.

4.3 Input of the model

The model uses four inputs:

- The c_j-distribution: this distribution defines the number of patients that a particular specialty is expected to operate in one OR-block.
- The d_j-distribution: this distribution defines how likely it is that a patient that is present currently is leaving on particular days.

- The current MSS: the current MSS can be evaluated and other MSS can be explored.
- W_z^j, which is the discrete distribution of the number of patients from specialty j going to ward z.

Each of them is described in detail in this paragraph, as well as how they were estimated.

4.3.1 Cj-distributions

The Cj-distributions are the distributions that denote the likelihood of occurrence of a certain number of patients being operating in a single OR-block. The distributions are specialty specific so they are different for each specialty (note that patients can be grouped according to other criteria if desired). To accurately define the distributions of the number of patients being operated in an OR-block a data-analysis has been carried out.

Table 4.1 shows the calculations of the discrete distribution of the number of surgeries of urology taking place in an OR-block. The data displayed in this table are the number of times either zero, one, two, three, four, five or six surgeries have been executed in an OR-block by the specialty urology. From the number of occurrence the fraction of the time either of these alternatives occurs follows. The strategy to obtain these values is as follows:

- The surgeries that need to be described are listed
- All the times this specialty has operated are sorted per week and then day
- For each of these the data from iZIS is compared to the MSS to find operations that took place in assigned OR-blocks (because on days when the specialty shouldn't have operated but still did, the number of operations does not reflect the amount of patients usually operated in an OR-block)
- The resulting list provides information about the number of operations that took place on each day. Therefore it is determined how many OR-blocks of that specialty are scheduled that day. Now we can calculate how many operations take place in a scheduled OR-block, by dividing the number of operations of that specialty by the number of OR-blocks assigned to that specialty on that day.
- It is determined how often a certain amount of operations in an OR-block occurs.
- Non-integers such as 0.5 are also counted, but divided equally over 0 and 1 and correspondingly for other non-integer values (non-integer values are a result from a number of patients divided by an odd number of OR-blocks assigned on some days).
- The numbers are rounded to two decimal points because accuracy is difficult to obtain.

Table 4.1: Cj-distributions for urology
Source: iZIS, 2010, n = 1457

	Urology: the calculation of the likelihood of operating x number of patients in the morning							Sum
Nr. Patients	0	1	2	3	4	5	6	
Occurrence	29	94	87	82	53	6	0	351
Fraction	0,08	0,27	0,25	0,23	0,15	0,02	0	1

Similar calculations are executed for all the specialties. The result is a table of c_j-distributions of all specialties which is inserted in the input sheet and calculation of the performance of the master surgery schedule.

4.3.2 D_j-distributions

The d_j-distributions describe the likelihood of discharge for a patient that is currently in the hospital on particular days. The d_j-distribution for each of the specialties is computed. If the MSS were more detailed it makes sense to ascribe more detailed to d_j-distributions to specialties, because then it is possible to define d_j-distributions for sub-specialties.

In the example of the distribution of LOS is given in Figure 4.2., almost 80 percent of patients have a LOS of 1 day and less than ten percent stays more than 2 days. The d_j-distributions help us determine that IF a patient is still in the hospital, then how big is the chance that she will go home today. A d_j-distribution is calculated from the lengths of stay of patients from a certain specialty.

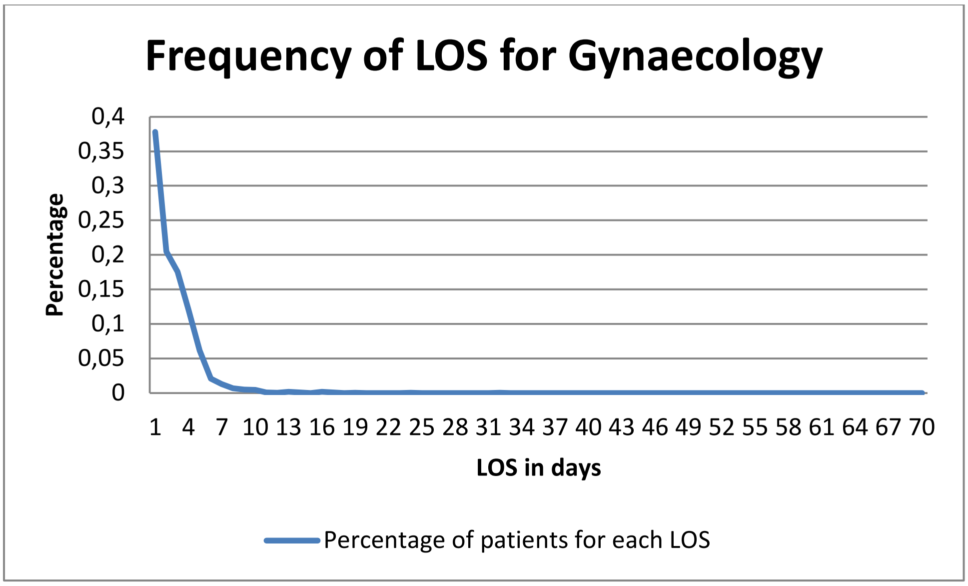

Figure 4.2: The frequency of the length of stay for Gynaecology surgery patients
Source: iZIS, 2010, n = 1910

To find the LOS of a specialty we have selected all surgery patients of the relevant surgeries while ignoring the emergency patients, and counted the number of occurrences of each number of days to discharge. Again the fractions of the total have been computed.

4.3.3 MSS

For MSSs are shown in Section 2.1.1 and 2.1.2. Note that in reality some OR-blocks are labelled empty while others are labelled flexible. Flexible slots can be used for whichever specialty needs operating time and empty OR-blocks are not being used at all. Both do not have any input values, and thus will be considered empty. In that sense the model does not distinguish between empty OR-blocks and flexible ones.

In this research the day care ORs are not considered, because:

- Both the day care operating rooms and the day care wards are organized well.
- The day care wards fail to conform to the assumptions of the model, e.g. in the day care wards a bed can handle multiple patients throughout the day. The planning of day care patients is detailed enough to ensure that a patient can leave the hospital and therefore stop occupying a bed. This bed can be used for patients scheduled later today.

4.4 Model extensions

4.4.1 Morning and afternoon shifts

Vanberkel's model does not explicitly allow for two specialties to operate in the same OR on the same day. At the Isala it is common to share an OR: one specialty operates in the morning, the other in the afternoon. To model this, the current MSS is split up into two parts, one with the morning schedules, the other one with the afternoon schedules. The names of these are MSSam and MSSpm respectively. These schedules are two MSS-matrices, which are convoluted to arrive at a complete MSS.

$$MSS_{TOTAL} = MSS_{AM} * MSS_{PM}$$

4.4.2 Admissions and discharges

The model can be used to calculate the number of admissions and discharges as well. To calculate the distribution of admissions we need to look at the OR-blocks on each day q. The number of admissions is exactly the same as the distribution of the amount of patients operated on an OR-day. To calculate the distribution of admissions we convolute the c_j-distributions of patients on each day.

To calculate the distribution of the discharges we use the distribution for the amount of patients in the hospital on day n, which is distributed according to h_n^j. On day n each patient has a probability of d_n^j of leaving the hospital and a probability of $(1 - d_n^j)$ of staying. From these two distributions the distributions of discharges follows:

$$\mathbb{P}(D_n^j = x) = \sum_{k=x}^{C^j} \binom{k}{x} (d_n^j)^x (1 - d_n^j)^{k-x} \mathbb{P}(h_n^j = k)$$

4.4.3 Analysis versus improvement

The model proposed in this chapter was initially used to evaluate changes proposed by stakeholders. In this research all possible one-step changes to the MSS are evaluated. This way the best possible swaps can be produced.

4.4.4 Ward-specific distributions

A common measure of inpatient workload is ward occupancy. The distribution of the number of inpatients on a ward follows from the basic model where the distributions of all recovering patients are computed. Suppose that patients are segregated into different wards depending on the type of surgery they have received. In that case the segregation can be modelled by selecting only the specialties that go to the ward of interest.

At the Isala Clinics patients from a specialty j go to a ward z with a probability a_z^j. That means that if a specialty is selected we cannot predict the workload at downward departments directly, because patients from one specialty may go to different wards. An additional step has to be introduced to accurately describe the distribution of the number of patients per ward.

The probability of x patients directed to a ward z (where x ≤ k) on the day of the operation is computed using the binomial distribution, (a_z^j) k–s $(1 - a_z^j)$ s.

The number of patients operated in an OR-block is distributed according to c_j. At the Isala Clinics patients from a specialty j go to a ward k with a probability a_z^j.

Let W_z^j be a discrete distribution of the number of patients from specialty j going to ward z. Given a_z^j and c_j, W_z^j can be computed with a binomial distribution as follows:

$$\mathbb{P}(W_z^j = x) = \sum_{k=x}^{C^j} \binom{k}{x} (a_z^j)^x (1 - a_z^j)^{k-x} \mathbb{P}(c_j = x)$$

4.5 Model assumptions

The model has some assumptions:

- There is always a bed available for a patient after surgery. This is true in reality because patients are guided to their beds before they go to surgery, and the bed is reserved for that specific patient.
- When a patient occupies a bed on a certain day, the patient occupies it for the whole day. On the day a patient leaves a new patient is able to move into the bed. This reflects reality except for the day care wards where multiple patients can be assigned to the same bed at different times of the day.
- Seasonality is ignored. Isala does make use of reduced MSS in the summer and in weeks where national holidays take place. However, because a reduced MSS always implies fewer patients operated, it should not be a problem if we take capacity itself into consideration. If there are fewer patients operated there are fewer beds occupied. Should knowledge about the occupancy be available, fewer personnel can be rostered accordingly.
- The models accounts only for some of the emergency patients. At the Sophia location one of the Operating Rooms is dedicated to emergency patients. This particular OR is included as well. The other emergency patients are ignored. Note that emergency patients are not the group that seem to cause variability on the wards.
- A maximum length of stay of 72 days is assumed. Every surgery patients leaves the hospital before this number in 2010.
- The MSS is always exactly the same. In reality several changes can occur. The fact that during some periods a reduced schedule is operational is already mentioned. But even during regular weeks the MSS is subject to changes.

4.6 Expectations

The model uses three inputs, the distribution of the number of patients per OR-block, the master surgery schedule, and the distribution of the LOS of patients. Later on a fourth input is added, the distributions of patients to specific wards. The output is the number of beds required to deal with the bed demand for surgery patients in the hospital on different days. It is expected that by altering each of the inputs, the outputs can be improved. It is necessary to decide how to evaluate the output of the model, which we address in the next chapter. Certain feasible changes in the input are expected to have positive effects on the output. The current solution and alternative solutions are compared in chapter 5.

If follows that there are a number of feasible interventions.

- *Have specialties operate on other OR-days than dictated by the current MSS.*
- *Set a limit to the amount of patients that may be operated in one OR-block.*

The amount of patients that can be operated in an OR block can be altered by prohibiting specialties to operate more than a certain number of patients in one block. This would result in a situation where it is impossible for a specialty to spread patients unevenly over the week, e.g. operate 3 patients on

Wednesday afternoon and 7 on Friday morning. If a maximum to the number of patients in one block should be implemented the patients will be spread more evenly.

The third input depends on the length of stay of patients. While there is no doubt that altering this distribution will have a huge impact on the number of beds needed, in practice this is the one that is the hardest to influence. Of course patient trajectories could and should be investigated and optimized as well, but this is beyond the scope of this research.

5 Results of experimentation

In this chapter the effectiveness of the interventions is discussed. To aid the calculations, the model is programmed in the numerical computing environment MATLAB (version R2010a). The model reads the input from input-sheets produced in Microsoft Excel. The calculations where performed on a laptop with a Intel(R) Core™ i3 CPU 2,27 GHz processor with 4,0 GB RAM.

5.1 Workload leveling

As a performance measure we define workload. The workload assists in the evaluation of MSSs. The workload on each day is a combination of the variability of the number of beds needed on the different days in a MSS cycle, the variability of the number of admissions, and the number of discharges of patients.

The model described in Chapter four can be used to measure all three of these performances. To measure variability of the workload we need a way to quantify the variability of the workload of potential solutions.

5.1.1 Bed demand

There are a number of ways to calculate the leveling of workload related to bed demand. To arrive at a proper way of evaluating workload we have to decide whether we want to level the workload on weekdays and on weekend days separately. It would even be possible to strive for equal workload on all days, thus trying to increase the amount of patients in the weekend, even though there still will not be operated in the weekend (safe emergency patients). If weekend workload is not individually optimized but in conjunction with the rest of the days in an MSS cycle this would greatly reduce the amount of beds needed.

To effectively analyse workload variability we need to be able to quantify it. The way we go about this is by using standard measures from statistics. We measure the quadratic difference from the mean for the weekdays (day 1 through 5 and day 8 through 12) as demonstrated in the first half of the formula and the quadratic difference of the mean for the weekend days (day 6 and 7 and 13 and 14) as demonstrated in the second half of the formula Performance A:

$$Performance\ A = \frac{5}{7}\left\{\sum_{i=1}^{5}(x_i-\bar{x})^2+\sum_{i=8}^{12}(x_i-\bar{x})^2\right\}+\frac{2}{7}\left\{\sum_{i=6}^{7}(y_i-\bar{y})^2+\sum_{i=13}^{14}(y_i-\bar{y})^2\right\}$$

For the first half of the formula: i is the rank number of the day in the cycle, x_i is the number of beds needed on day i and $\bar{x}$ is the average number of beds needed on days i = 1 through 5 and 8 through 12.

For the second part of the formula: i once again is the rank number of the day in the cycle, and y_i is the number of beds needed on day i and $\bar{y}$ is the average number of beds needed on days i = 6,7,13 and 14 (the Saturdays and Sundays).

The total workload in this scenario is: ((10 * WorkloadWeekDays) + (4*WorkloadWeekendDays))/14. The reason for this is that reduction during the week is more important than reducing variability in the weekend at this point. Note that the lower this value, the better a solution performs.

Performance A does not maximize the average number of patients during the week, or maximize the average number of patients present in the system or anything of that nature. The performance measure is indifferent to the ratio between the average numbers of patients on weekdays versus weekend days.

While minimizing the amount of patients in the weekends has its merits, it is much more expensive to take care of patients in the weekends for example. But because ward capacity is limited in the future there are also advantages to have more patients present in the weekends while lowering the average amount of patients on weekdays.

5.1.2 Admissions

The number of admissions on a given day would be levelled in an optimal scenario. Note that admissions of elective do not occur in the weekend. For this reason the quadratic differences from the mean of the admissions on all weekdays is taken as the measure. Note that a lower value represents a solution that outperforms a solution that has a higher value.

$$Performance\ B = \left\{ \sum_{i=1}^{5} (a_i - \bar{a})^2 + \sum_{i=8}^{12} (a_i - \bar{a})^2 \right\}$$

5.1.3 Discharges

Discharges are allowed during the week as well as the weekend. Discharges do contribute to workload as well, so they need to be leveled as well. Again, a lower value represents a solution that outperforms a solution that has a higher value. The leveling of discharges is calculated as follows:

$$Performance\ C = \sum_{i=1}^{14} \left(d_i - \bar{d}\right)^2$$

5.1.4 Aggregate Performance Measure

To account for these three measures the different values for the separate measures are added up.

Aggregate Performance Measure = Performance A + Performance B + Performance C

5.2 Increased performance

As pointed out in the previous chapter there are two feasible ways to increase performance on short notice. One of these is changing the MSS the other one is allowing only a maximum number of operations in an operation block. These two methods are investigated separately.

5.2.1 Altering the MSS

Because in the act of constructing an MSS downward departments have been largely ignored, the altering of the MSS to improve workload variability holds a lot of promise. The way we go about this is by applying a heuristic that goes through possible swaps in search for a solution where performance is better. By evaluating every possible one-step-swap we find possible improvements.

5.2.2 Setting a limit to the maximum amount of operations

Another way of manipulating the stream of patients through the ORs is to set a limit to the amount of patients that are permitted to be operated in a single OR-block. If a limit is to be set to the amount of patients being operated two things must be kept in mind.

