UNIVERSITY OF TWENTE.

Breaking down the walls between OR and ward

How to balance ward workload, without harming OR utilization

Author: Ronald Vollebregt

Supervisors: Ir. E. Bredenhoff (Gelre)
Dr.Ir. E.W. Hans (UT)
Dr. Ir. I.M.H. Vliegen (UT)

Date: February 2, 2011

Management Summary

This study is performed in the period of May 2010 to January 2011 at Gelre Apeldoorn on request of the manager patient logistics. Goal of this study was *“To investigate recurring OR planning policies that can help stabilize ward workload, and lead to an acceptable level of OR utilization for Gelre Apeldoorn”.*

Background

Gelre Apeldoorn is a Medical Teaching Hospital and one of the larger regional hospitals in the Netherlands. Due to increased spending in healthcare, it becomes increasingly important to reduce costs of healthcare and to optimize processes in hospitals.

Gelre Apeldoorn uses the Operating Room (OR) department efficiently, but problems occur when multiple departments need to cooperate. Workload on nursing wards for example, differs among the days of the week and surgeries often have to wait for the availability of X-Ray equipment.

Research approach

First, we analyzed surgical data and interviewed the stakeholders in order to describe the current situation. In 2008, utilization of the OR department was 84 percent, which is high compared to other OR departments in the Netherlands. In 2008, ward utilization for the surgical specialties during working days was 98 percent, measured in nursing days. Utilization is this high because we measure nursing days and we included the day-care ward, where during a day multiple patients use the same bed after each other.

Second, we developed a heuristic to distinguish surgery types, which are groups of medically homogeneous surgical procedures, based on their logistic characteristics. These surgery types are input for the simulation program “OR-manager”, which we use to evaluate the performance of the planning policies we investigate.

Finally, we test the performance of three versions of a Master Surgical Schedule (MSS). An MSS optimized on standard deviation of OR utilization, on standard deviation of ward utilization and on standard deviation of admissions and discharges. We tested these interventions with 2008 data and with 2011 data with the current (fixed) allocation of specialties to ORs and with an optimized allocation of specialties to ORs.

Results

- An MSS optimized on the standard deviation of daily ward utilization and with optimized (unrestricted) allocation of specialties to ORs saves 13 beds (6% reduction compared to the current planning policy and restricted allocation) during the peak utilization of the ward. Also, workload at the ward levels. The standard deviation of utilization declines with 23% and the standard deviation of the number of admittance and discharges declines with 47%. In order to reach these improvements, 12 changes in the schedule are necessary.
- An MSS optimized on the standard deviation of ward utilization and with fixed allocation of specialties to ORs saves 8 beds. The standard deviation of ward utilization declines with 18% and the standard deviation of the number of admittance and discharges declines with 35%.

- An extra advantage of introducing an MSS, is that it creates the possibility for patients to plan their surgery directly at the outpatient ward. This means an increase in customer satisfaction level for the patient.

Conclusions

The best performing recurring OR planning policy we investigated is an MSS optimized on daily ward utilization and with optimized allocation of specialties to ORs. It stabilizes the workload at the wards, without deteriorating the performance of the OR department.

Recommendations

- Implement an MSS optimized on the standard deviation of daily ward utilization with the current (fixed) allocation of specialties to ORs. This makes implementation easier, because it leaves the schedules of specialist unchanged.
- Incorporate the employees who need to work with the planning in all stages. It is helpful that they see the goals and the necessity of implementing an MSS. From that moment on, it is possible to use their knowledge of the surgeries and preferences of the specialist, to create the best possible surgery types and schedule.
- Investigate which swaps of OR days have the highest impact on the performance of ORs and wards and investigate the possibilities to incorporate these swaps in new OR schedules.
- Further research should involve the influence of urgent and emergency surgeries on the performance of the MSS, improving optimization heuristics and the inclusion of outpatient wards.

Management Samenvatting (Dutch)

Dit onderzoek werd op verzoek van de manager patiëntenlogistiek tussen mei 2010 en januari 2011 uitgevoerd bij Gelre ziekenhuizen te Apeldoorn. Doel van dit onderzoek is: *"Onderzoek of een cyclische planningsmethode in Gelre Apeldoorn bij kan dragen aan het stabiliseren van de werkdruk op de verpleegafdelingen, waarbij de bezettingsgraad op de OK afdeling gelijk blijft."*

Achtergrond

Gelre Apeldoorn is een topklinisch ziekenhuis en één van de grootste regionale ziekenhuizen in Nederland. Door de stijgende uitgaven aan gezondheidszorg en veranderingen in de financiering, wordt het steeds belangrijker processen te optimaliseren.

In Gelre Apeldoorn wordt de OK-afdeling efficiënt benut. Er ontstaan echter problemen wanneer meerdere afdelingen samen moeten werken. Voornamelijk op de verpleegafdeling wordt dit zichtbaar in de werkdruk op verschillende dagen van de week.

Aanpak

Als eerste is de huidige situatie onderzocht door middel van data-analyse en interviews. In 2008 was de bezettingsgraad van de OK afdeling 84%. Dit is hoog in vergelijking met andere OK afdelingen in Nederland. De bezettingsgraad voor (heelkundige) verpleegafdelingen, gemeten in verpleegdagen, was 98% in 2008. Dit is onder andere zo hoog omdat de dagverpleging wordt meegenomen, waar het regelmatig voorkomt dat twee patiënten (na elkaar) gebruik maken van hetzelfde bed.

Vervolgens zijn met het simulatieprogramma "OR-manager" verschillende versies van een Master Surgical Schedule (MSS) getest. Voordat we met de simulaties kunnen starten, zijn operatietypen onderscheiden. Hiervoor is een heuristiek ontwikkeld op basis van diverse bestaande methoden. Deze heuristiek combineert operaties in operatietypen gebaseerd op logistieke kenmerken.

Uiteindelijk zijn drie versies van een MSS getest: (1)een MSS geoptimaliseerd op OK bezettingsgraad; (2) een MSS geoptimaliseerd op de bezettingsgraad van de verpleegafdeling; en (3) een MSS geoptimaliseerd op het aantal opnames en ontslagen. Deze drie versies zijn getest met data van 2008 en 2011, onder de huidige toewijzing van specialismen naar OK dagen en met een geoptimaliseerde toewijzing van OK dagen.

Resultaten

- Een MSS geoptimaliseerd op de standaard afwijking van de bezettingsgraad van de verpleegafdeling onder een vrije toewijzing van specialismen naar OK dagen, reduceert de piek bezetting met 13 bedden (6% ten opzichte van de huidige planningsmethode en vaste allocatie). Daarnaast stabiliseert de werkdruk op de verpleegafdelingen. De standaard afwijking van de bezetting van de verpleegafdelingen daalt met 23% en de standaardafwijking van het aantal opnames en ontslagen daalt met 47%. Om deze verbeteringen te behalen, zijn 12 wijzigingen nodig in het huidige rooster (2011).
- Een MSS geoptimaliseerd op de standaard afwijking van de bezettingsgraad van de verpleegafdeling onder de huidige (vaste) toewijzing van specialismen naar OK dagen, bespaart 8 bedden. De standaard afwijking van de bezetting van de verpleegafdelingen daalt

met 18% en de standaard afwijking van de bezetting van het aantal opnames en ontslagen daalt met 35%.

- Een extra voordeel van de introductie van een MSS is de mogelijkheid voor patiënten om hun operatie al op de polikliniek in te plannen. Dit zorgt voor een verbetering van de patiënttevredenheid.

Conclusie

De best presterende cyclische OK planningsmethode die wij hebben onderzocht is een MSS geoptimaliseerd op de dagelijkse bezetting van de verpleegafdeling, met een geoptimaliseerde allocatie van specialismen naar OK dagen. Deze planningsmethode stabiliseert de werkdruk op de verpleegafdelingen zonder af te doen aan de bezetting van de OK afdeling.

Aanbevelingen

- Implementeer een MSS, geoptimaliseerd op de standaard afwijking van de bezetting van de verpleegafdeling onder de huidige toewijzing van specialismen naar OK dagen. Hierdoor wordt de implementatie vereenvoudigd omdat het niet nodig is om de roosters van de specialisten te veranderen.
- Betrek de betrokken medewerkers bij alle stadia van de implementatie. Het is belangrijk dat zij de doelen kennen en het belang van het implementeren van het MSS zien. Wanneer zij achter de implementatie staan, is het mogelijk om hun kennis van de operatietypen en voorkeuren van specialisten in te zetten om een zo goed mogelijke planning te krijgen.
- In de optimale allocatie van specialismen naar OK dagen zijn 12 veranderingen doorgevoerd. Onderzoek welke veranderingen in het rooster het positiefste effect hebben en probeer dit in de nieuwe OK roosters toe te passen.
- Doe vervolgonderzoek naar de invloed van urgente en spoedoperaties op de prestaties van het MSS, verbeteringen van de optimalisatieheuristiek and het meeplannen van de poliklinieken.

Preface

When I chose my master specialization a few years ago, it was clear that I definitely wouldn't choose the 'Healthcare and Logistics' specialization. A year and two courses on healthcare logistics later, I was not so sure anymore. These courses convinced me that healthcare logistics is a difficult, but also interesting area of expertise and therefore I decided to search for a graduation assignment in *Health Care Logistics*.

During my time in Apeldoorn I discovered that I enjoyed working with these problems. My biggest problem was to stay focused on my research goal. It was difficult not to include interesting sidesteps, but at the same time, this was a good lesson.

During my time at Gelre Apeldoorn, I lived in the 'zusterflat' near the former Juliana hospital. Although it was an old building which often suffered from maintenance issues, I really enjoyed living with the nursing and medical students. It gave me the opportunity to discuss many healthcare logistics issues with an open minded and experienced audience. It gave me new insights and I hope that I have created some awareness for the importance of logistics in healthcare. Also, I enjoyed the gossip about the hospital, patients and physicians and the regular parties. Thanks to all, you made it a great time!

In the hospital it was great to have nice colleagues, Annelies, Truus and Nick, thanks for the time we enjoyed lunches, coffee breaks and discussions together. Truus, also thanks for all the data you retrieved for me and the introduction to the hospital. Also, thanks to all other colleagues who helped me with data, interviews and tours through the hospital.

I also like to thank Ingrid, for the feedback on my report. Although you just started working at this university and this is a new field of expertise for you, I found your comments on my report very useful!

Last, a special thanks for Erwin and Eelco. You both helped me a lot during this project. Erwin, I enjoyed the short programming sessions, which often lasted the whole afternoon and sometime even past dinner! It was great that you did help me this much. And Eelco, thank you! I enjoyed the discussions about the project, about logistics and about the hospital. You promised at the start of the project to help me with writing in English. I'm sure you regret it by now, but your comments were very helpful while improving this report. I hope it suffices your expectations and thanks again!

Ronald Vollebregt

Apeldoorn – January 2010

Contact information:
E-mail: rvollebregt@gmail.com
Tel: 06 50 993 973

Contents

1 Introduction

Gelre Apeldoorn wants to increase productivity in the upcoming years. Currently, problems occur during peak usage of the wards. Therefore, more capacity is necessary, especially at the wards. This study evaluates methods to level the use of current capacity at the wards and ORs, without harming utilization. Our focus is on recurring planning methods, which can contribute to the service level for patients.

In the last decades, interest for health care logistics has increased in response to the increasing percentage of the GDP spent on health care. Since 2007, expenditures on health care in the Netherlands grew annually between 12 and 15 percent to a total spending in 2010 of € 3,300 (Centraal Bureau voor de Statistiek, 2010). Government regulations force hospitals to cut cost, while the market forces hospitals to deliver high quality care and service.

The Operating Room department is one of the largest cost and revenue centers in a hospital. An Operating Room (OR) is an expensive resource operated by highly skilled labor. Also, the OR department is linked to many other departments, like outpatient departments, wards, radiology, and sterilization. This interdependency makes its influence on the total hospital performance high and makes efficient OR department planning difficult. Therefore the OR department is a logical starting point to improve processes and cut costs. In the literature, various planning methodologies are proposed. Most research, however, focuses on a single department and ignores (part of) the complexity (Boer & Beuzekom, 2009; Cardoen, Demeulemeester & Beliën, 2010).

This chapter introduces Gelre Hospitals and presents an outline of this report. Section 1.1 describes the history of Gelre hospitals. Section 1.2 describes the motivation and goal of this study. Section 1.3 formulates the research questions and presents an outline of this report.

1.1 Gelre Hospitals: Gelre Apeldoorn

Gelre Hospitals is a member of the Association of Tertiary Medical Teaching Hospitals (in Dutch: Stichting Topklinische Ziekenhuizen: STZ). The hospitals in this association deliver a level of care more specialized than in general hospitals, but less specialized than in Academic hospitals. The association and its members aim to stimulate education, high quality patient care, and applied scientific research (Gelre Ziekenhuizen, 2010).

Gelre Hospitals is one of the larger regional hospitals in the Netherlands with over 3,300 employees (2.300 FTEs), 180 medical specialists, and a service area population of 280,000 inhabitants. It was founded in October 1999, as a result of the merger of the Zutphen based regional hospital 'the Spittaal' and the Apeldoorn based regional hospital 'Hospital center Apeldoorn'. This study focuses on Gelre Apeldoorn.

Gelre Apeldoorn has ten Operating Rooms (ORs, or in literature also referred to, as Operating Theatre), 345 inpatient beds, and thirteen different specialties. Inpatient beds are divided among eleven wards; eight wards of 33 beds, one of 17 beds, one of 16 beds, and one of 36 beds. Most inpatient beds are allocated to specific specialties. Often, a ward combines several specialties, while some of the larger specialties are divided over more than one ward. Gelre Apeldoorn has two day care wards, with a total of 52 outpatient beds that are used for General Surgery and Spectroscopy. The hospital also has ten ICU beds.

1.2 Problem

Subsection 1.2.1 describes the motivation and the goal of this study. Subsequently, Subsection 1.2.2 presents a theoretical framework used in the literature and positions our study in this framework.

1.2.1 Motivation and goal

Gelre Apeldoorn believes that their ward performance is not optimal. The hospital experiences a high variation in ward-workload, measured by bed occupation, admissions and discharges of different wards during a period of time (interview with Brummelhuis, 2010, and Groters-Kremer, 2010). These high variations hamper planning the right amount of personnel and thus ensure that enough beds are available. In 2008, 56 percent of all admissions involved a visit to the OR department. Gelre Apeldoorn wants to reduce the variety in patients planned for surgery, in order to reduce variety and ease workload of the wards.

Gelre Apeldoorn prefers a cyclic block/slot planning that offers patients the opportunity to make an appointment for surgery directly after examination at the outpatient department. As private hospitals have become more accepted by patients and health care insurance companies, traditional hospitals like Gelre Apeldoorn experience increasing competition, especially on customer service. Gelre Apeldoorn wants to improve their service by offering patients more influence on the planning.

Another advantage of reducing variety is its influence on OR utilization. High variety in the workload on wards can deteriorate OR utilization. For instance, when there are insufficient beds surgeries are cancelled and OR capacity is lost. Currently, utilization of the OR department of Gelre Apeldoorn is 81% (March 2009). This is high compared to other OR departments in the Netherlands (Plexus, 2009).

Therefore, the goal in this study is: "*To investigate recurring OR planning policies that help stabilize ward workload, and lead to an acceptable level of OR utilization for Gelre Apeldoorn.*"

1.2.2 Theoretical framework

Hans et al. (2010) developed a theoretical framework for hospital planning and control (see Figure 1.1). This framework is a graphical representation of the hospital's multilevel and multidisciplinary environment. The vertical axis describes hospital planning on Strategic, Tactical, Offline operational, and Online operational levels. The horizontal axis describes four managerial areas: Medical, Resource Capacity, Materials, and Financial.