- The probabilities of all the possible occurrences must sum up to one
- The total amount of patients being operated is still the same.

Take the following hypothetical illustration as an example. In this scenario the number of patients being operated is a number between 0 and 4. The occurrences are in the following Table 5.1: there is a ten percent chance that zero patients are operated in a block, a twenty percent chance that one patient is operated, a thirty percent chance that 2 patients are operated and so on. However, if one sets the maximum amount of operations to 3, one cannot simply add the fraction of 0, 1 to x -1 operations. The fractions would still add up to one, but the number of patients being operated in that particular block deteriorates to only 2 on average.

For this reason the following set of equations needs to be solved:

$$\sum_{i=1}^{N} \alpha_i x_i = Total\ Number\ of\ Patients$$

$$\sum_{i=1}^{N} \propto_i = 1$$

In these equations α_i represents the fraction of the time the event occurs and x_i is a vector ranging from zero to N, where N is the maximum number of possible operations in one operation block.

Table 5.1: Demonstration of how to alter fractions of occurrences of the number of patients operated in an OR-block

Nr. of patients	0	1	2	3	4	Sum of fractions	Nr. Of patients being operated
Fraction of the time	0,1	0,2	0,3	0,3	0,1	1,0	2,1
Wrong fractioning	0,1	0,2	0,3	0,4	X	1,0	**2**
New fractioning	0,1	0,14	0,32	0,44	X	1,0	2,1

5.3 Current performance and improvement techniques

5.3.1 Improvement heuristic: Steepest Descent

From a purist point of view the Steepest Descent method would suggest swapping OR-blocks instead of OR-days. Swapping OR-days is more logical and convenient for different reasons.

- Sometimes specialists need a total OR-day to do specific operations. Cutting OR-days in two OR-blocks makes it impossible to do surgeries that take longer than one OR-block
- Surgeons, anaesthesiologists, other personnel and material needs to be available on a specific OR-day only, and not during two OR-blocks on different days
- The efficiency of the OR-department is better when OR-days are kept intact (Vlijm, 2011b)
- It has been tested in this research that swapping OR-days instead of OR-blocks yields higher gains after a limited amount of swaps (although the solutions might converge faster or have a worse optimal solution).
- Dividing an OR-day over two specialties happens only sporadically, so the solution space does not suffer greatly from constraining to OR-days instead of OR-blocks.

For the Weezenlanden location of the Isala Klinieken the base MSS is assumed to be as depicted in Figure 5.1 and 5.2. The MSS is not exactly the same throughout the year, but this is not a problem: a start solution is analysed in order to find an improved schedule.

This time the indices of the rows and columns are also displayed, to make interpretation of results easier, e.c. swapping (1,1) with (5,1) means swapping the specialty operating on the first Monday in Operating Room 1 (Orthopaedics) with the one operating on the first Friday in operating room 2 (none). Note that it does not matter whether we actually swap any other Monday OR-block as long as it is an Orthopaedics block from the first Monday of the cycle. So swapping (1,1) is the same as swapping either (1,3 or (1,9). The same is true for the second of the swap-pairs: We need to swap with any empty OR-day on the first Friday of the cycle.

WEEZENLANDEN	1	2	3	4	5	6	7	8	9	10
	OR 1		OR 2		OR 4		OR 5		OR 6	
	M	A	M	A	M	A	M	A	M	A
1	2	2	2	2	8	8	14	14	2	2
2	2	2	2	2	8	8	14	14	2	2
3	2	2	2	2	8	8	14	14	8	8
4	2	2	2	2	8	8	14	14	22	22
5	2	2	42	42	8	8	14	14	42	42
6										
7							M	A		
8	2	2	2	2	8	8	14	14	2	2
9	2	2	2	2	8	8	14	14	2	2
10	2	2	2	2	8	8	14	14	2	2
11	2	2	2	2	8	8	14	14	8	42
12	42	42	42	42	8	42	14	14	42	42
13										
14										

Figure 5.1: The current MSS of the Weezenlanden location (a)

WEEZENLANDEN	11	12	13	14	15	16	17	18	19	20
	OR 7		OR 8		OR 9		OR 10		OR 11	
	M	A	M	A	M	A	M	A	M	A
Monday	22	22	15	20	20	20	20	20	20	20
Tuesday	4	4	20	20	20	20	20	20	20	20
Wednesday	4	4	20	20	20	20	20	20	20	20
Thursday	4	4	20	20	20	20	20	20	20	20
Friday	4	4	42	42	20	20	20	20	20	20
Saturday										
Sunday										
Monday	4	42	15	20	20	20	20	20	20	20
Tuesday	4	4	20	20	20	20	20	20	20	20
Wednesday	8	8	20	20	20	20	20	20	20	20
Thursday	4	4	20	20	20	20	20	20	20	20
Friday	4	4	42	42	20	20	20	20	20	20
Saturday										
Sunday										

Figure 5.2: The current MSS of the Weezenlanden location (b)

The algorithm as implemented in Matlab provides a list of the top 5 of best swaps after each iteration. Steepest Descent dictates selecting the best neighbour if it decreases the objective value and while demonstrating the heuristic we adhere to this rule. Keep in mind that a top 5 list of best possible swaps offers a wider array of options, each of which can be scrutinized and deliberately chosen in order to choose a swap that is least inconvenient for the stakeholders involved.

5.3.2 The solution space

To ensure arriving at an optimal swap it is necessary to go through all swaps and compare their performance. Complete enumeration is only possible when the solution space is reasonably small.

In this case the solution space is biggest for the larger instance, which is the Weezenlanden location. The solution space of the Weezenlanden has an upper limit of:

- 7 specialties currently operating
- 10 days to consider
- Swapping with one of each of the 9 remaining days
- 6 specialties that could be available for swapping (7 minus 1, because e.g. jaw surgery is not being swapped with jaw surgery)

The total number of swaps is seven times ten times nine times six possible swaps which equals 3780 swaps. Note that this number is an upper bound for the total amount of swaps. Because each iteration takes slightly less than three seconds and the solution space is smaller in practice (about 900 calculations), the solution the duration of one iteration amounts to approximately 30 minutes.

5.3.3 The heuristic

To get insight in the code the pseudo code of the heuristic is displayed in this paragraph. Calculate the performance of the current solution

1. Take First Day as d = 1 until 14 (if 14 is executed, go to step 9)
2. For every specialty that is in set R^d ($R^d \in R$) and set R contains all available specialties (if all specialties are used, go to step 1)
3. Take second day as day following the first day: d = Day1 +1 until 14 (if 14 is executed, go to step 2)
4. For every specialty occurring on day 2. (If every specialty is used, go to step 3.)
5. Make the swap
6. Calculate the performance
7. Compare the performance to set of best solutions so far
8. Rank the solution accordingly. (Go back to step 4.)
9. Display top 5 of best solutions.

This pseudo-code describes a single iteration of the model. This means that every change to the MSS has to be made manually and after that the model repeated. While it is also possible to let the model alter the MSS and repeat, the heuristic is not modelled thusly in order to strive for carefully considered alterations to the MSS.

5.3.4 Data validation

The bed demand according to the model versus the real data is displayed in Figures 5.4 and 5.5. The model considers a cycle of 14 days as is demonstrated. To validate the model, the model output is compared to real data of the year 2010. For the MSS cycle the model output of the first week is comparable to the second week. For this reason the averages and standard deviations of single weeks is compared to the average output on all days. In the tables the blue columns represent the day averages from 2010. The green and red lines represent the plus and minus the standard deviation of each day. The green columns represent the model output. For the calculations the 84^{th}-percentile of demand is used.

The x^{th}-percentile of demand is interpreted as the amount of time the number of warm beds available is enough to cover demand in x percent of the cases. Assuming the average number of patients follow a normal distribution, we would expect 84% of the cases to be below the average plus the standard deviation. (See Figure 5.3) About 16% will be above the average plus the standard deviation.

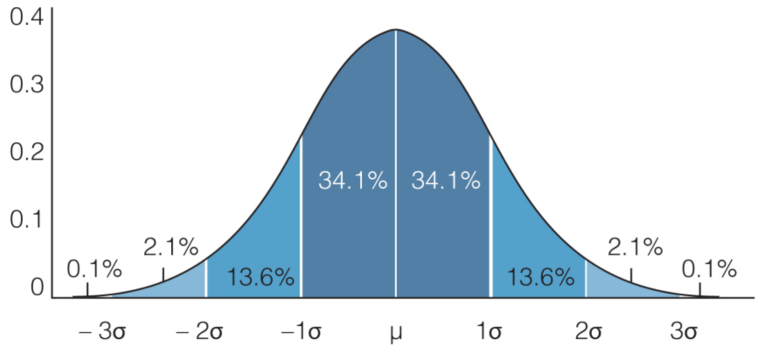

Figure 5.3: Bell curve: the mean plus the standard deviation covers about 84 percent of cases

If we calculate the model output and we determine the 84th-percentile of demand we expect the model output to be reasonably close to the real data. Figure 5.4 and 5.5 shows the comparison between the real data and the model output. It turns out that the model actually overestimates the number of beds needed. It turns out that factor with which the model overestimates the number of beds required is about ten percent, which is shown in Figure 5.6 and 5.7.

The reason for this may be that the model ignores seasonality. The real data shows the average number of beds needed throughout the whole year, so including periods where fewer patients are hospitalized due to reduced schedules.

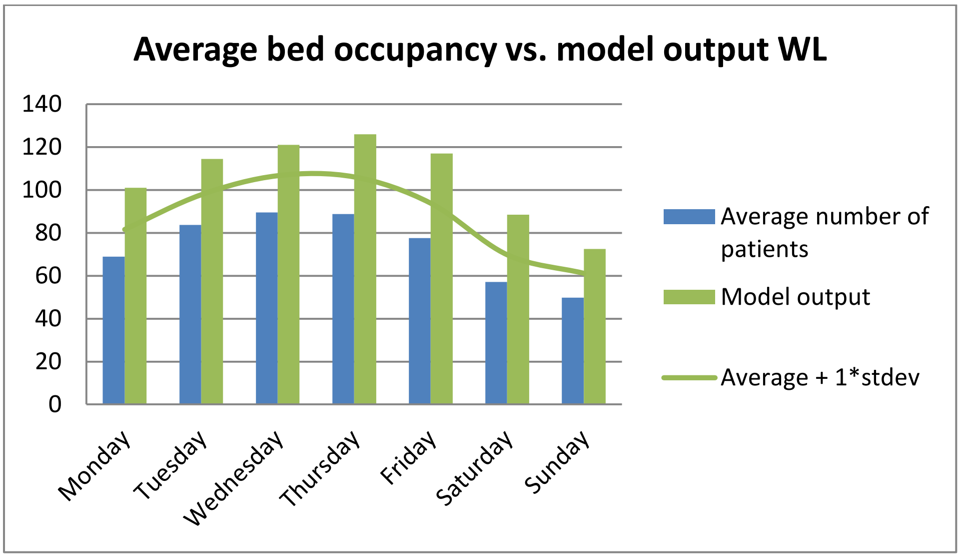

Figure 5.4: The average bed demand versus the model output for the WL case
Source: iZIS, 2010, n = 17318

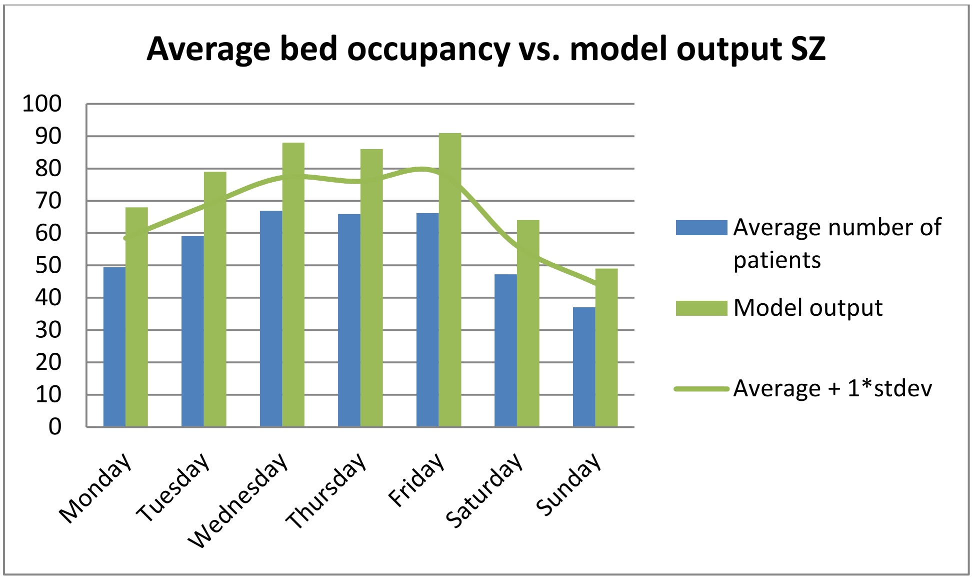

Figure 5.5: The average bed demand versus the model output for the SZ case
Source: iZIS, 2010, n = 14904

Second of all, while the columns for the real data and the simulated data show comparable patterns. It seems that the model overestimates the number of beds needed approaching the weekend. The reason for this is probably similar to the reason laid out in Section 2.4.2: patients are more likely to be discharged when the weekend approaches because personnel prefers to have lower occupancy in the weekend.

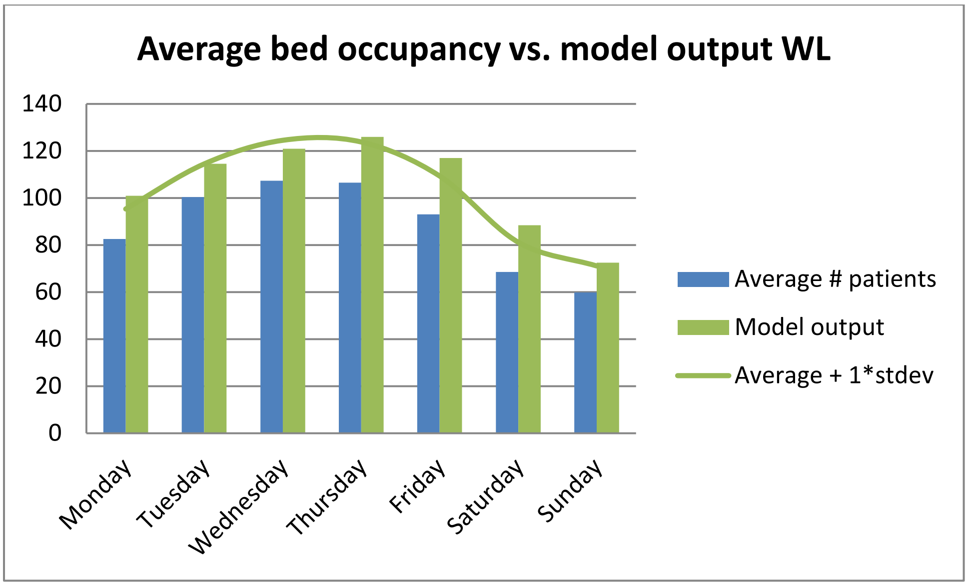

Figure 5.6: The average bed demand versus the model output (times 0.88) for the WL case

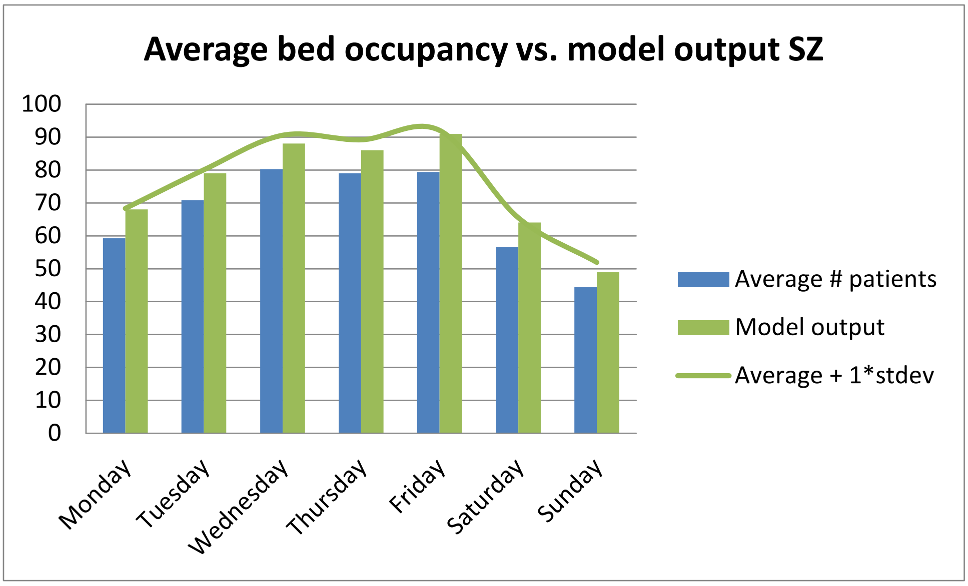

Figure 5.7: The average bed demand versus the model output (times 0.9) for the SZ case

Summarizing: the model output simulates the real data well enough. The slight overestimation of the number of beds required will not invalidate suggestions for improvement.