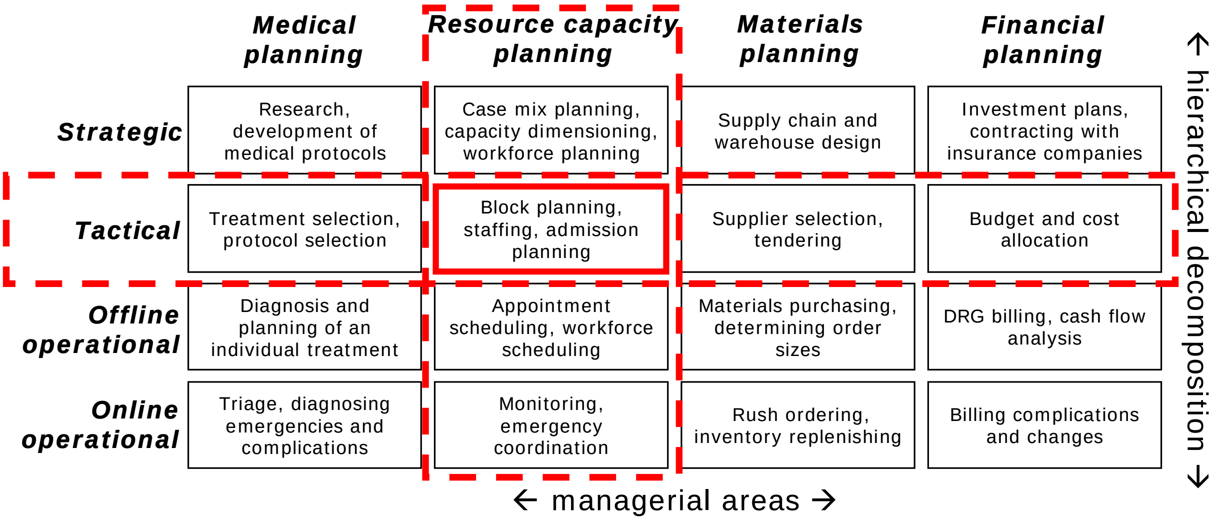


Figure 1.1: Framework for hospital planning and control (Hans et al., 2010)

The first level in resource capacity planning is *Strategic Planning.* Strategic planning is performed by the hospital board. The board determines the case mix, dimensions capacity, and agrees with insurance companies about production targets (e.g. the number of admissions for the different specialties).

The second level is *Tactical Planning*. Tactical planning translates production targets into OR time. For each specialty, sufficient OR time is reserved in the yearly OR schedule in order to realize production targets.

The third level is *Offline Operational Planning*. Offline operational planning considers the elective surgeries, planned three weeks in advanced during available OR time.

The last level is *Online Operational planning*. Online operational planning considers the ad hoc changes made in the schedule of today and tomorrow in order to cope with emergency patients, cancelled patients and potential overtime.

Our study is a *Resource capacity planning* problem on a *tactical level,* as highlighted in Figure 1.1.

1.3 Research Questions and approach

To attain the goal of this study, we formulate several research questions. Each paragraph in this subsection discusses one research question and its position in the research approach.

RQ 1: What is proposed in the literature for planning of Operating Rooms?

In Chapter 2, we review the literature on planning policies for OR departments. First, we give an overview of the literature on planning policies. Second, we focus on policies that include wards and are cyclical. Third, we give special attention to the construction of surgery types, necessary to construct a cyclic planning.

RQ 2: Which performance indicators express performance of the wards and OR department?

In order to evaluate different planning policies, performance indicators are necessary. In Chapter 2, we discuss measures of OR and ward performance. We select a set of measures for the evaluation in this study. The selected measures are described in more detail.

RQ 3: What is the current situation at Gelre Apeldoorn?

To gain insights in the current situation we held interviews with stakeholders and analyzed historical data. Chapter 3 describes this situation. First, we discuss the system characteristics (system), like size and type of patients. Second, we discuss the current planning policies (control). Third, we discuss the current performance.

RQ 4: How to evaluate different planning policies?

To test planning policies, we use a simulation study. Section 4.1 describes the simulation model, the assumptions underlying the model and how to use the simulation model to evaluate policies.

RQ 5: How to construct surgery types for planning purposes?

Because we want to test a cyclic schedule, we need surgery types for planning purposes. A surgery type is a group of surgeries that is performed with the same resources (Surgeon, OR, ward and X-Ray) and has comparable logistic characteristics. Section 4.2 describes our heuristic to construct surgery types, which is based on existing grouping heuristics.

RQ 6: Is the simulation model valid?

To test the validity of the simulation model, we discussed the model with Gelre hospital planning experts. Furthermore, we compared the performance of the current situation with the results of the simulation. Section 4.3 describes this validation.

RQ 7: Which planning policies should be evaluated?

Section 4.4 describes the different planning policies we evaluated. The planning policies were selected based on the goal of this study and the possibilities of the simulation software. We also evaluate the division of the allocated OR capacity per period. We compare the current (fixed) allocation with an optimized (free) allocation. We did not resize the allocated capacity per specialty.

RQ 8: What is the performance of the proposed planning policies?

We compare the results from the simulations with the current performance, and we explain why performance improves or deteriorates. Chapter 5 presents the results of the simulations and the sensitivity analyses.

Chapter 6 is dedicated to the conclusions and recommendations. We discuss our recommendations for implementations and for further research.

2 OR planning and performance measurement

This chapter gives a theoretical background of OR planning. Section 2.1 provides a short overview of the literature on OR planning. Section 2.2 elaborates in more detail on cyclic schedules and variety in surgery duration. Section 2.3 gives a short summary of performance indicators mentioned in the literature and explains the performance indicators we have chosen for this study.

2.1 Introduction to OR planning

The Operating Room Department is of high interest for hospital management, as it is a hospital's largest cost and revenue centre. The literature shows many studies that focus on improving OR utilization. For an extensive literature review we refer to Cardoen et al. (2010). Only recently, researchers focus more on an integrated approach, which includes preceding and subsequent departments in the optimization process (Cardoen et al., 2010). Due to conflicting priorities, preferences, and scarce resources, like OR-staff, it is difficult to manage the OR department (Boer & Beuzekom, 2009).

Cardoen et al. (2010) performed a literature study on operations research approaches for Operating Room planning. They summarized 124 articles and constructed a two-dimensional schedule to classify literature on the level (discipline, surgeon, patient) and type (date, time, room, capacity) of decision. Apparent is the discussion about centralized and decentralized planning. In a centralized planned OR, the planning is made for all specialties together, which leads to better integration of different processes and higher robustness of the schedule. At a decentralized planned OR, workload shifts to the online operational control with specialists all planning individually, which harms the integration of different process and the robustness of the schedule. The advantage of decentralized planning, however, is that less data is necessary to generate a schedule (van Oostrum, Bredenhoff & Hans, 2008).

Another literature study is presented by Jun et al. (1999), who conclude that there is "a void in the literature focusing on complex integrated systems". Ten years later, Vanberkel et al. (2009) conclude that researchers still often confine themselves to a single department and overlook some of the complexity of health care. Since OR planning is a main objective in literature, many types of schedules are developed.

2.2 Cyclic surgical planning

A Master Surgery Schedule (MSS) is often mentioned in the OR scheduling literature. An MSS is an extension of a surgical schedule, which is already available in all hospitals. In literature there are different definitions of an MSS. Van Oostrum et al. (2008 p. 2) describe an MSS as an approach which "cyclically executes a master schedule of surgery types, which contains slots for surgery types that recur at least once every cycle". Beliën and Demeulemeester (2007, p.1186) use a more general definition in which OR time is reserved for a surgeon instead of for a surgery type. Unfortunately, there is no consensus between scientists about the use of definitions (Cardoen et al., 2010), we will use the definition of Van Oostrum et al. (2008). In the framework for hospital planning (Hans et al., 2010), the MSS is positioned on the tactical level.

Van Oostrum et al. (2008) constructed an MSS through a linear program which minimizes ward variance and maximizes OR utilization. The LP is solved using column generation and generates a solution within reasonable time.