5.3.5 Validation of admissions and discharges

To further investigate the reliability of the model the number of admissions and the number of discharges of the year 2010 is compared to the model output. The admissions are considered first. In Figures 5.6 and 5.7 the admissions are displayed for the two cases. Again, we expect the model output to be close to the average plus the standard deviation once.

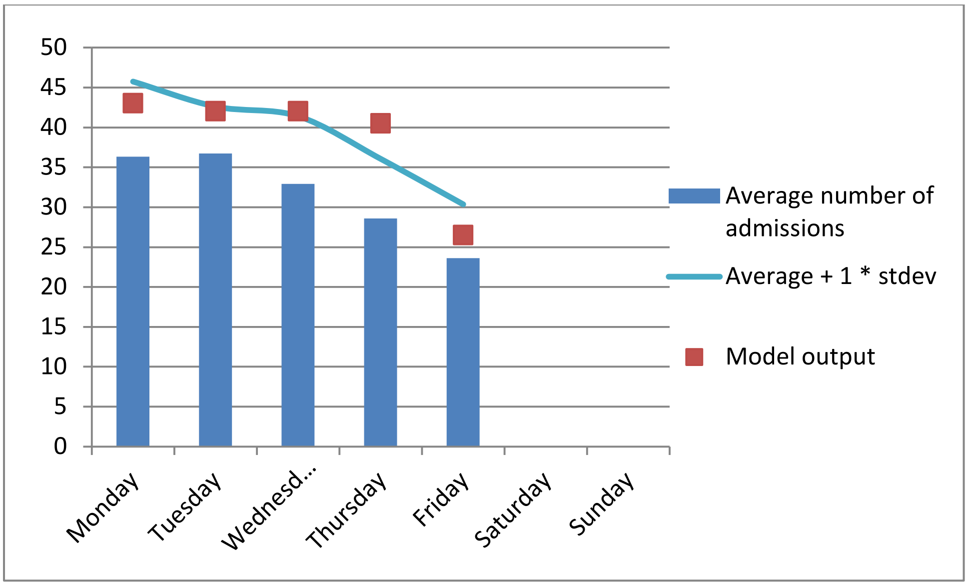

Figure 5.8: The average number of admissions for WL versus the model output
Source: iZIS, 2010, n = 8470

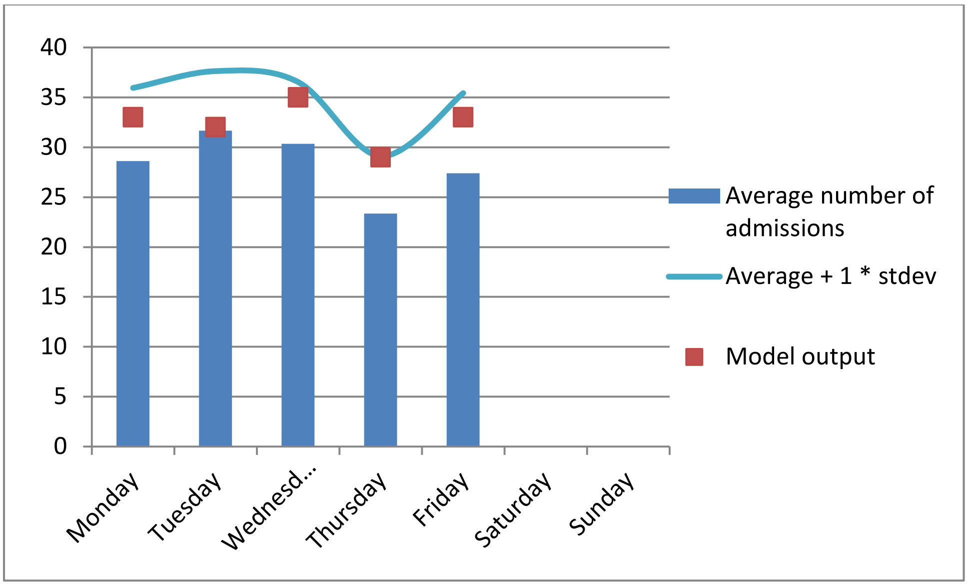

Figure 5.9: Average number of admissions for SZ versus the model output
Source: iZIS, 2010, n = 7728

The discharges as gathered from the data are compared to the model output in Figure 5.8 and 5.9.For the Weezenlanden location the number of discharges on Friday is underestimated. An explanation is raised in chapter 2 already: the number of discharges is artificially increased because patients are discharged on Fridays if possible, so that they do not require hospital care in the weekend.

For the Sophia location we see the same problem. The model underestimates the number of discharges on Fridays. Furthermore, the number of discharges is structurally lower than the average plus the standard deviation. It is possible that the average number of discharges is more robust for the Sophia location in comparison to the Weezenlanden. In general the values from the model output compare reasonably well to the real data, i.e. the same patterns can be distinguished.

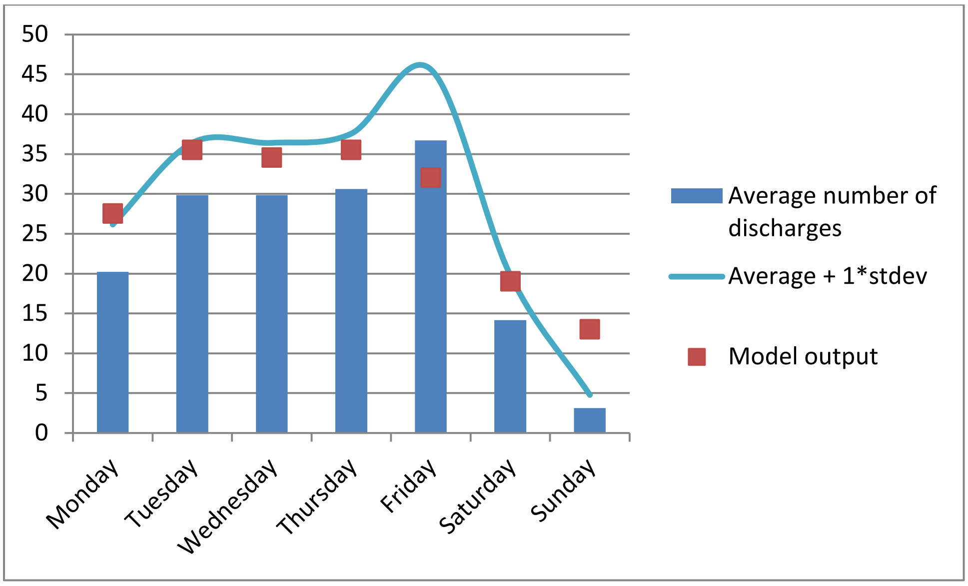

Figure 5.10: Average number of discharges for WL versus model output
Source: iZIS, 2010, n = 8470

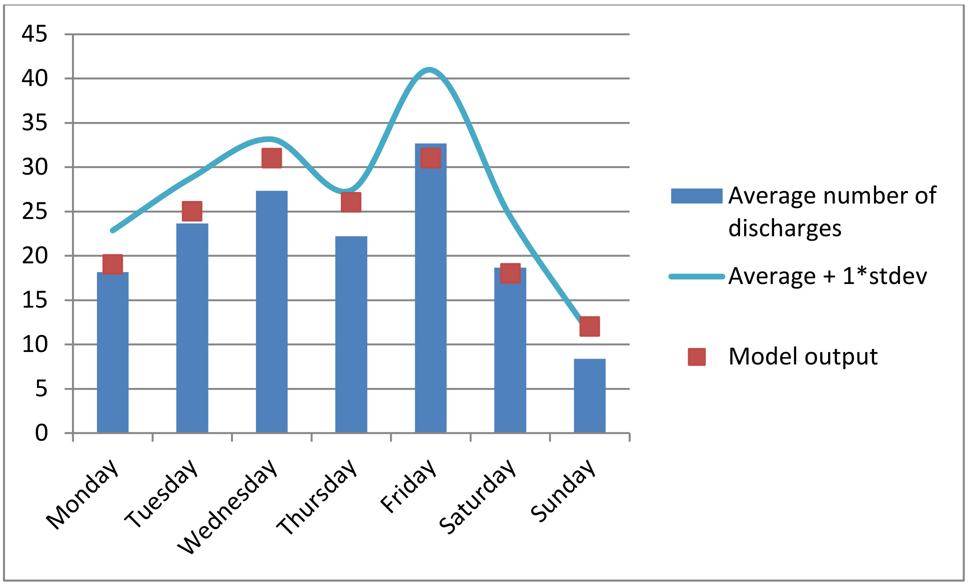

Figure 5.11: Average number of discharges for SZ versus model output
Source: iZIS, 2010, n = 7728

5.4 Altering the master surgery schedule

5.4.1 The case study I: Weezenlanden

Figure 5.12 shows the 99th percentile of staffed beds required. The 99th percentile of bed demand means that in 99 percent of the cases the number of beds is actually enough to cover complete demand. This also implies that a lot of the time beds will be empty because not every time out of the 99 percent all the beds will be occupied. For this reason it might make sense to aim for a lower percentile of demand. Note that for departments such as Intensive Care the coverage of demand should be considerably closer to 100 percent than for other departments.

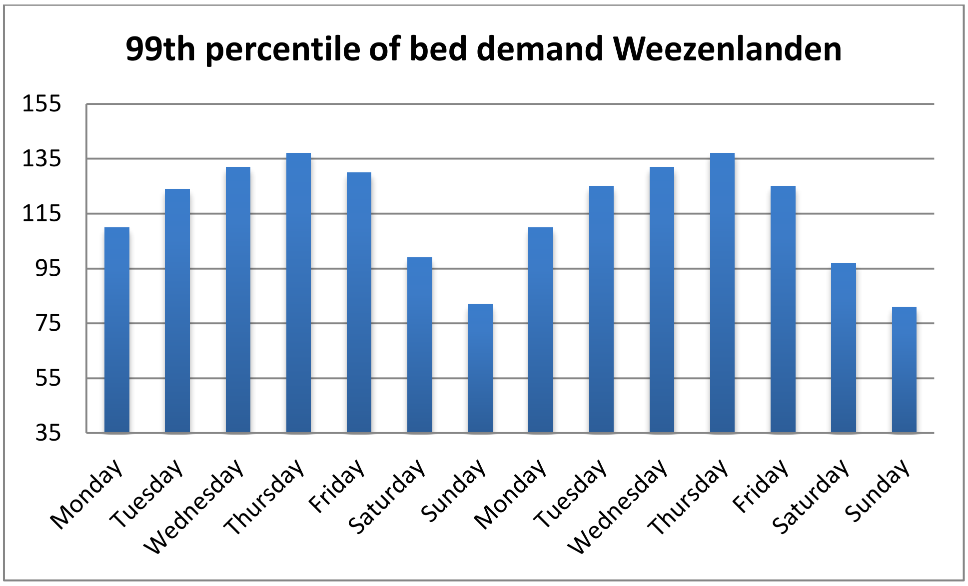

Figure 5.12: The model output for the Isala Klinieken

The heuristic goes through every single one-step-swap, evaluates its performance and records the top five best solutions. Steepest Descent suggests we take the best solution and then go through a second iteration. While in practice the top 5 might offer more logical, more flexible or more agreeable swaps, we select the best nearest neighbour and then proceed.

In Table 5.2 the bed demand is given for each subsequent accepted swap. Note that this heuristic does not explicitly minimize bed demand at all, because its aim is leveling workload. This still results in fewer beds needed.

In the table the maximum number of beds is bolded. It is also interesting to keep track of the minimum number of beds needed on the weekdays. These two values gradually move towards the mean value for weekdays. In the current situation the difference between these values is 27 beds while after six iterations this amount is already reduced to 15 beds. It is obvious that reducing this amount not only leads to a situation where fewer beds are needed in general, but also improves bed occupancy. If 137 beds are present, and on one of the days in the cycle only 110 beds are occupied, the best case scenario for bed occupancy on that particular day is only a little more than 80 percent. If the maximum amount of beds needed is 130 and the minimum 115 however, the bed effectiveness rises to almost 90 percent. The convergence of the minimum number of beds required in a week and the maximum number of beds required is demonstrated in Figure 5.13.

Table 5.2: The number of beds needed on every day in the cycle for the current situation and consequent iterations

	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Current	**110**	124	132	**137**	130	99	82	**110**	125	132	**137**	125	97	81
Iteration														
1	112	126	128	134	128	98	81	**110**	125	132	**137**	130	100	83
2	113	126	128	**134**	128	98	81	**110**	125	127	133	133	102	84
3	**112**	126	128	**133**	130	100	83	113	124	125	132	132	102	83
4	**114**	124	126	131	127	100	84	**114**	125	126	**132**	**132**	102	83
5	**113**	124	126	**131**	**131**	104	86	115	126	127	128	129	100	82
6	**115**	125	125	129	**130**	103	85	**115**	126	126	128	129	101	84
7	**115**	124	126	129	**131**	102	85	**115**	126	126	128	129	101	84

In Table 5.3 it is displayed how the number of daily admissions evolve through the iterations. In the current situation the maximum amount of admissions is 44 on the first Monday while the minimum amount is only 23 on the last Friday. Naturally the nurses may feel a big difference in workload through the MSS cycle. Through the iterations the numbers get much closer to the average value. The maximum number of admissions gets 45, but the minimum number climbs to 33. The general workload *considering this element* has improved drastically.

Table 5.3: The number of daily admissions in the cycle for the current situation and consequent iterations

	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Current	**44**	42	42	41	30			42	42	42	40	**23**		
Iteration														
1	**44**	42	37	41	30			42	42	42	40	**28**		
2	**44**	42	37	41	**30**			42	42	37	40	33		
3	**44**	42	37	39	**30**			**44**	42	37	40	33		
4	**45**	42	37	39	**29**			44	42	37	40	33		
5	**45**	42	37	39	34			44	42	37	35	**33**		
6	**45**	42	37	39	34			44	42	37	35	**33**		
7	**45**	41	37	39	35			44	42	37	35	**33**		

Table 5.4 shows the discharges in a cycle for the different iterations. In this table the differences are harder to discern. Still, the performance improves slightly by increasing the minimum amount of discharges during the week from 33 to 37 after a couple of iterations.

Table 5.4: The number of daily discharges in the cycle for the current situation and consequent iterations

	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Current	34	41	42	44	40	25	17	33	42	41	41	38	23	17
Iteration														
1	35	42	41	43	40	25	17	33	42	41	41	40	25	18
2	35	42	41	43	40	25	17	33	42	40	39	41	26	18
3	35	42	41	40	40	25	17	37	43	40	39	40	26	18
4	38	42	41	39	36	24	17	37	43	40	39	40	26	18
5	38	42	40	39	38	26	18	37	44	40	38	39	26	18
6	38	44	41	39	37	26	18	37	43	40	38	37	25	18
7	38	42	42	39	39	25	18	37	43	40	38	37	25	18

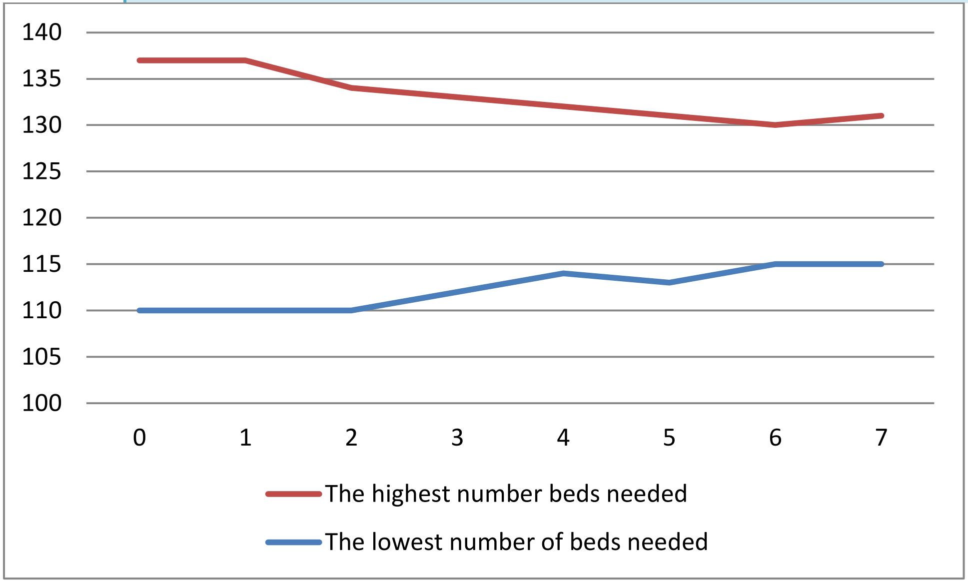

Figure 5.13: The development of the bed demand through iterations

The current performance turns out to be 1260.9. This value helps to compare alternative solutions. To demonstrate the effectiveness of the heuristic the results and the swaps for each of the first seven iterations are displayed in Table 5.5 and 5.6. The swap pairs are to be interpreted using the MSS displayed in Figure 5.1.

Table 5.5: The top five best swaps and their performance of seven iterations (a)

Top 5:	Iteration 1		Iteration 2		Iteration 3		Iteration 4	
	Result	Swap Pair	Result	Swap Pair	Result	Swap Pair	Result	Swap Pair
1	1004	(3,1) and (12,1)	855,9	(10,5) and (12,3)	763,1	(4,7) and (8,1)	686,6	(1,1) and (5,7)
2	1031,8	(10,5) and (12,1)	876,7	(10,1) and (12,3)	777,6	(4,5) and (5,15)	688,0	(9,1) and (12,11)
3	1036,5	(3,5) and (12,1)	880,6	(4,7) and (8,1)	778,4	(4,5) and (5,3)	691	(1,5) and (5,11)
4	1040,2	(2,1) and (12,1)	895,1	(8,1) and (11,7)	779,3	(4,11) and (5,3)	696,3	(1,5) and (5,7)
5	1043,8	(4,5) and (12,1)	896,8	(1,1) and (4,7)	780,7	(1,1) and (4,7)	698,3	(4,5) and (5,15)

Table 5.6: The top five best swaps and their performance of seven iterations (b)

Top 5:	Iteration 5		Iteration 6		Iteration 7	
	Result	Swap Pair:	Result	Swap Pair:	Result	Swap Pair:
1	613,8	(5,3) and (11,5)	558,1	(2,1) and (12,11)	524,6	(2,7) and (5,11)
2	616,6	(5,3) and (9,5)	559,4	(1,3) and (12,11)	527	(5,11) and (8,3)
3	617,3	(5,3) and (9,1)	562,3	(1,3) and (5,11)	529,1	(5,11) and (9,7)
4	622,2	(4,5) and (5,3)	570	(5,11) and (8,5)	532,6	(2,3) and (5,15)
5	624,3	(5,15) and (11,5)	570,5	(9,1) and (11,13)	535,4	(9,1) and (12,15)

The first thing that catches the eye is how the top five results see a drastic decline after each swap. This means that improvements that can be made are impressive. The original performance is 1260.9, after the first iteration the result is 1004 which is an improvement of about 20 percent. By the seventh iteration the result has already dwindled down to 524.6 which is an improvement of about 60 percent.

Having the program provide a top five of most beneficial swaps allow us to understand what the sore point in the MSS is at any given time. If we take a closer look to the first iteration, we see that the heuristic suggests we at least should swap with an empty OR-day on the last Friday of the MSS-cycle. Whether we choose orthopaedics from the first Tuesday or Wednesday, urology from either the first or the second Wednesday or the first Thursday seems to be slightly less important. In other words, it might not matter that much which swap we want to continue with swapping specialty 2 or 8. We just need to fill up an empty entry on the last Friday of the cycle. For arguments sake we stay with the heuristic and swap (3, 1-2) with (12, 1-2).

After seven iterations of the Steepest Descent heuristic the bed demand looks like as is displayed in Figure 5.14. The picture shows how many beds are needed in the current situation (blue) and the number of beds needed after seven iterations (red).

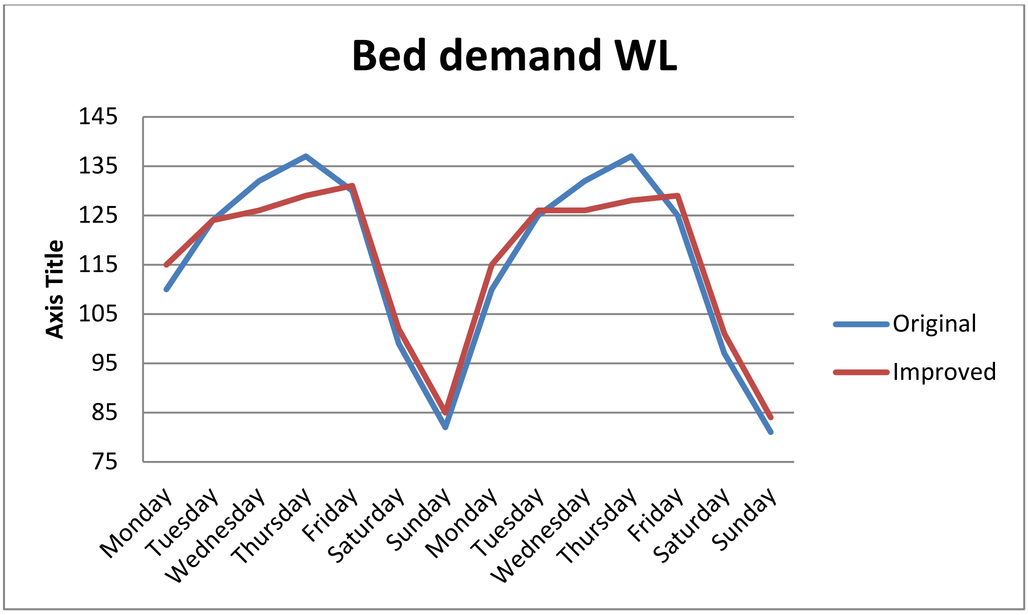

Figure 5.14: A comparison between the current bed performance and an improved solution

The figure shows how the bed demand has improved after seven iterations. Both the highs and lows have been flattened out. The variability for the bed demand specifically has been reduced from 683.9 to 283.5 which is a reduction of about 60 percent. Notice that in general fewer beds are needed, they can effectively be closed.

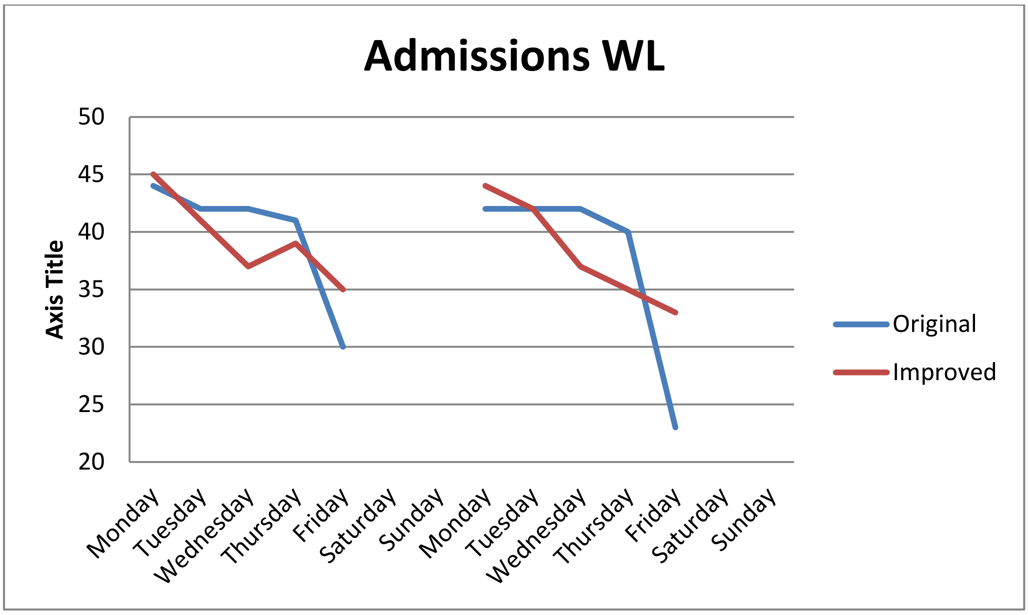

Figure 5.15: A comparison between the number of daily admissions now and after seven iterations

Figure 5.15 shows how the admissions of patients have evolved after seven iterations of the heuristic. The sum of the quadratic differences from the mean for the admissions has been reduced dramatically from 165.4 to 91.5 (about 45 percent).

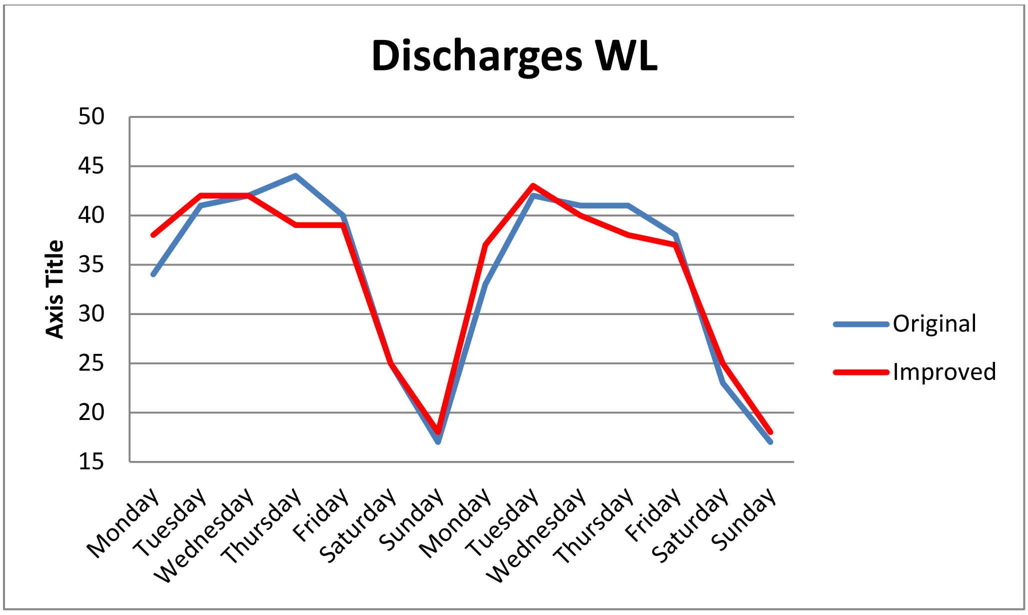

Figure 5.16: A comparison between the number of daily admissions now and after seven iterations

In Figure 5.16 the amount of daily discharges are showed. The result of Performance C has decreased from 411.6 to 149.6 through seven iterations, for an improvement of over 60 percent.

Every iteration improves the performance of the wards. Figure 5.17 displays how the different contributors to workload behave through the iterations. All separate components of workload improve, as can be seen in Figure 5.17. The variability is the largest contributor to the workload measurement in the current scenario and continues to be through the iterations. It is possible to re-evaluate the system by adding different weights to the three contributors of workload. The model is capable of incorporating weight factors.

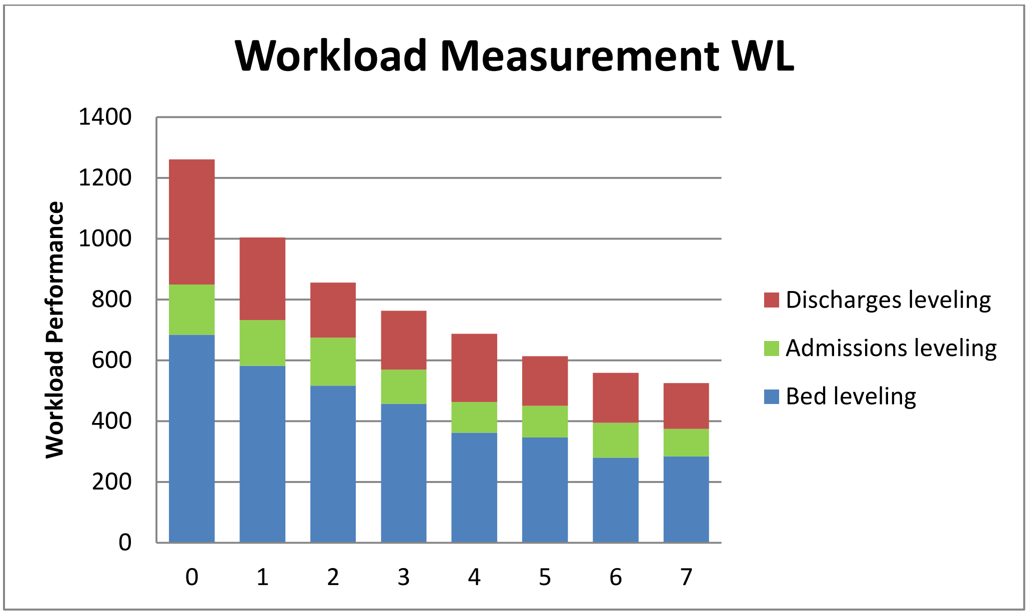

Figure 5.17: The evolution of workload through several iteration and the contribution of each factor

After seven iterations the MSS looks as displayed in Figure 5.18 and 5.19.

	WEEZENLANDEN	1	2	3	4	5	6	7	8	9	10
	Even weeks	OR 1		OR 2		OR 4		OR 5		OR 6	
		M	A	M	A	M	A	M	A	M	A
1	Monday	14	14	2	2	8	8	14	14	2	2
2	Tuesday	4	4	2	2	8	8	4	4	2	2
3	Wednesday	42	42	2	2	8	8	14	14	8	8
4	Thursday	2	2	2	2	8	8	2	2	22	22
5	Friday	2	2	8	8	8	8	2	2	42	42
6											
7	Odd weeks							M	A		
8	Monday	14	14	2	2	8	8	14	14	2	2
9	Tuesday	2	2	2	2	8	8	14	14	2	2
10	Wednesday	2	2	2	2	42	42	14	14	2	2
11	Thursday	2	2	2	2	42	42	14	14	8	42
12	Friday	2	2	8	8	8	42	14	14	42	42
13											
14		0									

Figure 5.18: An improved version of the MSS of the Weezenlanden location (a)

	WEEZENLANDEN	11	12	13	14	15	16	17	18	19	20
	Even weeks	OR 7		OR 8		OR 9		OR 10		OR 11	
		M	A	M	A	M	A	M	A	M	A
1	Monday	22	22	15	20	20	20	20	20	20	20
2	Tuesday	4	4	20	20	20	20	20	20	20	20
3	Wednesday	4	4	20	20	20	20	20	20	20	20
4	Thursday	4	4	20	20	20	20	20	20	20	20
5	Friday	14	14	42	42	20	20	20	20	20	20
6											
7	Odd weeks										
8	Monday	4	42	15	20	20	20	20	20	20	20
9	Tuesday	4	4	20	20	20	20	20	20	20	20
10	Wednesday	8	8	20	20	20	20	20	20	20	20
11	Thursday	4	4	20	20	20	20	20	20	20	20
12	Friday	2	2	42	42	20	20	20	20	20	20
13											
14											

Figure 5.19: An improved version of the MSS of the Weezenlanden location (b)

5.4.2 The case study II: Sophia location

The current bed demand for the Sophia location is given in Figure 5.20. The current performance of the Sophia location is 940.2. In Table 5.7 number of beds needed on each of the days is displayed. Once again the maximum number and the minimum number of beds during the week are bolded. In Figure 5.21 the maximum and minimum numbers of beds are displayed as they evolve throughout the heuristic.