After the construction of an MSS (the tactical level), the next level is operational planning. The first phase in operational planning is offline planning, where the reserved blocks are filled with elective patients for the specific specialty. There are multiple ways of planning within the blocks, ranging from simple (longest duration) to more advanced planning algorithms (regret-based).

The second phase in operational planning is the online planning, which is the daily planning and rescheduling of surgeries because of emergency surgeries, or variances in surgery duration.

2.2.1 Construction of surgery types

Before an MSS can be generated, the patients need to be grouped in such way that each group contains sufficient surgeries to plan regularly. The groups should have a small internal variance and a large variance among the groups. The groups are the basis for the performance of the scheduling policy and therefore important. When the groups are too small, it is not possible to plan them cyclically, but when the groups are too big, variance within the group will increase and deteriorates performance. Furthermore, groups should be stable during the year, which means that the group suffers limited seasonality.

Maruster et al. (2002) suggest a grouping policy with classification rules, based on the software package SPSS. They suggest to use the SPSS ´two-step' clustering method to form clusters. This method finds the optimal number of clusters, which have a minimal internal variance and a maximum variance between the groups, based on multiple variables. Drawback is that it is not completely clear how the trade off is made between many small groups with low variances and a few big groups with higher variances.

Bagirov and Churilov (2003) suggest a non-smooth and non-convex optimization. Based on the Length Of Stay (LOS) they divide the dataset in different groups, which are used in a subsequent stage to create groups of a minimum size. Drawback is that this solution is complicated, demands a lot of arbitrary decisions by the researcher, and is only capable of taking one variable into account.

El-Darzi et al. (2009) discuss five clustering techniques in their article: Diagnosis Based Grouping, Resource Consumption Based Grouping, Patient Pathway Grouping, Multi-stage Grouping, and Clustering Based Grouping. Most of these techniques are too specific, or do not take into account the logistic characteristics. The authors finally test three clustering techniques and conclude that best is to use a Gaussian Mixture Model (GMM) to construct clusters that cover the patients and reduce variability. A drawback is that these clusters are only based on the length of stay and El-Darzi et al. (2009) only tested this model on specific type of patients (stroke patients).

Van Oostrum et al. (2008) suggest a clustering policy that starts with surgery types. In the first iteration each surgery type is a separate group, and in each iteration two surgery types which yields the highest savings, are combined into one new surgery type until one surgery type is left. The savings are calculated based on the reduction in Error Sum of Squares (ESS) of the LOS and duration and the in- or decrease of the dummy volume. The dummy volume is the number surgeries that not fit in a block[1]. Finally, the iteration with the best tradeoff between the dummy volume and ESS is chosen. Some drawbacks of this method are that the dummy volume has a high influence on the groups and that the administrative surgery types, used as a starting point, are often not recognizable to planners.

2.2.2 Dealing with uncertainty

Planning in hospitals is difficult because several stakeholders are involved: surgeons, nurses, OR staff, and patients. All have their own preferences and schedules. Therefore, there is a lot of uncertainty for the hospital about duration of the surgery, LOS, and arrival patterns. In this subsection we discuss a general method to deal with uncertainty caused by the patients (e.g. duration) and emergency surgeries, which is also used at Gelre Apeldoorn or in this study.

Uncertainty in duration

A possibility to deal with uncertainty is the introduction of slack (Hans, Wullink, van Houdenhoven & Kazemier, 2008). The amount of slack can be reduced with the portfolio effect and Hans et al. (2008) suggest regret-based sampling as the most efficient method to construct a robust schedule, which suffers least of uncertainty.

Deal with urgent and emergency surgeries

Emergency cases arrive randomly, at all possible moments. One way to cover emergencies is to reserve an OR solely for emergency surgeries. However, often this OR is empty and it also happens that more than one emergency patient needs surgery. It is difficult to plan emergency surgeries, due to their nature, but from historic data it is possible to collect data about their frequency and the time necessary to perform the emergency surgeries. When this data is known, it is possible to reserve OR time, which can be used to perform the emergency surgeries quickly without harming the original OR schedule (van Oostrum, van Houdenhoven, et al., 2008).

2.3 Performance measurement

In order to compare different interventions with each other and with the current situation, we need to choose performance indicators. Subsection 2.3.1 explains the performance indicators named in the literature and indicates the ones we have chosen for our study. Subsection 2.3.2 explains the indicators in more detail.

2.3.1 OR and ward performance measures

In the literature, the following performance indicators are proposed to measure OR and ward performance: waiting time, throughput, utilization, leveling, makespan, patient deferrals, financial measures and preferences. (Beliën & Demeulemeester, 2007; Beliën, Demeulemeester & Cardoen, 2009; Cardoen et al., 2010). We selected nine performance indicators for this study: OR utilization; OR overtime; leveling of ORs; ward utilization; leveling of Bed count of the wards; leveling admissions

[1] For example: when on average 6.2 surgeries per cycle are performed, than the size of the dummy volume is the multiplicity of 0.2 * the number of cycles.

and discharges of the wards; leveling of x-ray usage; patient deferrals; and patient refusals. The next subsection explains the indicators and the reason why we have chosen them.

2.3.2 Selected key performance indicators in this study

In this subsection the performance indicators are explained. Per performance indicator we explain why we consider it to be relevant and how the indicator is calculated.

KPI 1: OR utilization

OR utilization is included as KPI because it quantifies the efficiency of the OR department. Utilization is especially important for the OR department, because the OR is the most expensive resource.

OR utilization is defined as the fraction of time the OR is used and Equation 2.1 shows how it is calculated. Utilization is the sum of time that an OR was in use during session time divided by the total of the session durations. All surgery types (also emergency surgeries) are included. When a surgery is (partly) performed outside regular opening hours, only the part performed during opening hours is included in the utilization. We evaluate on the normal opening hours. This means that when two specialties use the same OR and the first specialty generates overtime, the second specialty starts later and gets punished because there is less utilized time.

Equation 2.1: Utilization of the OR

$$U_s^{OR} = \frac{\sum_p \left(T_{p,s}^{depart} - T_{p,s}^{arrival}\right)}{D_s} \times 100\% - O_s$$

$U_s^{OR} = Utilization\ of\ the\ OR\ time\ of\ specialty\ s$

$T_{p,s}^{depart} = Time\ patient\ p\ of\ specialty\ s\ leaves\ the\ OR$

$T_{p,s}^{arrival} = Time\ patient\ p\ of\ specialty\ s\ arrives\ at\ the\ OR$

$D_s = Available\ session\ time\ for\ specialty\ s$

$O_s = Percentage\ of\ overtime\ for\ specialty\ s$

A risk of using this measure is that it is possible to influence the results and create a high utilization, but low efficiency (e.g. the surgeon records more time than necessary). Nevertheless, we use this measure because a benchmark study of OR departments in the Netherlands (Plexus, 2009), showed surgery durations in Apeldoorn were not different from other OR departments in the Netherlands. We therefore assume that the current surgery durations resemble realistic surgery durations.

KPI 2: OR overtime

Overtime is included as KPI because it shows how often the OR is in use outside its opening hours. This is important because overtime is expensive due to the required high skilled labor. Overtime can also be dangerous, because OR overtime means longer working hours for personnel, which means a higher risk for making mistakes, because of fatigue.

Overtime is defined as the percentage of time used outside regular opening hours to finish surgeries that started during normal opening hours, divided by the total regular time. A (n emergency) surgery performed completely outside opening hours is not considered to be overtime, because this surgery is performed by a special team, which is available for emergency surgeries outside opening hours.

Equation 2.2: OR overtime

$$O_s = \frac{\sum_P \left(T_{p,s}^{depart} - T_s^{session\ ends}\right)^+}{D_s} \times 100\%$$

$O_s = Percentage\ of\ overtime\ for\ specialty\ s$

$T_{p,s}^{depart} = Time\ patient\ p\ of\ specialty\ s\ leaves\ the\ OR$

$T_s^{session\ ends} = Normal\ ending\ time\ of\ the\ session\ for\ specialty\ s$

$D_s = Available\ session\ time\ for\ specialty\ s$

KPI 3: Leveling OR duration

In an ideal situation, there is no overtime and no unused OR time at the end of the day (waste of capacity). We call this measure the leveling of OR duration. When OR leveling is high, workload differs, which is undesired by OR personnel.