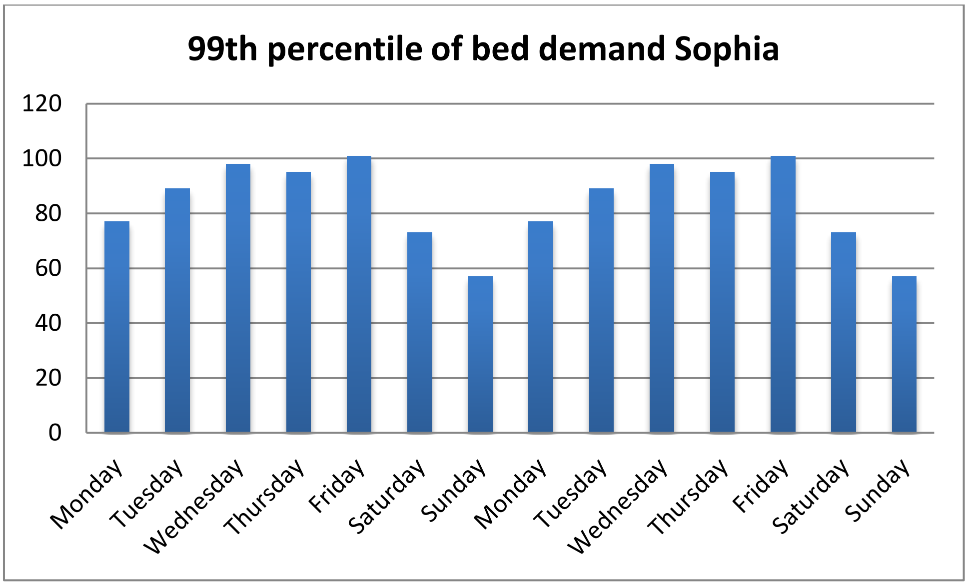

Figure 5.20: The model output for the current bed demand for the Sophia location

Table 5.7: The number of beds needed on every day in the cycle for the current situation and consequent iterations

	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Current	**77**	89	98	95	**101**	73	57	**77**	89	98	95	**101**	73	57
Iteration														
1	81	88	95	94	100	73	57	77	89	97	95	100	76	60
2	81	88	95	94	99	75	60	81	88	95	94	99	75	60
3	82	88	96	94	99	75	60	81	86	93	92	98	76	62
4	82	87	93	93	98	76	62	82	87	93	93	98	76	62
5	82	87	93	93	98	76	62	84	86	91	93	98	76	62
6	84	86	91	93	98	76	62	84	86	91	93	98	76	62
7	85	87	92	93	98	76	62	84	86	91	92	96	76	64

Table 5.8: The number of daily admissions in the cycle for the current situation and consequent iterations

	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Current	33	32	35	29	33			33	32	35	29	33		
Iteration														
1	35	32	35	29	33			33	32	35	29	31		
2	35	32	35	29	31			35	32	35	29	31		
3	35	32	35	29	31			35	32	35	29	31		
4	35	32	35	29	31			35	32	35	29	31		
5	35	32	35	29	31			36	32	33	29	31		
6	36	32	33	29	31			36	32	33	29	31		
7	36	32	33	29	31			36	32	33	29	31		

Table 5.7 shows how in the current situation the number of excess beds is 24, which is an excess of about 25 percent. Table 5.8 gives an overview of how the numbers of admissions behave through the iterations. It turns out that the situation actually worsens slightly. The performance of the admissions deteriorates from 32.4 to about 54. Because the Aggregate Performance Measure is a combination of three types of performance measure it is possible to improve one measure more than it deteriorates another measure. It turns out that both in the original situation as in the scenario after seven iterations the variability of admissions is not particularly large, especially so in comparison to the other measures of workload.

Table 5.9: The number of daily discharges in the cycle for the current situation and consequent iterations

	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Current	24	31	38	32	37	24	16	24	31	38	32	37	24	16
Iteration														
1	30	32	37	32	37	23	16	24	31	38	32	33	23	17
2	30	32	37	32	33	23	17	30	32	37	32	33	23	17
3	30	33	37	32	33	23	17	31	33	36	31	31	21	18
4	32	34	36	31	31	21	18	32	34	36	31	31	21	18
5	32	34	36	31	31	21	18	35	33	33	31	31	21	18
6	35	33	33	31	31	21	18	35	33	33	31	31	21	18
7	35	34	33	31	31	21	18	35	33	35	32	28	19	19

Table 5.9 displays the number of discharges per day during a typical cycle. The maximum and minimum develop from 38 versus 24 to 35 versus 28 during the week. In the weekends fewer discharges take place and the values from Saturdays get closer to the values on Sundays.

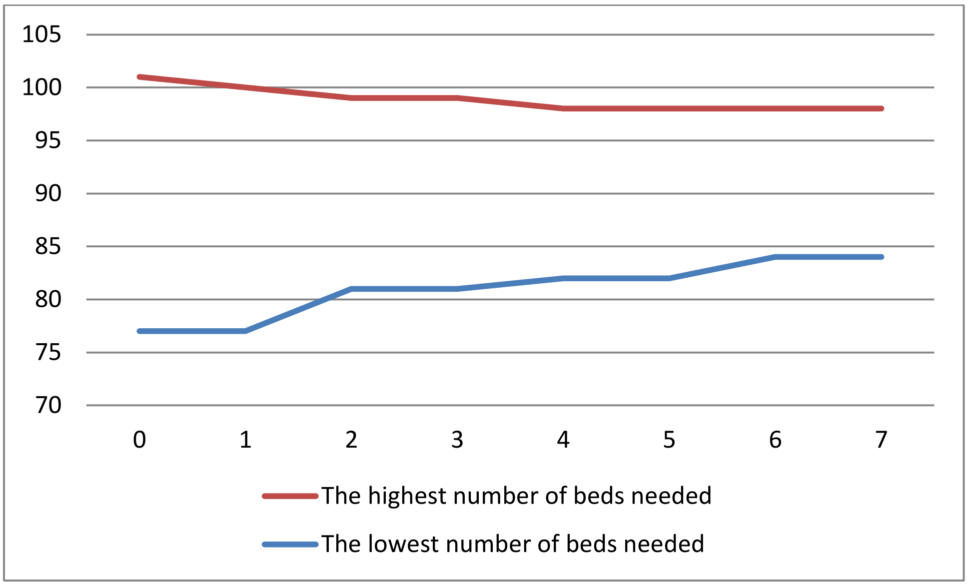

Figure 5.21: The development of bed demand through iterations

The top five of best results is displayed Table 5.10 and the required number of beds in Figure 5.21. The result of these swaps is displayed in Figures 5.22-24. The Workload Performance Measure has reduced to about 30 percent after seven iterations.

Table 5.10: The top five best swaps and their performance of seven iterations

Top 5:	Iteration 1		Iteration 2		Iteration 3		Iteration 4	
	Result	Swap Pair	Result	Swap Pair	Result	Swap Pair	Result	Swap Pair
1	706.1	(1,1) and (12,7)	490	(5,7) and (8,1)	446.1	(8,9) and (12,1)	375.9	(1,9) and (5,1)
2	706.1	(5,7) and (8, 1)	548.7	(8,1) and (12,15)	466.1	(1,9) and (5,1)	385	(1,9) and (5,15)
3	733.4	(8,1) and (12,7)	563.6	(8,13) and (10,11)	446.4	(1,9) and (12,15)	385.3	(1,9) and (12,3)
4	733.4	(1,1) and (5,7)	566.1	(5,7) and (8,13)	446.4	(5,15) and (8,9)	389.9	(3,11) and (11,3)
5	736.8	(8,13) and (12,7)	575.3	(5,1) and (8,1)	447.9	(5,1) and (8,9)	391.5	(2,9) and (5,1)
Top 5:	Iteration 5		Iteration 6		Iteration 7			
	Result	Swap Pair:	Result	Swap Pair:	Result	Swap Pair:		
1	348.1	(8,3) and (10,11)	319.9	(1,3) and (3,11)	297.9	(10,9) and (12,3)		
2	348.1	(1,3) and (3,11)	323.6	(3,9) and (5,3)	297.9	(3,9) and (5,3)		
3	349.8	(4,3) and (10,11)	324.8	(3,11) and (11,3)	304.7	(5,3) and (11,13)		
4	349.8	(3,11) and (11,3)	325.4	(10,9) and (12,3)	304.7	(4,13) and (12,3)		
5	351.4	(5,3) and (10,9)	327.2	(10,9) and (12,13)	308.2	(3,9) and (5,13)		

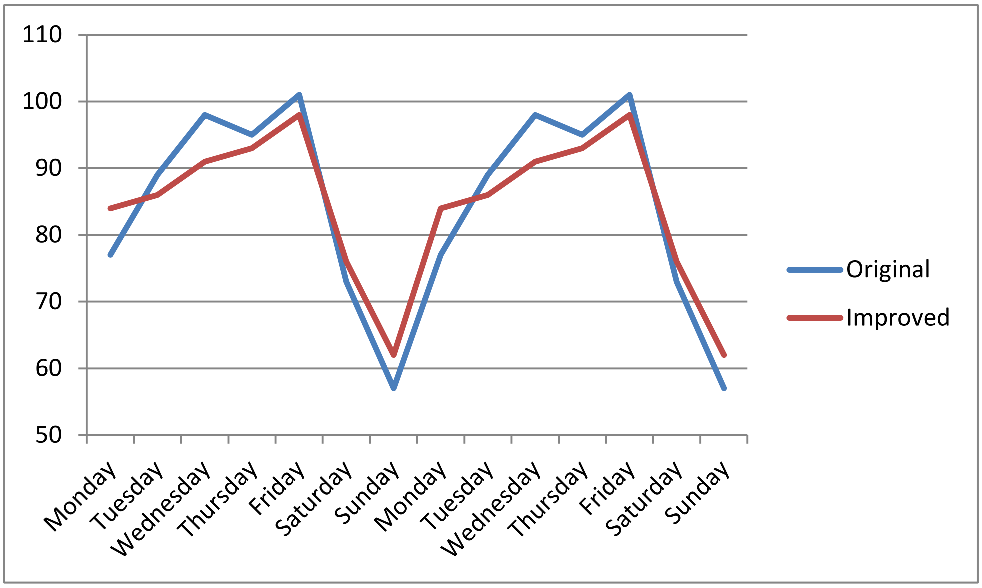

Figure 5.22: A comparison between the current bed performance and an improved solution

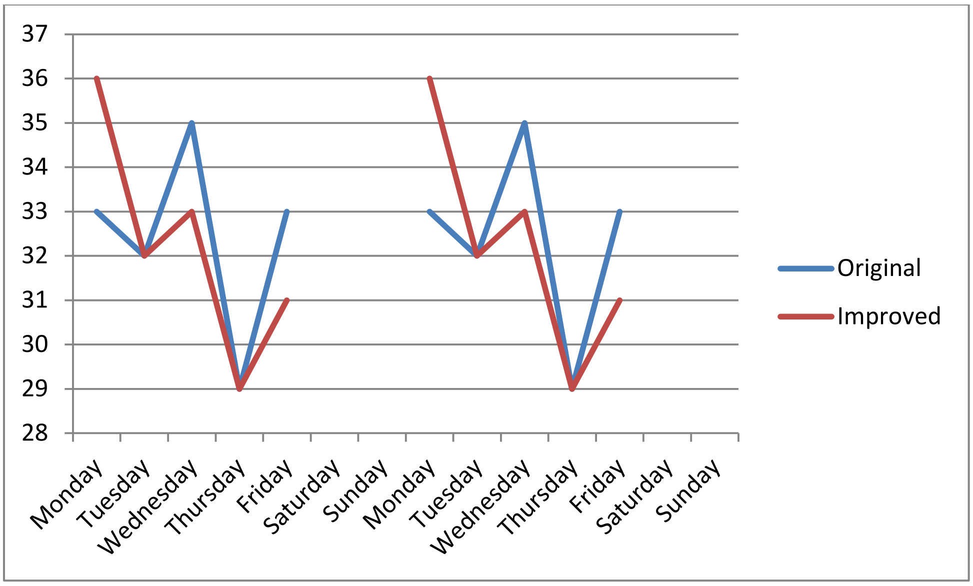

Figure 5.23: A comparison between the number of daily admissions now and after seven iterations

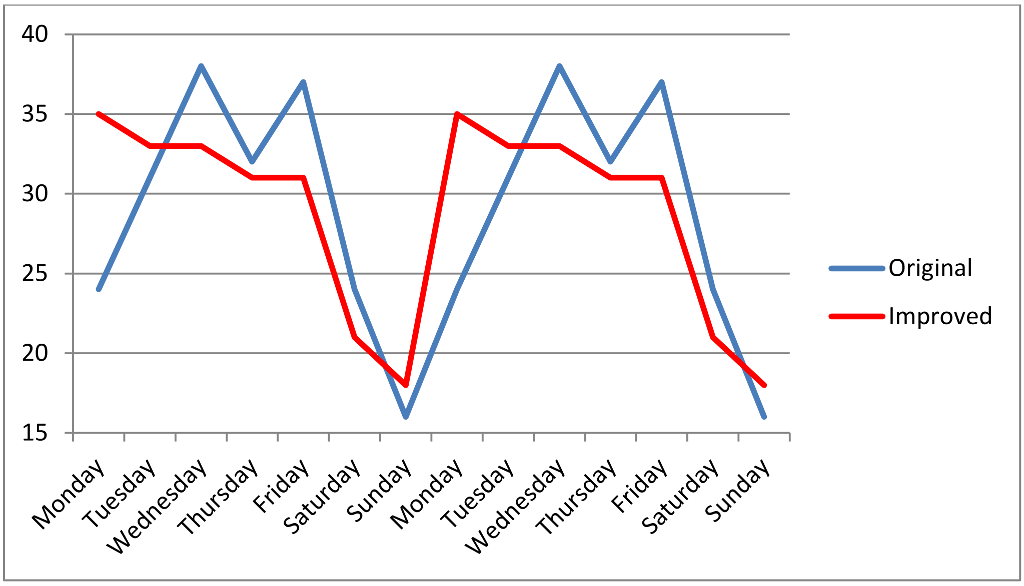

Figure 5.24: A comparison between the number of daily discharges now and after seven iterations

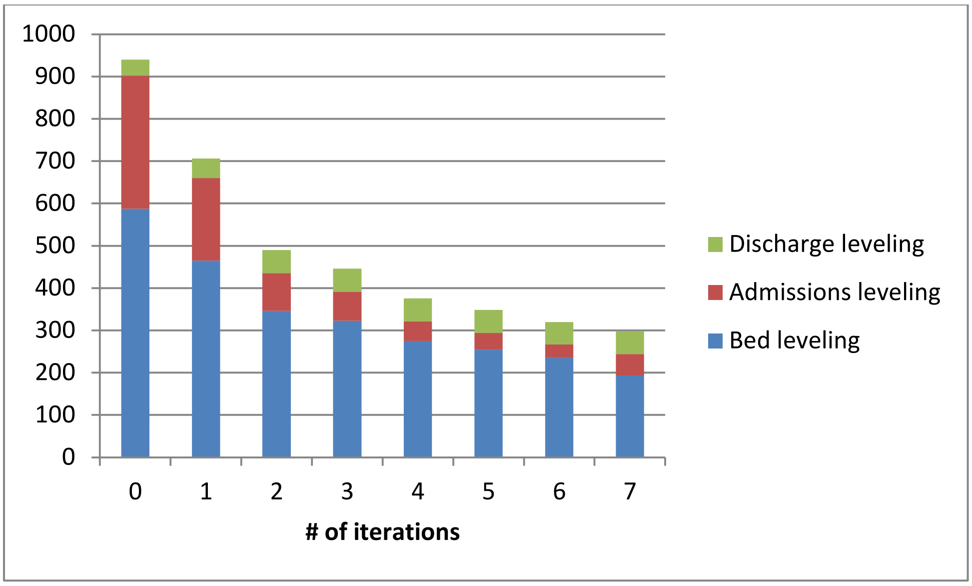

Figure 5.25: The evolution of workload through several iteration and the contribution of each factor

Figure 5.25 shows how big the contributors to workload relate to each other. As in the Weezenlanden case, the variability of the bed leveling is bigger than the other contributors. Both the leveling of the admissions and leveling of the bed demand show considerable improvements, apparently at a slight cost to leveling of discharges.

5.4.3 The new location

The approach taken in this research is useful for altering an MSS but not so much for constructing one. As of now the MSS of the new location is not defined. This means that for the new hospital an MSS still needs to be constructed. This cannot be done directly by making use of the model proposed here. However, it is possible to construct an initial MSS and then predict its performance and make adjustments if necessary / beneficial.

5.5 Restricting the number of operations within an OR-block

It is conceivable that some variability on the wards can be taken away by controlling the amount of patients that are operated in an OR-block. It is clear that if any specialty decides to do ten operations in an OR-block, all these ten patients need a bed, and create a challenge for the nursing ward.

In Table 5.11 we can find a list of the maximum amount of patients that are operated in an OR-block by any of the specialties. There are some numbers we cannot tinker with, such as the amount of emergency patients in the emergency OR of the Sophia location. Another one that may not yield feasible results is anaesthetics, since this specialty only operate once a week at the Weezenlanden location. It stands to reason that for specialties that operate several times a week it is much easier to find patients that can easily be operated on a later or earlier date in the same week, i.e. leveling the number of operations during the week.

Table 5.11: The maximum number of patients operated in an OR-block for several specialties

Specialty	Max # patients	Specialty	Max # patients
General surgery	4	ENT surgery	5
Orthopaedics	4	Anaesthetics	6
Plastic surgery	5	Neurosurgery	3

Jaw surgery	5	Thorax surgery	2
Urology	5	Dental surgery	3
Gynaecology	4	Emergency OR SZ	2

5.5.1 General Surgery

Let's consider general surgery. The distribution of the amount of patients is given in Table 5.12, along with some arbitrarily chosen new fractions. The only rules that the new fractions need to comply with are: the fraction still sum up to one and the new average total of patients operated are the same as in the current situation. If it is not allowed to operate four patients in an OR-block the time that three patients are operated increases.

Table 5.12: A possible new distribution for general surgery

# patients	0	1	2	3	4	Totals
Fraction	0,07	0,300	0,4	0,21	0,02	1
Average total	0	0,3	0,8	0,63	0,08	1,81
Adj. Fraction	0,06	0,310	0,39	0,24	0	1
New avg. total	0	0,31	0,78	0,72	0	1,81
Adj. Fraction	0	0,190	0,81	0	0	1
New avg. total	0	0,19	1,62	0	0	1,81

General surgery only operates at the Sophia location according to the MSS. The current performance of the OR-planning is 940.2 and with the modified input is 924.2. This means that restricting the amount of patients operated in OR-block for general surgery has a small but noticeable impact on the performance of the nursing wards. Restricting the number of operations to only two generates a performance of 888.4.

5.5.2 Plastic surgery

For plastic surgery the distribution for the number of patients are displayed in Table 5.13. Restricting the amount of patients to four does not increase the performance of the MSS. We adjust the fraction one more time, and restrict the number of patients operated to three. Rerunning the model suggest that the new performance will be 894.6. So restricting the amount of plastic surgery patients per OR-block to four gives a better performance, but further reducing this amount will deteriorate the performance, albeit slightly.

Table 5.13: A possible new distribution for plastic surgery

# patients	0	1	2	3	4	5	Totals
Fraction	0,07	0,14	0,21	0,4	0,16	0,02	1
Average total	0	0,14	0,42	1,2	0,64	0,1	2,5
Adj. Fraction I	0,07	0,14	0,21	0,38	0,2	0	
New avg. total	0	0,14	0,42	1,14	0,8	0	2,5
Adj. Fraction II	0,06	0,06	0,2	0,68	0	0	1
New avg. total	0	0,06	0,4	2,04	0	0	2,5

5.5.3 Other specialties at Sophia

Similar calculations show that restricting the amount of patients for gynaecology improves the Performance Measure to 888.4. Further reducing the number of operations is not beneficial.

Altering the distribution for neurosurgery improves the performance to 912.6 as compared to the current performance.

5.5.4 Specialties at Weezenlanden

Restricting the number of operations allowed in an OR-block for orthopaedics does not result in a better performance. Reducing the amount of patients for dental surgery by either one or two patients weakens the performance.

Adding constraints to urology is improves the performance, but the difference will be barely discernable as reducing the number of operations from five to four increases the performance by one percent and reducing to three leads to an improvement of about three percent. Similar results are found for anaesthetics.

Putting restrictions on ear, nose and throat surgery or dental surgery does not result in better performances.

5.5.5 Conclusion

For the Sophia it seems that restricting the number of operations per OR-block is beneficial, while for the Weezenlanden such a practice is futile.

We further investigate the implications of restricting the number of patients to be operated in an OR-block, because if such a simple rule would really result in an improvement of five percent, it may be worthwhile to implement. In Table 5.14 the bed distribution through the MSS cycle is displayed, if restrictions are put on general surgery. The total values for the number of beds required and the other contributors total to lower values. This leads to believe that putting a restriction on the number of operations in an OR-block minimizes workload on the nursing wards only because of rounding errors.

Table 5.14: The distributions after the intervention for general surgery

																Total
Max 4	Beds	77	89	98	95	101	73	57	77	89	98	95	101	73	57	1180
	Dis	24	31	38	32	37	24	16	24	31	38	32	37	24	16	404
	Adm	33	32	35	29	33	0	0	33	32	35	29	33	0	0	324
Max 3	Beds	77	89	97	95	101	73	57	77	89	97	95	101	73	57	1178
	Dis	24	31	38	32	37	24	16	24	31	38	32	37	24	16	404
	Adm	33	32	35	29	33	0	0	33	32	35	29	33	0	0	324
Max 2	Beds	76	88	96	94	100	73	57	76	88	96	94	100	73	57	1168
	Dis	24	31	37	32	37	23	16	24	31	37	32	37	23	16	400
	Adm	32	31	34	28	32	0	0	32	31	34	28	32	0	0	314

5.6 Sensitivity analysis

In this section we will establish the robustness of the model. Two inputs have effectively been tested elsewhere in this writing. One of them is the c_j-distribution in the previous paragraph. It is shown that alterations have no noticeable impact on the performance, i.e. the model is not sensitive to changes in the c_j-distributions.

The second input that is tested elsewhere is the separation of specialties into sub-specialties, which is tested in Section 5.8. It is assumed that increasing the solution space increases the odds of finding better solutions. It is often difficult to obtain the distributions for sub-specialties so it is not immediately clear whether this exercise pays off.

In this specific paragraph another factor that has an impact on the results of the analysis is tested. We consider the percentile of bed demand. Previously we have used a 99th-percentile to calculate the bed demand and discharge distributions.

As is evident the different percentiles of demand do not propose the exact same swaps, but most of them appear in the top five lists (see Table 5.15). The other swaps show similarities since they have pairs in common. The fourth suggestion in the 90 percentile scenario for example shows up as the first suggestion in the fifth iteration in the original scenario.

The improvements that are to be achieved are of similar size, confirming the effectiveness of swapping OR-days to improve performance. The fact that the proposals are not exactly the same, but do appear in the top five solutions further strengthens our belief that the approach of supplying the users with a top five list of swaps to choose from will offer alternatives without sacrificing performance too much.

Table 5.15: Proposed swaps for different percentiles of bed demand

	Original			Results for 95th percentile				Results for 90th percentile			
0	**1260,9**	**Swaps**		**1179,8**			**Appears as:**	**1146,9**			**Appears as:**
1	1004	(3,1) and (12,1)	79,6	964,45	(3,5) and (12,1)	81,7	3	910,8	(3,5) and (12,1)	72,2	3
2	855,9	(10,5) and (12,3)	67,9	833,49	(10,5) and (12,3)	70,6	1	807,2	(10,1) and (12,3)	64,0	2
3	763,1	(4,7) and (8,1)	60,5	711,32	(4,7) and (8,1)	60,3	1	700	(1,1) and (4,7)	55,5	5
4	686,6	(1,1) and (5,7)	54,5	648,96	(1,1) and (12,11)	55,0	x	622,5	(5,3) and (11,5)	49,4	x
5	613,8	(5,3) and (11,5)	48,7	589,93	(5,3) and (9,1)	50,0	3	575,8	(5,7) and (8,1)	45,7	x

5.7 Specific Ward distributions

While minimizing the workload for the hospital is all good and well we have ignored the workload at specific wards up until this point. It is still possible that irregularities go by unnoticed. On some days one ward may experience a high workload while another one experiences a low workload. The point is that when looking at the hospital as a whole in this particular scenario the workloads at the two wards may cancel each other out. So the hospital as a whole may perform well, but under the surface the problem is still there.

The purpose of this chapter is twofold: laying bare the weak points of the MSS on the ward level and setting up the next step in improving the model. First of all, pointing out areas that may prove worrisome can be dealt with if they are known in advance. Measures can be taken to prepare the hospital for irregularities at the wards. For example: perhaps it is wise to train nurses to be able to perform well at more than one ward and schedule them where the workload is expected to be high.

Second: It is sensible to construct a performance measure for the distribution of patients to the different nursing wards. The number of patients directed to each ward varies greatly. Calculating the variance is of little value because bigger wards will be punished too much. It is possible to compute the coefficient of variability to account for this. In that case high variability over small numbers is punished more severely.

A possible way to measure the performance of the wards would be to add up the variance for the weekdays and the variance for the weekend days. This value can be divided by the average number of patients on the ward to adjust the value to their respective sizes. The resulting values can be added up iteratively for all the wards. This value can serve as a performance measure for a particular configuration.

This performance measure can be evaluated using the heuristic as well. Note that adding the ward specific distributions to the model drastically increases computation time. One iteration takes up to 60 seconds and there are about 900 possible configurations, so the run time of the heuristic will soar to about 15 hours.

For now the way we go about using the distribution to the wards is to evaluate the performance of the heuristic as a whole, run through a number of iterations, and then display and evaluate the ward configuration again. Note that partitioning the patients to wards and having a 99th-percentile dictates having more beds available in order to meet demand compared to considering the hospital as a whole.

5.7.1 Distribution to wards for the Weezenlanden

The ward distributions in the current situation are displayed in Tables 5.16 and 5.17. In the top row the different wards are displayed, and in the first column the days throughout an MSS cycle. From the table we can see how many beds are required on every day for each of the wards. The row dubbed Performance states the variability of the wards, the Average is simply the average number of beds needed for each ward, and the coefficient of variability is calculated to account for the fact that wards are of different sizes.

In the bottom right of Table 5.17 the total values we find the total values. Of particular interest is the total of the coefficient of variability of all the wards, which is a measure of the performance of the MSS. The ward distributions in the improved situation are displayed in Table 5.18 and 5.19.The situation has improved overall: the sum total has dropped from 2.41 to 2.16. Note that the objective of the heuristic is not to decrease variability on the ward level.

Table 5.16: Ward distributions Weezenlanden (a)

Day number	**WL|A2**	**WL|A2K**	**WL|A4**	**WL|A5**	**WL|A6**	**WL|A7**
1	36	10	18	10	3	51
2	44	11	21	11	3	53
3	47	12	21	14	2	55
4	49	14	22	14	2	56
5	45	12	20	13	2	57
6	27	7	15	10	1	53
7	19	5	12	8	1	49
8	37	8	18	10	3	51
9	45	10	22	11	3	53
10	46	10	24	14	2	55
11	48	12	23	15	2	56
12	42	11	18	13	2	57
13	26	7	15	10	1	53
14	18	5	12	8	1	49
Performance	**33,54**	**3,40**	**6,46**	**4,05**	**0,24**	**8,64**
Average	**37,79**	**9,57**	**18,64**	**11,50**	**2,00**	**53,43**
Coeficient of variability	**0,89**	**0,36**	**0,35**	**0,35**	**0,12**	**0,16**

Table 5.17: Ward distributions Weezenlanden (b)

WL|B1	WL|B1IC	WL|B3	WL|B4	WL|B5	WL|B6	WL|IC	Totals
2	1	2	11	3	2	4	
2	1	2	11	3	2	4	
2	1	2	11	3	2	4	
2	1	2	12	3	2	4	
2	2	2	12	3	2	4	
2	1	2	11	3	2	4	
2	1	2	10	3	2	4	
2	1	2	11	3	2	4	
2	1	2	11	3	2	4	
2	1	2	11	3	2	4	
2	1	2	12	3	2	4	
2	2	2	12	3	2	4	
2	1	2	11	3	2	4	
2	1	2	10	3	2	4	
0,00	**0,16**	**0,00**	**0,49**	**0,00**	**0,00**	**0,00**	**56,98**
2,00	**1,14**	**2,00**	**11,14**	**3,00**	**2,00**	**4,00**	**158,21**
0,00	**0,14**	**0,00**	**0,04**	**0,00**	**0,00**	**0,00**	**2,41**

Table 5.18: Ward distributions WL after seven iterations of the heuristic (a)

Day number	WL|A2	WL|A2K	WL|A4	WL|A5	WL|A6	WL|A7
1	41	12	17	10	3	51
2	45	12	18	11	3	53
3	44	12	16	14	2	55
4	43	13	21	14	2	56
5	43	11	22	16	2	57
6	28	7	16	12	1	53
7	20	5	13	9	1	49
8	41	10	17	11	3	51
9	46	11	21	12	3	53
10	44	10	23	12	2	55
11	44	10	23	11	2	56
12	43	10	23	13	2	57
13	28	6	18	10	1	53
14	20	5	14	8	1	49
Performance	**18,24**	**1,78**	**10,78**	**5,23**	**0,24**	**8,64**
Average	**37,86**	**9,57**	**18,71**	**11,64**	**2,00**	**53,43**
Coeficient of variability	**0,48**	**0,19**	**0,58**	**0,45**	**0,12**	**0,16**

Table 5.19: Ward distributions Weezenlanden after seven iterations of the heuristic (b)

WL|B1	WL|B1IC	WL|B3	WL|B4	WL|B5	WL|B6	WL|IC	Totals
2	1	2	11	3	2	4	
2	1	2	11	3	2	4	
2	1	2	11	3	2	4	
2	1	2	12	3	2	4	
2	2	2	12	3	2	4	
2	1	2	11	3	2	4	
2	1	2	10	3	2	4	
2	1	2	11	3	2	4	
2	1	2	11	3	2	4	
2	1	2	11	3	2	4	
2	1	2	12	3	2	4	
2	2	2	12	3	2	4	
2	1	2	11	3	2	4	
2	1	2	10	3	2	4	
0,00	**0,16**	**0,00**	**0,49**	**0,00**	**0,00**	**0,00**	**45,55**
2,00	**1,14**	**2,00**	**11,14**	**3,00**	**2,00**	**4,00**	**158,50**
0,00	**0,14**	**0,00**	**0,04**	**0,00**	**0,00**	**0,00**	**2,16**

An example of a ward that has improved through the iterations is ward A2. The results are displayed in Figure 5.26 An example of a worsened performance is for ward A4, as can be seen in Figure 5.27.