Leveling of OR duration is calculated by dividing the sum of the absolute differences of the actual end time and the time the session ends, by the total available OR time. Equation 2.3 shows the calculation for this performance indicator. The best possible value is for leveling is zero.

Equation 2.3: OR leveling

$$L_O = \frac{\sum_d \left|T_{d,o}^{finished} - T_{d,o}^{session\ ends}\right|}{D_o} \times 100\%$$

$L_O = Degree\ of\ leveling\ for\ Operating\ Room\ O$

$T_{d,o}^{finished} = Time\ OR\ o\ is\ finished\ on\ day\ d$

$T_{d,0}^{session\ ends} = Time\ the\ regular\ time\ ends\ for\ OR\ o\ on\ day\ d$

$D_o = Total\ available\ OR\ time$

KPI 4: Leveling of usage of radiology equipment

There are three X-Ray devices in use. Two are reserved for use in the OR department and one is for use in other parts of the hospital. Most important is to prevent situations where three devices are in use simultaneously at the OR department, because that results in capacity problems elsewhere in the hospital. Equation 2.4 shows a measure, in which the situations where three X-Rays are in use simultaneously are compared to the total amount of X-Ray use.

Equation 2.4: Leveling of radiology

$$L_s^{radiology} = \frac{C_s^3}{C_s} \times 100\%$$

$L_s^{radiology} = Degree\ of\ levelling\ for\ radiology\ for\ specialty\ s$

$C_s^3 = Count\ of\ three\ X - Rays\ in\ use\ simultaneaously, where\ the\ third\ X - Ray\ is\ used\ for\ specialty\ s$

$C_s = Total\ number\ of\ surgeries\ that\ use\ X - Ray\ for\ specialty\ s$

KPI 5: Patient deferral (delays)

Patient deferral together with the next KPI, patient refusals, gives insight in customer satisfaction. This gives an indication on the accuracy of a schedule. Patients prefer to be treated on the planned time. This KPI is calculated by dividing the total number of patients delayed by the total number of patients treated by the specific specialty.

Equation 2.5: Patient deferral

$$C_s^{deferrals} = \frac{C_s^{waiting}}{C_s} \times 100\%$$

$C_s^{deferrals} = Patient\ deferrals\ for\ specialty\ s$

$C_s^{waiting} = count\ of\ patients\ that\ have\ to\ wait\ of\ specialty\ s$

$C_s = count\ of\ patients\ for\ specialty\ s$

KPI 6: Patient refusals (cancelations)

There are multiple reasons why surgeries are cancelled. Examples of reasons of cancellation are: cancellation because of health issues of the patient, technical issues, or logistical issues. In this KPI, logistical issues like resource shortage and time constraints are evaluated.

Equation 2.6: Patient refusal

$$C_s^{refusal} = \frac{C_s^{cancel}}{C_s} \times 100\%$$

$C_s^{refusal} = Patient\ refusals\ for\ specialty\ s$

$C_s^{cancel} = count\ of\ cancellations\ by\ the\ hospital\ for\ specialty\ s$

$C_s = count\ of\ total\ number\ of\ surgeries\ for\ specialty\ s$

KPI 7: Ward utilization

Ward utilization is defined as the sum of nursing days over all (working) days and all specialties, divided by the number of beds, reserved for each specialty. Equation 2.7 shows how the measure for utilization of the wards is calculated. This measure only takes working days into account and ignores beds opened or closed on the spot. The measure shows if the beds allocated to specialty s are sufficient to endure the demand during the period.

In practice the number of patients at a ward can never exceed ward capacity. However, when multiple patients use of the same bed during a day after each other, it is possible to get utilization above 100 percent. This is due to the measure 'nursing days' which is commonly used in hospitals.

Equation 2.7: Utilization of the wards

$$U_s^{wards} = \frac{\sum_p \left(D_{p,s}^{discharged} - D_{p,s}^{admitted} + 1\right)}{B_s^{reserved}} \times 100\%$$

$U_s^{wards} = Utilization\ for\ ward\ of\ specialty\ s$

$D_{p,s}^{admitted} = Date\ patient\ p\ is\ admitted\ for\ specialty\ s$

$D_{p,s}^{discharged} = Date\ patient\ p\ is\ discharged\ for\ specialty\ s$

$B_s^{reserved} = Bed\ capacity\ for\ specialty\ s$

We only evaluate working days, because during the weekends capacity declines.

KPI 8: Leveling ward bed count

The goal is to stabilize ward bed count, rather than minimize bed count. As Equation 2.8 shows, ward bed count is based on the standard deviation of specialty S on working days as fraction of the average bed count for specialty S, on working days. Only working days are taken into account because during weekends the number of beds and employees are reduced, because the OR department is only available for emergency surgeries and therefore there are almost no admitted patients.

Equation 2.8: Leveling ward bed count

$$W_s = \frac{\sigma_s^{bedcount}}{\mu_s^{bedcount}} \times 100\%$$

$W_s = Leveling\ of\ patients\ at\ a\ ward\ for\ specialty\ s$

$\mu_s^{bedcount} = Average\ number\ of\ patients\ for\ specialty\ s$

$\sigma_s^{bedcount} = St.deviation\ of\ number\ of\ patients\ for\ specialty\ s$

We only evaluate working days, because during the weekends the available capacity declines.

KPI 9: Leveling ward admissions and discharges

The number of admissions and discharges are closely related with the workload of the nursing ward. The difference between the workload of an admission or discharge is limited (interview with Brummelhuis and Groters-Kremers in 2010) and therefore these measures are taken together. Because all patients should be admitted and discharged during the year, the sum of the patients will be constant and only the moment can be influenced. To measure how patients are leveled over time, leveling of admissions and discharges is expressed in percentage standard deviation of the mean.

The distribution of admissions and discharges over time is expressed by Equation 2.9 in the fraction standard deviation. Only working days are taken into account, because during weekends there are no elective surgeries and therefore fewer admissions.

Equation 2.9: Leveling admitted and discharged patients

$$A_s = \frac{\sigma_s^{adm\,\&\,dis}}{\mu_s^{adm\,\&\,dis}} \times 100\%$$

$A_s = Leveling\ of\ admitted\ and\ discharged\ patients$
$\qquad after\ a\ surgery\ for\ specialty\ s$

$\mu_s^{adm\&dis} = Average\ number\ of\ admissions\ and -$
$\qquad discharges\ for\ specialty\ s$

$\sigma_s^{adm\&dis} = St.deviation\ of\ admissions\ and\ discharges -$
$\qquad for\ specialty\ s$

We only evaluate working days, because during the weekends there are many discharges and only limited admissions.

3 Current situation

In this chapter we discuss the current situation. We analyze the system, control and performance based on interviews with different stakeholders and data-analysis. Section 3.1 is dedicated to the system characteristics. Section 3.2 elaborates about the planning policy (control). Section 3.3, elaborates about the current performance, measured by the performance indicators distinguished in Subsection 2.3.2.

3.1 System and its characteristics

This section presents the system characteristics of Gelre Apeldoorn. Subsection 3.1.1 describes the patient flow through the hospital and the OR department. Subsection 3.1.2 discusses the case mix of Gelre Apeldoorn and Subsection 3.1.3 the capacity of the hospital and the characteristics of the surgeries.

3.1.1 Patient flow through the hospital

Figure 3.1 shows the patient flow at Gelre Apeldoorn for all patients that visit the OR department.

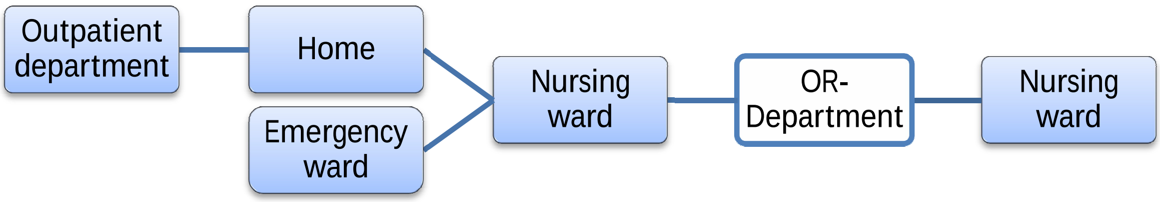


Figure 3.1: Flow diagram of patients at Gelre Apeldoorn

Patients enter the hospital via an outpatient department or the emergency ward. When the physician concludes at an outpatient department that a patient needs (elective or urgent) surgery, the patient can go home. The surgery is planned by the planning department and the patient returns to the hospital, only a few hours before surgery. Then the patient is admitted to a nursing ward, awaiting the surgery.

In case a patient is admitted to the emergency ward or to an outpatient department and needs an emergency surgery, the patient can go directly to the OR department. Most of the times the patient, however, is transferred to a regular nursing ward first.

Figure 3.2 shows the patient flow after the patient arrived at the OR department.

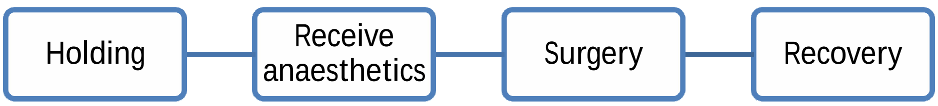


Figure 3.2: Patient flow at the OR department

First, the patient is received at the holding. Here the patient waits until the Operating Room and personnel is ready for surgery. Second, the patient is taken to the OR, where the patient receives anesthetics and the surgery is accomplished. Last, the patient is taken to the recovery room, where the anesthetics can wear off before the patient returns to the nursing ward. The patient stays at the nursing ward, until treatment is completed and the patient can be discharged.

3.1.2 Surgical case mix

There are three surgical categories at Gelre Apeldoorn: elective surgeries (3 months until 2 weeks before surgery), urgent surgeries (2 weeks until 2 days before surgery) and emergency surgeries (within 2 days before surgery). Table 3.1 shows the number of surgeries for and the utilization of OR time for each category.

Table 3.1: Type mix Gelre Apeldoorn for surgical patients 2007, 2008, and 2009

The fractions in the table are based on surgery duration (time a patient is at the OR), because that is the time the OR is really occupied and not available for other purposes. [Source: ChipSoft on 14-7-2010]

		2007			2008			2009		
		Surg. Count	Surg. Dur. (h)	Fraction	Surg. Count	Surg. Dur. (h)	Fraction	Surg. Count	Surg. Dur. (h)	Fraction
During regular hours	Emergencies	532	744	5.5%	602	831	6.1%	1,595	1,086	7.6%
	Urgent	0	0	0.0%	22	33	0.2%	1,441	1,917	13.4%
	Elective	12,197	10,639	78.9%	12,428	10,517	77.7%	11,971	9,268	65.0%
	Utilization	**12,729**	**11,383**	**84.4%**	**13,052**	**11,382**	**84.1%**	**15,007**	**12,271**	**86.1%**
	Available		**13,483**			**13,531**			**14,257**	
Outside regular hours	Emergencies	1,751	2,149	31.9%	1,691	2,036	30.3%	2,385	2,354	35.0%
	Urgent	1	5	0.1%	11	13	0.2%	282	220	3.3%
	Elective	1,477	710	10.6%	1,427	663	9.9%	1,024	360	5.4%
	Utilization	**3,229**	**2,866**	**42.6%**	**3,129**	**2,713**	**40.3%**	**3,691**	**2,935**	**43.6%**
	Available		**6,736**			**6,728**			**6,728**	
	Unknown	40	25	0.2%	15	9	0.1%	14	4	0.0%
	Total	**15,998**	**14,276**		**16,196**	**14,105**		**18,712**	**15,211**	

Interesting in Table 3.1 is the increase in urgent surgeries in 2009. The sharp increase Table 3.1 shows can be explained by the introduction of the category of urgent surgeries in December 2008. The increase in patients since 2009 can be explained by finishing rebuilding of extra capacity in first months of 2009. In order to fill the extra capacity, extra patients are treated. The relatively high number of surgeries outside regular time is explained by some extra session during weekends and surgeries performed in the two ORs which are opened longer to deal with the emergency patients. At those ORs are also elective patients treated when an emergency patients is treated during their planned time.

3.1.3 Hospital capacity

Table 3.2 shows the reserved beds, number of patients, nursing days, and average Length Of Stay (LOS) per surgical specialty. The figures only consider inpatient patients. We make a distinction between elective patients and all patients, including emergency patients, because elective surgeries are planned.

Table 3.2: Ward characteristics 2008 per specialty

Outpatients patients are grouped for all specialties together. [Source: KeyView and ChipSoft on 22-6-2010]

Specialty	Beds	ALL SURGERIES Pat. Count	ALL SURGERIES Sum of nursing days	ALL SURGERIES Average LOS (d)	ELECTIVE SURGERIES Pat. Count	ELECTIVE SURGERIES Sum of nursing days	ELECTIVE SURGERIES Average LOS (d)
General surgery	62	2,769	25,710	9.3	1,334	8,501	6.4
Orthopaedic	26	1,640	8,801	5.4	1,348	6,380	4.7
Obstetrics & Gynaecology	27	763	3,334	4.4	377	1,451	3.8
Eye surgery	0	48	103	2.1	46	97	2.1
ENT	6	620	1,399	2.3	582	1,257	2.2
Plastic Surgery	3	288	1,081	3.8	269	1,028	3.8
Anaesthetics	1	119	791	6.6	110	688	6.3
Urology	6	427	1,709	4.0	393	1,474	3.8
Oral surgery	1	31	90	2.9	27	83	3.1
Neurosurgery	0	21	70	3.3	21	70	3.3
Subtotal	***132***	***6,726***	***43,088***	***6.4***	***4,507***	***21,029***	***4.7***
Other specialties	174	80	196	2.5	77	156	2.0
Subtotal	***306***	***6,806***	***43,284***	***6.4***	***4,584***	***21,185***	***4.6***
Surgery Day Care (outpatient)	32	9,390	9,394	1.0	9,319	9,323	1.0
TOTAL	**338**	**16,196**	**52,678**	**3.3**	**13,903**	**30,508**	**2.2**

Table 3.2 shows that General Surgery and Gynecology deal with many emergency patients. This can be explained because General Surgery deals with most of the emergency patients and Gynecology performs multiple caesarean surgeries per week.

Table 3.3 shows the surgical characteristics of all patients at the OR department. Per surgical specialty, the total number of patients, total use of OR time and average duration of the surgery are shown.

Table 3.3: Surgery characteristics 2008 per specialty

[Source: ChipSoft on 14-7-2010]

Specialty	ALL SURGERIES Surg. Count	ALL SURGERIES Surg. Duration (h)	ALL SURGERIES Av. Dur. (h:mm)	ELECTIVE SURGERIES Surg. Count	ELECTIVE SURGERIES Surg. Duration (h)	ELECTIVE SURGERIES Av. Dur. (h:mm)
General surgery	4,009	5,708	1:25	2,551	3,736	1:27
Orthopaedic	2,799	2,727	0:58	2,494	2,333	0:56
Obstetrics & Gynaecology	958	1,152	1:12	565	772	1:22
Eye surgery	2,825	1,028	0:21	2,817	1,025	0:21
ENT	1,293	931	0:43	1,248	902	0:43
Plastic Surgery	1,031	924	0:53	1,011	896	0:53
Anaesthetics	2,069	661	0:19	2,048	652	0:19
Urology	662	619	0:56	628	579	0:55
Oral surgery	230	241	1:02	226	234	1:02
Neurosurgery	22	27	1:14	22	27	1:14
Other Specialties	*298*	*83*	*0:16*[2]	*293*	*77*	*0:15*[2]
TOTAL	***16,196***	***14,105***	***0:52***	***13,903***	***11,238***	***0:48***

[2] These short treatments are performed by OR personnel, but not necessarily at the OR. For example: inserting drips, giving anaesthetics or treatment with a cardioverter defibrillator.