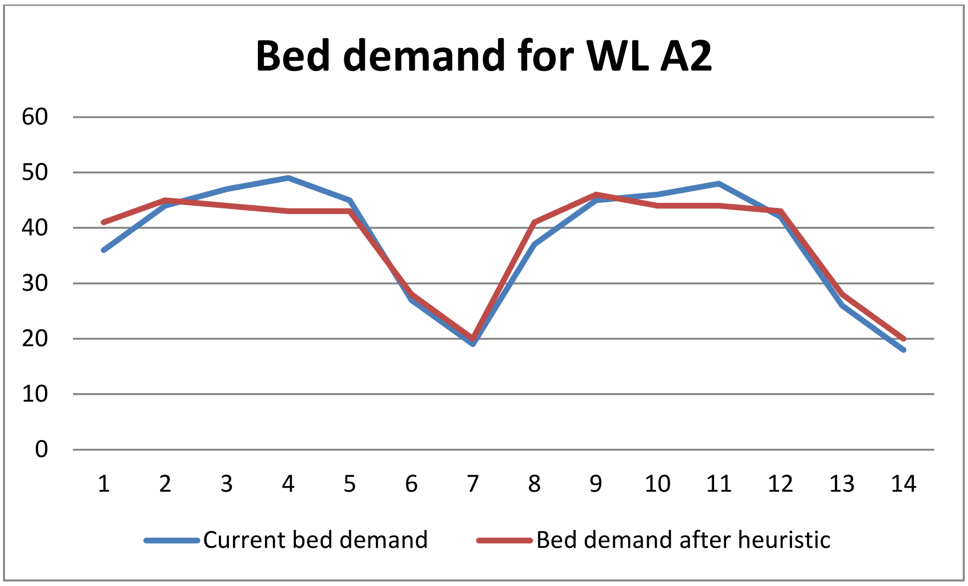

Figure 5.26: Bed demand for WL ward A2 now versus after implementation of the heuristic

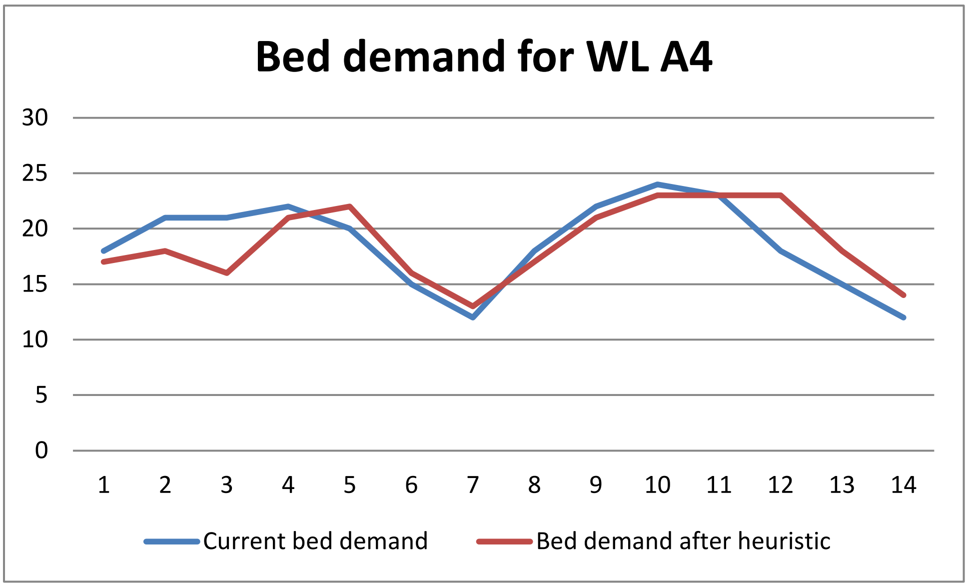

Figure 5.27: Ward distributions Weezenlanden after seven iterations of the heuristic

5.7.2 Optimizing on the ward-level

It is possible to evaluate the performance of the MSS on the ward level, and thus to seek improvements using the heuristic. A definite performance measure needs to be agreed upon, and this one can simply be inserted in the heuristic to calculate the performance of each configuration of the MSS. Calculating the ward distributions takes up to 60 seconds however, and evaluating almost 1000 configurations would take up considerable computing time.

5.8 Defining sub-specialties

This paragraph serves to demonstrate the flexibility and the applicability of the model. First some issues with adapting the model are discussed. The second segment deals with the case. Instead of aggregating sub-specialties into specialties we consider a situation where sub-specialties are defined in the master surgery schedule. Every sub-specialty has its own specific cj-distribution and dj-distributions.

5.8.1 Concerning lower levels of detail

For some specialties it is possible to reconstruct sub-specialties, like urology and orthopaedics. If data is available it becomes possible to improve the MSS with or without swapping specialties for other specialties, i.e. we can optimize the MSS for a specific specialty as well as in essence adding more specialties to the MSS. Doing this increases the solution space, which could allow for better solutions.

The case as described in this paragraph requires more detailed information than before. There are a couple of issues when a lower level of detailed is required. The necessary data is difficult to acquire, whereas the general data about specialties as a whole are easily obtained from the hospital's information systems.

Furthermore, even if subspecialties can be defined, along with specific cj-distributions and dj-distributions, the operations seem to occur randomly through the week, i.e. on the one hand the MSS is not stable throughout the year, on the other hand one can barely decide which operations on which days belonged to which subspecialty.

5.8.2 The case

A consultancy firm is doing several projects at the Isala Klinieken in collaboration with the departments Patient Logistics and I-Lean. At one point during their efforts they wanted to investigate the impact of the surgery departments on their specific wards. In order to do this the specialty general surgery has been split up into sub-specialties: general (number 10), vascular surgery (number 5), oncology (number 7), gallbladder surgery (number 12) and trauma (number 11). Each of these has their own specific c_j-distributions and d_j-distributions. The sub-specialties are displayed in Figure 5.28. The reason that some OR-days are painted purple is that usually plastic surgery is operating in these blocks. These OR-blocks are likely candidates for swapping and could be considered as well.

In this instance we are only interested in optimizing the bed occupancy for general surgery. Therefore we consider an MSS that only involves the surgery blocks and insert the respective sub-specialties accordingly. Now we adjust the heuristic so that swapping with empty OR-days is not allowed.

The research team was specifically interested in the minimum number of beds needed and wanted to achieve this by increasing the number of occupied beds in the weekends. This means that the MSS is judged by how well it performs on the following performance indicator:

$$Performance\ of\ general\ surgery = \sum_{i=1}^{14} (x_i - \bar{x})^2$$

The performance indicator minimizes the sum of every day's quadratic differences from the average number of beds needed.

Even weeks	OR 1		OR 2		OR 3		OR 4		OR 5		OR 6		OR 7		OR 8	
	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A
Monday	0	0	11	11	0	0	11	11	0	0	10	10	0	0	0	0
Tuesday	5	5	7	7	0	0	11	11	0	0	0	0	0	0	0	0
Wednesday	7	7	7	7	0	0	7	7	0	0	0	0	0	0	0	0
Thursday	0	0	5	5	0	0	5	5	0	0	5	5	0	0	5	5
Friday	5	5	12	12	0	0	0	0	0	0	0	0	0	0	0	0
Odd weeks	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A
Monday	0	0	11	11	0	0	11	11	0	0	10	7	0	0	0	0
Tuesday	7	7	7	7	0	0	11	11	0	0	0	0	0	0	0	0
Wednesday	7	7	7	7	0	0	7	7	0	0	0	0	0	0	0	0
Thursday	0	0	5	5	0	0	7	7	0	0	10	7	0	0	5	5
Friday	0	10	12	12	0	0	0	0	0	0	0	0	0	0	0	0
	0															

Figure 5.28: An MSS that only includes the sub-specialties of general surgery

Table 5.20: The most effective swaps of each iteration when considering sub-specialties of general surgery

Iteration	Suggested swap	Performance after change	Max vs. min number of beds
0	-	560,9	66 vs. 48
1	(1,11-12) & (5,1-2)	492,0	65 vs. 48
2	(4,11-12) & (8,11-12)	418,9	64 vs. 48
3	(8,3-4) & (10,7-8)	378,9	64 vs. 48
4	(1,3-4) & (3,7-8)	336,9	64 vs. 48
5	(9,1-2) & (11,3-4)	308,9	64 vs. 49
6	(3,3-4) & (10,1-2)	286,9	63 vs. 49
7	(3,1-2) & (4,3-4)	284,9	63 vs. 49
8	(3,3-4) & (4,7-8)	284,9	63 vs. 49

It is shown in Table 5.20 that the heuristic converges to a (local) optimum after seven iterations. The optimized schedule performs at a rate of about 50 percent of the original situation. The number or required beds has been reduced from 66 to 63.

While these improvements are not shabby there is still a vast gap between the number of beds needed during the week and the number of beds needed during the weekend. In order to occupy more beds in the weekends, more rigorous measures may be required. The number of OR-blocks scheduled on Fridays is only 3 or 4, whereas on other days the number is at least four and up to eight. If the goal is to increase bed demand in the weekends, then more and heavier operations need to be executed close to the weekend.

Because the difference in distributions between the sub-specialties is not large it may serve the purpose better to define groups in a different way. It may be more fruitful to distinguish between operations that typically require longer lengths of stay and operations that cause patients to stay only for shorter times.

6 Implementation

The research has an academic feel about it. The findings of the research are applicable, but there are some points that need to be considered carefully. In this chapter the implementation of the research is discussed.

6.1 Swapping OR-blocks

To clearly demonstrate once more what exactly a swap entails the master surgery schedule for operating room 4, 5 and 6 are displayed in Figure 6.1. A swap constitutes switching one OR-block for another one. An OR-block has two properties: the day on which we are operating and the operating room number. Swapping OR-block *Monday-OR4* with OR-block Friday-OR6 would result in the change displayed in Figure 6.2). Likewise Wednesday-OR6 can be switched with Thursday-OR6, as shown in Figure 6.3.

Even weeks	OR 4		OR 5		OR 6	
	M	A	M	A	M	A
Monday	URO	URO	KNO	KNO	ORT	ORT
Tuesday	URO	URO	KNO	KNO	ORT	ORT
Wednesday	URO	URO	KNO	KNO	ORT	ORT
Thursday	URO	URO	KNO	KNO	BIJZ. T	BIJZ. T
Friday	URO	URO	KNO	KNO	FLEX	FLEX
Saturday						
Sunday						

Figure 6.1: A possible new distribution for general surgery (a)

Even weeks	OR 4		OR 5		OR 6	
	M	A	M	A	M	A
Monday	URO	FLEX	KNO	KNO	ORT	ORT
Tuesday	URO	URO	KNO	KNO	ORT	ORT
Wednesday	URO	URO	KNO	KNO	ORT	ORT
Thursday	URO	URO	KNO	KNO	BIJZ. T	BIJZ. T
Friday	URO	URO	KNO	KNO	URO	FLEX
Saturday						
Sunday						

Figure 6.2: A possible new distribution for general surgery (b)

Even weeks	OR 4		OR 5		OR 6	
	M	A	M	A	M	A
Monday	URO	URO	KNO	KNO	ORT	ORT
Tuesday	URO	URO	KNO	KNO	ORT	ORT
Wednesday	URO	URO	KNO	KNO	BIJZ. T	ORT
Thursday	URO	URO	KNO	KNO	BIJZ. T	ORT
Friday	URO	URO	KNO	KNO	FLEX	FLEX
Saturday						
Sunday						

Figure 6.3: A possible new distribution for general surgery (c)

Changing the OR-schedule is not just an administrative change: To change the content of an OR-block means that the roster of OR-assistants, physicians and anaesthesiologists change as well. Changing the roster of the specialists is especially difficult because every specialist may have more rosters to comply to. Specialists have to do outpatient consultations. They may operate for more than one specialty, work in other hospitals, teach, and go to conferences and so on.

It is also possible that a proposed swap is impossible because a certain operation needs facilities that are not available in other ORs.

6.2 Tactics vs. operations

Furthermore, it is important to realize that the proposed changes take place on the tactical level. That means that changing the MSS is not everyday business, but is only applied sometimes, and only because it is expected to yield positive results. In other words, the changes proposed on the tactical level translate in benefits on the operational level. Ideally the change in MSS will not decrease performance of the OR, but substantially improves the performance on the wards. This does imply that a tactical level of decision making is made available. Currently it seems that there is a big gap between decisions made at the strategic level (Board of Directors) and the operational level (ward managers, OR-planners, surgeons).

6.3 Involved stakeholders

Many people are directly and indirectly involved with the operating theatre and the nursing wards. To implement the changes a lot of people need to be included. We need to decide what part of decision-making should take place on which levels. It is important to realize which stakeholders are involved in changing the OR-schedule. The major stakeholders are listed:

- Hospital management
- RVE management
- Surgeons
- OR personnel
- OR planners
- Nurses
- Patients

6.4 A model for change

6.4.1 Step 1: Make people aware of the problem and the costs associated with this

There is a real problem at the moment. The problem has qualitative grounds and has been quantified as well. Nowadays it is crucial to use your resources as effectively as possible. In the current situation the variability is responsible for a difference of 16 beds. Staffing of these beds is costly, frustrating and difficult. If one does not account for the variability by staffing more or fewer nurses on specific days, then sometimes too much personnel is present and other times the workload gets too high.

If you do account for the variability it gets hard for personnel to get certain days off, since almost everybody will be required to work at days where a lot of patients are expected.

The associated benefits come in two forms. There are monetary benefits and non-monetary benefits. The non-monetary benefits associated with level workload are listed below:

- Effectively plan personnel
- Increased patient safety
- Lower risk of mortality
- Lower failure-to-rescue rates
- Lower risk of nurse burn-out
- Lower job dissatisfaction
- Better able to deal with the arrival of emergency patients

- Lower dependency on flex-workers
- Lower the amounts of patients on the 'wrong wards'

There are also monetary benefits:

6.4.2 Step 2: Make people aware of the reliability and the possibilities

By calculating the performance of different MSS configurations the performance of these can be calculated. The current workload can be accurately predicted. Consequently it is also possible to model different configurations and predict the new configuration's specific performance. If we were to check all configurations following the current MSS (i.e. all specific swaps) then we can select the best possible swaps. A list of beneficial swaps can be produced and given consideration.

6.4.3 Step 3: Generate a cooperative spirit

It is not easy to alter an MSS, but the benefits are significant. Some swaps listed might actually be impossible, some might be difficult to achieve, others may be possible. Note that different swaps might deal with different specialties altogether. If a decision needs to be made between two specialties it is important for everyone involved that cooperation is crucial. It is important for everybody involved to understand that these swaps can be beneficial for many reasons: costs decrease, planning gets easier, health care gets better, less capacity is required, etc. Better care is our goal here, and the esprit de corps needs to be present.

6.4.4 Step 4: Discuss different options

When analysing the MSS several swaps can be proposed. They are not all equally beneficial, but they can be close. In that case the alternatives can be considered carefully. Some swaps will be easier to implement, while others may be harder. When determining the first swap it is recommendable to select a swap that is agreeable. If then this swap shows significant results in the future tougher choices can be made.

6.4.5 Step 5: Make it an iterative process

The process as discussed in these recommendations can be done repeatedly. It need not take a lot of time before the changes become noticeable. As soon as a decision regarding which OR-blocks to swap is made, and the swap is actually implemented, it should take only a couple of weeks before the data shows positive results. Note that it may be safer to wait 6 weeks rather than 2 to be sure get more reliable results.

6.4.6 Step 6: Make a choice and wait for the results

Now that the alternative swaps have been evaluated and one of the options selected it is time to implement the change. A new MSS is introduced, sessions need to be assigned and patients can be scheduled as usual. In a few weeks the data should show better results. Hopefully the ward manager and the personnel will already experience the differences on their wards.

6.4.7 Step 7: Report the results back / show effectiveness

The number of elective surgery patients at any given time can be extracted from iZIS. The data of the time before the swap and after the swap can be compared. The model predicts what changes in the data and the data should thus show a similar pattern. At any rate, the results should be reported back to anyone involved in the process. If the anticipated changes occur the effectiveness of the model can be asserted.