When we compare the sum of nursing days and OR duration of Table 3.2 and Table 3.3, we see that some specialties, like eye surgery, use much OR time, but only limited nursing days. This difference is the result of many short, outpatient surgeries.

3.2 The planning and control mechanism

Subsection 3.2.1 elaborates on the planning process and the responsibilities. Subsection 3.2.2 elaborates on how to deal with uncertainties like emergency and urgent surgeries and describes how to deal with uncertainty of surgery duration.

3.2.1 Planning processes

In Section 1.2.2 the hospital planning framework of Hans et al. (2010) was discussed. In this subsection, the framework is applied to the situation of Gelre Apeldoorn. Because this study focuses on ‘Resource capacity planning’, Figure 3.3 shows only the corresponding part of the framework highlighting the area we focus on.

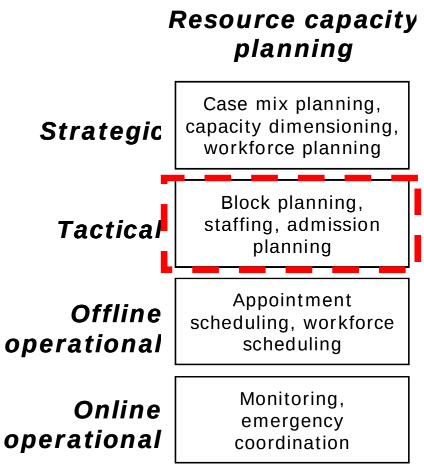


Figure 3.3: Part of the hospital planning framework (Hans et al., 2010)

Strategic planning

The highest level of resource capacity planning addresses the determination of the case mix and dimensioning of capacity. Decisions about capacity planning and case mix planning are made by (representatives of) the specialists, the hospital board and insurance companies.

Tactical planning

The second highest level addresses tactical planning issues like block planning and admission planning. Gelre Apeldoorn currently plans capacity in a two weeks recurring cycle. When a surgeon is unable to operate, the OR time is mostly used by a colleague of the same specialty, on expense of time at the outpatient department. Admission planning is currently not used in Gelre Apeldoorn.

Offline operational planning

The third level, offline operational planning, is performed by various departments. Currently two of the 10 available ORs are planned separately by the secretary of the eye surgeons and anesthesiologists. The eight other ORs are planned by the planning department. When the surgeon sees a patient at the outpatient department and decides that the patient needs elective surgery, the patient is added to the waiting list. The planning department calls the patient, and plans the patient during an OR block for the specific specialty. The patient gets two appointments, first an appointment at the ward (for more details about the admission; in Dutch: “opnamegesprek”) one day before surgery, and second, the actual surgery. The patient does not receive the time of surgery, only the date of surgery. The planning department handles the patients on a First Come, First Served order from the waiting list. Urgent patients are also planned by the planning department. Those patients are also planned First Come, First Served during time which is especially reserved for this purpose. Emergency and urgent patients get priority over elective patients. Therefore, it is possible that an elective surgery is cancelled when there is not enough time available to handle all emergency and urgent surgeries.

Online operational planning

Every day, the OR schedule for the next day is sent to the OR day coordinator, who is responsible for the OR program during the day. The OR day coordinator evaluates the schedule and adapt it to technical attainability, and the order preferred by the surgeons. From this moment on, the planning is “online”, and can only be adapted by the day coordinator.

Patients are expected a day before surgery at the preoperative admission department for the last checks and information. The patient gets the OR time for his surgery and usually he can go back home, to return to the hospital only a few hours before surgery.

When the schedule is online, every change has a high influence on OR performance. Therefore only the OR day coordinator is allowed to make changes to the schedule in order to deal with delays, changes in the schedule and Emergency patients. In Subsection 3.2.2 we elaborate in more detail on the planning of urgent and emergency surgeries.

3.2.2 Buffer against uncertainty

There are two types of uncertainty in planning an OR department. First, we discuss the uncertainty around planning of urgent and emergency surgeries and second, the planning of uncertainty of duration.

Slack as buffer against uncertainty of emergency and urgent surgeries

Table 3.1 shows that in 2009 during opening hours, 80 percent of the patients were elective patients, 9 percent were urgent patients, and 11 percent were emergency patients. In surgery duration this is respectively: 76, 16, and 8 percent.

Most of the urgent and emergency surgeries are performed by general surgery. Therefore, two ORs allocated to general surgery, are labeled as “emergency OR”. This means that these ORs are not fully planned; until two weeks in advance. 200 minutes on both ORs are reserved for urgent and emergency surgeries. This empty OR time is called “slack” (in Dutch: “Witte Vlek” or “uitloop”), and is positioned at the end of each day. Urgent surgeries are planned in both ORs until 100 minutes per OR is left. This way, every day two ORs have 100 minutes available for emergency surgeries. Emergency patients are preferably planned during the slack time. If the patient cannot wait until the end of the day for surgery, the patient will go to the first (emergency) OR that becomes available. All other patients in that OR are delayed in order to create OR time for the emergency patient.

Currently, Gelre Apeldoorn has no policy regarding start time optimization for the two ORs that handle the emergency surgeries. So theoretically, it is possible that both emergency ORs are not available for many hours. In that case, the emergency patient can be operated at another OR, and the patient(s) from that OR are moved to the slack time of the emergency ORs. The last two years this has never happened, and therefore we conclude that the use of slack time works very well. After implementation of slack time last year, working in overtime and waiting time for emergency patients decreased (interview with Eelco Bredenhoff (manager patient logistics), 2010).

Slack for buffering against uncertainty of surgery duration

At Gelre Apeldoorn, the ORs are planned every day until 15 minutes before they close. This means that every day 15 minutes of slack time is available to buffer against uncertainty, independently of the type of surgeries that are performed on that day.

3.3 Current performance

This section gives the current performance of Gelre Apeldoorn for 2008. The 2008 data is evaluated, based on the nine Key Performance Indicators identified in Subsection 2.3.2. We also looked into data of 2007 and 2009 to take into account patients that had surgery in 2008, but were admitted or discharged in 2007 or 2009. The results are split into two sections, because some KPIs are measured for all specialties on the OR and some are measured for the specialties on the wards.

3.3.1 Performance of the OR department

In Table 3.4 the performance per KPI is shown for the KPIs that are measured per specialty on the OR. The total value is the weighted average over all specialties.

Table 3.4: Performance 2008, per OR (specialty)

***) The difference of 0.1 percent point with Table 3.1 can be explained because in Table 3.1 other surgeries are excluded. There was no data available for leveling of duration and for patient deferrals and refusals.** [Source: KeyView on 22-6-2010; ChipSoft on 14-7-2010]

	OR			Radiology	Quality	
	Utilization	Overtime	Leveling duration	Leveling	Deferrals	Refusals
Anesthetics	78.4%	0.2%	n.a.	0	n.a.	n.a.
General Surgery	83.4%	6.2%	n.a.	3.2%	n.a.	n.a.
ENT	88.2%	1.7%	n.a.	0	n.a.	n.a.
Oral Surgery	80.8%	0.4%	n.a.	0	n.a.	n.a.
Neurosurgery	77.6%	3.4%	n.a.	0	n.a.	n.a.
Eye surgery	73.8%	0.9%	n.a.	0	n.a.	n.a.
Orthopedics	84.9%	4.1%	n.a.	0.7%	n.a.	n.a.
Plastic Surgery	82.0%	0.6%	n.a.	0	n.a.	n.a.
Urology	86.3%	1.9%	n.a.	18.8%	n.a.	n.a.
Gynecology	109.6%	4.0%	n.a.	0	n.a.	n.a.
Others	83.4%	0.2%	n.a.	0	n.a.	n.a.
TOTAL:	84.2%*	3.6%	n.a.	1.8%	n.a.	n.a.

For 2008 information about OR leveling, number of deferrals, and number of refusals was unavailable. In the simulation, however, it is possible to measure those performance indicators and use them to compare the different solutions.