6.4.8 Step 8: Apply next swap and repeat

When swapping two OR-days yields desirable results the model can be applied again to generate a new list of possible improvements. Again the alternatives need to be considered and a choice needs to be made. After implementation the performance at the wards should increase.

6.4.9 Step 9: Know when to stop iterating / the point of diminishing returns

Although we are dealing with an iterative process we have to realize that at some point we will hit the point of diminishing returns. At this moment the performance between before-and-after situations is not significant anymore. After several swaps it should be clear how much effort it takes to implement swaps, and the model can aid in predicting the improvements as a percentage of any given current situation.

7 Conclusions

At the start of this research it was pointed out that problems occur because of the variability of workload on the nursing wards. It the second chapter these concerns are quantified and it is concluded that elective surgery patients are the main source of variability at the nursing wards. It is possible to influence this patient stream and the way to do this is to make changes to the master surgery schedule.

To evaluate the performance of an MSS the model of Vanberkel is extended and used. The model requires three inputs: the distribution of the length of stay of patients for each specialty, the distribution of the amount of patients that are operated in an OR-block for each specialty, and the master surgery schedule. The model produces three outputs: the number of beds needed on the different days throughout a typical cycle, the number of admissions on each day of the cycle, and the number of discharges on each day of the cycle. The model is used to create a fourth output: the distribution of the patients to the individual wards.

To generate improvements of the master surgery schedule an algorithm has been written that analyses small changes to the current MSS and calculates their respective performances.

The research objective was as follows:

Create a decision tool that uses readily available data as input and is able to predict the effects of alterations in the master surgery schedule, so that the current master surgery schedule may be improved incrementally.

This decision tool is programmed in Matlab. The model contains the calculation steps of Vanberkel and reads an input sheet from Microsoft Excel with relevant data. The model includes heuristics that go through all the alternative MSSs, calculates the workload for each, and keeps score by supplying the user with a top five list of most effective swaps.

7.1 Research questions

How is the hospital organized and how does planning take place?

Currently the MSS is reconstructed every three months anticipating the demand. In practice the MSS is mostly a copy of the MSS of the last quartile.

What are indicators for the workload and how well is the hospital currently performing?

The workload at the nursing wards consists of three major factors: the amount of patient admissions on a day, the amount of discharges of patients on a day, and the amount of patients that are on the nursing wards in total.

How can we connect OR planning to ward planning in order to improve performance?

We use Vanberkel's approach to connect the OR-planning to the nursing wards. Vanberkel stresses that there is a direct relationship between these two. The model allows us to predict the workload at the nursing wards solely based on the master surgery schedule.

How can we evaluate the performance of a master surgery schedule?

To assess the performance of an MSS a measure for the workload has been constructed. The performance measure is a combination of: the sum over all days of the quadratic differences from the average number of beds required daily in a cycle, the sum over all days of the quadratic differences from the average number of daily discharges in a cycle, and the sum over all weekdays of the quadratic differences from the average number of daily admissions in a cycle.

How do we model the relationship and do we construct alternative OR-schedules?

We construct alternative MSS's by one-step-swapping OR-days. This means that we simply switch one specialty that takes place on a particular day, with another specialty on a different day. Using this logic we generate all possible new solutions for a total of about a thousand new configurations for each of the two cases.

Another intervention we tested is reducing the amounts of patients operated in an OR-block, while still fulfilling demand. This measure does not clearly lead to an improved performance.

How would the hospital perform after implementing the alternative solutions?

After about 4 iterations the workload measure is already reduced to less than 50 percent of the original workload. This means that the variability of workload has significantly been reduced after only a handful of changes.

What are the implications of the research in practice?

Because this method prescribes an iterative process it is advisable to carefully plan the execution of the implementations. It is possible to implement many changes at the same time, but it is reasonable to assume that a minor change first leads to a more receptive attitude from stakeholders involved. This way the improvements can be measured and monitored as soon as changes are implemented.

7.2 Relevance

Vanberkel's method to relate recovering surgical patient workload to the MSS has been applied in several hospitals in the Netherlands (e.g. Leiden University Medical Center, Nederlands Kanker Instituut) and it has shown good results. To the author's knowledge this is the first research that actively seeks the best possible one-step-swaps by going through all the alternative solutions and calculating their results. It is also the first research that uses Vanberkel's model to measure the workload on the nursing wards using these three measures. Another development is the prediction of the workload at the nursing ward level.

7.3 Limits and future directions

The current research is not applicable to an empty schedule. This is a drawback as it does not aid in constructing an OR-schedule for the new location. An initial MSS needs to be constructed through other means, and can be improved iteratively before it is actually implemented.

This research has not focused on reducing the length of stay of patients. The reason is that this intervention is the hardest to attain. Nevertheless, the effects of reducing the LOS can be investigated using this model and modifications to the model are hardly needed.

To take huge strides in attaining reductions in capacity (i.e. beds) other planning rules have to be tested. This research has focused on staying close to the current MSS, make small changes in order to improve performance. But if the goal is to drastically reduce beds, for example by planning patients in the weekends, it is necessary to either: plan heavier (with longer LOSs) elective patients at the end of the week, or plan more operations at the end of the week and less at the beginning of the week in general. Note: one is free to define new groups of patients, it is not necessary to group patients according to specialty or sub-specialty.

The current model does not calculate the number of beds needed in the reduction period. Reduction can take two forms: operate less patients in particular OR-blocks, or simply remove some OR-blocks and leave the distributions for the existing blocks intact. In the latter case it would be possible to predict the workload in the following way. Instead of calculating the steady state distribution of patients, just assume an MSS that is the size of a multiple of the current MSS. The MSS should be as long as the longest LOS and it should include the reduced schedules. Now repeat the model but omit Step III. The output that will be generated is the distribution of the number of beds required during a ‘cycle’. One should find that in the period where the reduced schedule is used, fewer beds are required to handle bed demand.

The model used in this research focuses on the workload at the nursing wards. It is advisable to also include other departments, such as IC and PACU. The procedure for including these departments is similar to calculating the distributions to the ward level, so if the necessary data (to determine the distributions of groups of patients to these departments) is available it is possible to include these departments.

It is important to distinguish between actual emergency patients and patients that require urgent or semi-urgent patients. The term emergency patients should only refer to patients that need surgery as soon as possible. If a patient needs an operation cannot be queued because he needs to be operated this week a more suitable term would be ‘urgent’. When these patient streams are properly defined they can be predicted with the model as well. In fact even non-surgical patient streams can be analysed as well.

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Appendix: Distribution to wards for the Sophia location

The results for the specific nursing wards are discussed for the Sophia location as well.

Table 5.1: Ward distributions for Sophia (a)

Day number	SZ|A1	SZ|A1P	SZ|A3	SZ|A5	SZ|A5C	SZ|A6
1	17	9	1	2	1	1
2	20	10	2	3	1	1
3	24	10	2	3	1	1
4	20	11	2	3	1	1
5	23	11	2	3	1	1
6	15	9	1	2	0	1
7	11	7	1	2	0	1
8	17	9	1	2	1	1
9	20	10	2	3	1	1
10	24	10	2	3	1	1
11	20	11	2	3	1	1
12	23	11	2	3	1	1
13	15	9	1	2	0	1
14	11	7	1	2	0	1
Performance	**10,16**	**1,56**	**0,16**	**0,16**	**0,00**	**0,00**
Average	**18,57**	**9,57**	**1,57**	**2,57**	**0,71**	**1,00**
Coeficient of variability	**0,55**	**0,16**	**0,10**	**0,06**	**0,00**	**0,00**

Table 5.2: Ward distributions for Sophia (b)

SZ|B1	SZ|B2	SZ|B3	SZ|B4	SZ|B5	SZ|B5G	SZ|B6
21	1	20	10	5	6	0
22	1	23	11	6	9	0
24	1	27	12	6	9	0
26	1	24	13	6	9	0
26	1	27	12	6	9	0
22	1	17	9	5	7	0
17	1	13	7	4	5	0
21	1	20	10	5	6	0
22	1	23	11	6	9	0
24	1	27	12	6	9	0
26	1	24	13	6	9	0
26	1	27	12	6	9	0
22	1	17	9	5	7	0
17	1	13	7	4	5	0
10,41	**0,00**	**10,96**	**2,04**	**0,41**	**2,44**	**0,00**
22,57	**1,00**	**21,57**	**10,57**	**5,43**	**7,71**	**0,00**
0,46	**0,00**	**0,51**	**0,19**	**0,08**	**0,32**	

Table 5.3: Ward distributions for Sophia (c)

SZ|D3	SZ|IC	SZ|K1B	SZ|K2	SZ|K3	Totals
0	0	1	3	2	
0	0	1	4	3	
1	0	1	4	3	
0	0	1	4	2	
1	0	1	4	3	
0	0	0	3	2	
0	0	0	2	2	
0	0	1	3	2	
0	0	1	4	3	
1	0	1	4	3	
0	0	1	4	2	
1	0	1	4	3	

0	0	0	3	2	
0	0	0	2	2	
0,24	**0,00**	**0,00**	**0,41**	**0,24**	**39,19**
0,29	**0,00**	**0,71**	**3,43**	**2,43**	**109,71**
0,84		**0,00**	**0,12**	**0,10**	**3,49**

The current distributions to the wards are displayed in Figures 5.19-21 After using the heuristic the distributions are like they are displayed in Tables 5.23-25. The sum of the coefficients of variability has increased from 3.49 to 3.52. In general the performance after the heuristic is applied is about the same as it is in the current situation. Some wards perform better and others do not.

Table 5.4: Ward distributions for Sophia after seven iterations (a)

Day number	SZ|A1	SZ|A1P	SZ|A3	SZ|A5	SZ|A5C	SZ|A6
1	22	9	1	2	1	1
2	22	9	2	3	1	1
3	22	10	2	3	1	1
4	21	11	2	3	1	1
5	20	11	2	3	1	1
6	13	9	1	2	0	1
7	11	8	1	2	0	1
8	22	9	1	2	1	1
9	22	9	2	3	1	1
10	23	10	2	3	1	1
11	21	11	2	3	1	1
12	19	11	1	3	1	1
13	13	9	1	2	0	1
14	11	8	1	2	0	1
Performance	**2,24**	**1,05**	**0,21**	**0,16**	**0,00**	**0,00**
Average	**18,71**	**9,57**	**1,50**	**2,57**	**0,71**	**1,00**
Coeficient of variability	**0,12**	**0,11**	**0,14**	**0,06**	**0,00**	**0,00**

Table 5.5: Ward distributions for Sophia after seven iterations (b)

SZ|B1	SZ|B2	SZ|B3	SZ|B4	SZ|B5	SZ|B5G	SZ|B6
19	1	26	10	5	6	0
18	1	24	11	6	9	0
19	1	26	12	6	9	0
23	1	24	13	7	9	0
31	1	22	11	6	9	0
27	1	16	8	4	7	0
23	1	13	7	4	5	0
18	1	26	10	5	6	0
18	1	24	11	6	9	0
15	1	27	13	7	9	0
18	1	25	14	7	9	0
31	1	21	10	5	9	0
29	1	15	8	4	7	0
25	1	13	7	4	5	0
33,40	**0,00**	**4,94**	**2,10**	**0,60**	**2,44**	**0,00**
22,43	**1,00**	**21,57**	**10,36**	**5,43**	**7,71**	**0,00**
1,49	**0,00**	**0,23**	**0,20**	**0,11**	**0,32**	

Table 5.6: Ward distributions for Sophia after seven iterations (c)

SZ|D3	SZ|IC	SZ|K1B	SZ|K2	SZ|K3	Totals
1	0	1	4	3	
1	0	1	4	3	
1	0	1	4	3	
0	0	1	4	2	
0	0	1	4	2	

0	0	0	3	2	
0	0	0	2	2	
1	0	1	4	3	
1	0	1	4	3	
1	0	1	4	3	
0	0	1	4	3	
0	0	1	3	2	
0	0	0	3	2	
0	0	0	2	2	
0,24	**0,00**	**0,00**	**0,34**	**0,21**	**47,93**
0,43	**0,00**	**0,71**	**3,50**	**2,50**	**109,71**
0,56		**0,00**	**0,10**	**0,08**	**3,52**

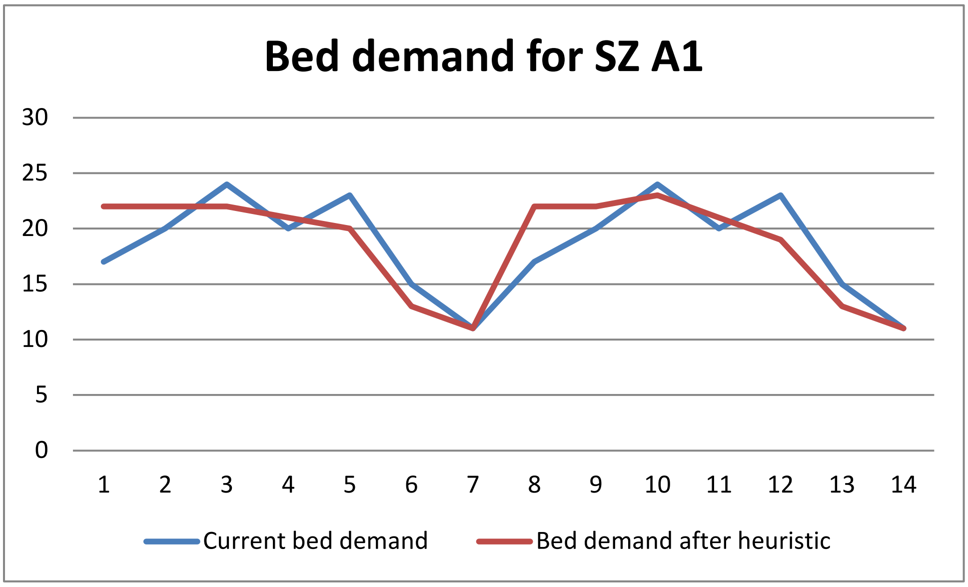

Figure 7.1: Bed demand for SZ ward A1 now versus after implementation of the heuristic

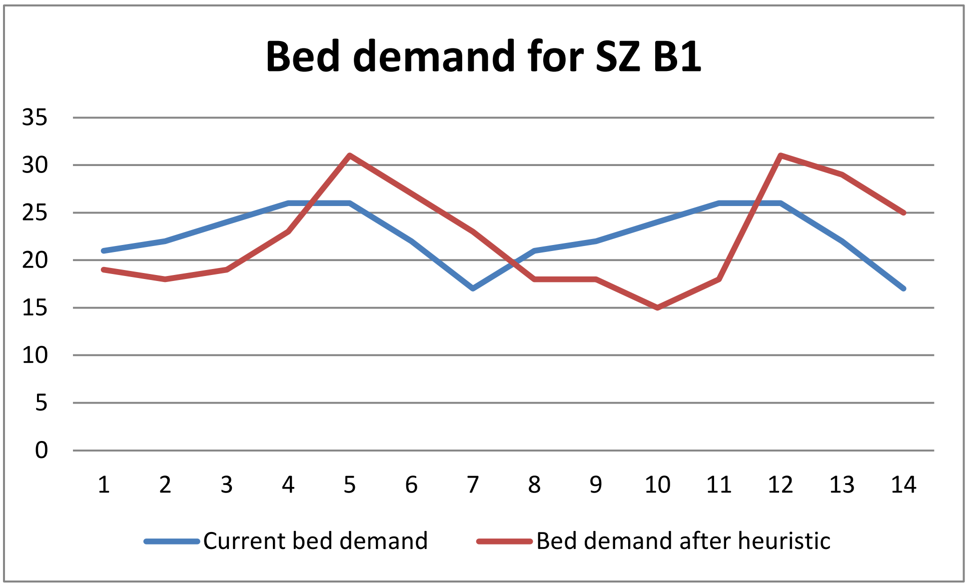

Figure 7.2: Bed demand for SZ ward A1 now versus after implementation of the heuristic