OR utilization (1)

According to the Plexus (2009) benchmark, the utilization of 81 percent measured in March 2009 for OR time, is above the average of Dutch OR departments. The difference with the utilization measured in 2008 can be explained due to two new ORs that are in use since January 2009 and because Plexus measured utilization only one month, while in Table 3.4 utilization is based on a entire year.

When taking a closer look to the utilization figures, it is apparent that eye surgery has a low utilization, and gynecology, neurosurgery and 'others' have a high utilization. An explanation is that eye surgery has many short surgeries and therefore more time between surgeries is 'wasted' to setup and cleaning the OR. Gynecology, neurosurgery and 'others' often use OR time of other specialties, what results in a higher utilization. It is striking that Gelre Apeldoorn has one of the highest OR utilizations of the Netherlands, even without any policy for planning patients within a day.

OR overtime (2)

In the Plexus (2009) benchmark 5% overtime was measured. Table 3.4 shows that in 2008 3.6% overtime was recorded. Overtime of 5% means that on average, at every OR it is necessary to work an additional 16 minutes.

General Surgery and Neurosurgery are the specialties that have the most overtime. According to Gelre Apeldoorn, this can be explained because Neurosurgery often starts later than planned, and therefore it is necessary to continue after OR closing time to finish the program. General surgery performs many urgent and emergency surgeries. These are primarily performed at the end of the session, but if necessary they are scheduled during the day. These additional surgeries disturb the OR planning and can cause the additional overtime.

OR leveling (3)

Because the two hospital locations in Apeldoorn physically merged in 2008, the operating rooms also moved, and were renamed. Due to the new ORs, the equipment per OR changed and therefore it is impossible to calculate a value for OR leveling.

Leveling of radiology (4)

In 1.8% of all surgeries that make use of radiology equipment, there are three devices in use at the same time. This seems to be low, but it causes serious problems at the radiology department, therefore we should aim on zero conflicts for the use of X-ray equipment. High values on this KPI for some specialties show that these specialties were often involved with the problem situations. In absolute terms anesthetics most often causes problems.

Number of deferrals (5)

There is no registration of the number of deferrals.

Number of refusals (6)

There is no registration of the number of refusals.

3.3.2 Performance of the wards

In this section the performance of the nursing wards is discussed. A distinction is made between the day care wards and the clinical (or long stay) wards. Also, performance is measured per specialty. This differs from the actual situation, where some (small) specialties are combined.

Table 3.5 shows the performance of 2008 per ward. The difference with Table 3.4 is that Surgery Day care is specified. On the wards, day care patients show a different pattern as long stay patients and are therefore separated.

Table 3.5: Performance 2008, per ward (specialty)

*) **For this specialty there are no reserved beds. Therefore it was not possible to calculate a utilization percentage and the absolute utilization is shown.** [Source: KeyView on 22-6-2010; ChipSoft on 14-7-2010]

	Ward		
	Utilization	Leveling wards	Admissions & Discharges
Anesthetics	253.4%	64.3%	127.1%
General Surgery	120.6%	21.5%	27.9%
ENT	33.4%	54.6%	60.7%
Oral Surgery	74.8%	199.7%	322.2%
Neurosurgery	0.3*	317.0%	354.4%
Eye surgery	0.2*	211.8%	245.5%
Orthopedics	30.5%	27.9%	34.7%
Plastic Surgery	95.2%	56.3%	87.0%
Urology	110.4%	55.8%	100.6%
Gynecology	92.4%	36.0%	51.3%
SUBTOTAL:	94.9%	18.8%	21.7%
Others	0.6	194.7%	270.0%
Surgery Day Care	111.6%	37.5%	43.8%
TOTAL:	98.6%	19.4%	31.8%

Utilization ward beds allocated to a specialty (7)

On most wards, beds are allocated to multiple specialties. Therefore the pooling effect can be used to decrease variations. Total utilization in 2008 is 98.6%, for surgical specialties. This is a high value, considering that Gelre Apeldoorn strives for a bed usage of 85% for all beds. This high value can be achieved because capacity of non-surgical specialties is used, when available and if necessary.

Leveling ward bed count (8)

Leveling of ward bed count is optimal when it is zero. The value in 2008 for this KPI is 18.8%, which is low compared to the values for leveling per specialty, because of the pooling effect (Hans et al., 2008). The high values for leveling bed count per specialty can be explained because Gelre Apeldoorn does not include LOS into their planning. Another cause is that some of the (small) specialties have only a few times per week OR time available. Therefore it is impossible to completely stabilize ward bed count.

Leveling of admissions and discharges (9)

Leveling of admissions and discharges is optimal when it is zero. For all beds, leveling is 21.7%. This value is high per specialty and much lower in total due to the pooling effect (Hans et al., 2008). High leveling values for some specialty can be explained because of the small turnover of clinical patients. For urology and plastic surgery, the differences can be explained by the fact that during 2008, there were only surgeries on some days during the week. This causes high variability in the admissions and discharges of patients.

3.4 Conclusions

This chapter discussed the organization of the OR department of Gelre Apeldoorn. It is apparent that the single departments are organized well, but because of lack of synchronization, the total process performs less. For example, the number of patients at the different departments is instable. This lack of synchronization is caused by the focus of the hospital planning process, which is almost entirely on the OR department.

For the OR department this generates a high utilization and low percentage of overtime, but for other departments this causes high variation and makes it hard to reach high utilizations. Especially radiology and nursing wards are managed reactive, which demands high flexibility of personnel and causes stress at those departments. In the 2010 employee research (Ommen, 2010), this became visible.

We expect that improvements on utilization and leveling are possible when interdepartmental relations and communications are improved. When the process is managed in an integrated way (through the entire hospital), instead of per department, it will be possible to improve performance even more.

4 Simulation design

Section 4.1 elaborates about the simulation model. The simulation model, assumptions and experimental design are explained. The simulation constructs an MSS using blocks of surgery types. The MSS is then optimized using the demand profile of the surgery types. Section 4.2 explains the heuristic we used to construct the surgery types. A surgery type is defined as a group of surgical procedures which can be performed on the same OR, and have comparable logistical characteristics (van Oostrum, van Houdenhoven, et al., 2008). Section 4.3 validates the simulation with the realization of 2008. Finally, Section 4.4 presents the experiments we performed and explains their utility in this study.

4.1 Model

All simulations were performed in the simulation software “OR manager”, developed by E.W. Hans of University of Twente. This program is developed to simulate any OR department and its related resources. Inputs to the simulation are poison distributions for the arrival pattern of surgeries and lognormal distributions for the surgery duration and LOS. We derived these distributions of the 2008 hospital data, and expect them to match the current situation (see also Appendix A).

Assumptions

When we set up the simulation we made choices for settings. We tried to match reality and, if not possible, we verified the performance of the settings with the performance of the current situation. The assumptions we made are listed in this paragraph:

1. Surgeries are cancelled if more than 35% of the expected duration is outside opening hours.
2. Surgeries are not allowed to move to other ORs (according to the manager patients logistics, this rarely happens in reality).
3. Emergency surgeries can be performed in all ORs and are planned within one day (was the situation in 2008).
4. All outpatient patients leave on the day of surgery (in 2008 0.04% of the inpatient patients stayed more than one day).
5. The allocation of ORs to specialties is the same for every period (in reality there are sometimes changes based on the actual demand and availability).
6. When in the simulation resources are unavailable (e.g. over utilized), the surgery is not cancelled (there is no information available from reality, but it is necessary for analytical purposes).
7. Cleaning time between surgeries is 2 minutes. Currently it is expected that 8 minutes are needed for cleaning, but after analyses of the data we discovered that the cleaning time is often already included in the surgery duration.

Cycle length

The cycle length is a tradeoff between OR time necessary per specialty and recurring cycle. Currently the OR department is planned using a two week cycle. Because some specialties use only halve an OR day per week, it is not preferable to decrease cycle length. Increasing the cycle length is also undesirable, because it becomes hard to recognize the cycles. Therefore the hospital prefers to leave the cycle length unchanged and we will use a cycle length of two weeks in all simulations.

Run length, warm-up period and number of replications

During the year the hospital suffers of seasonal influences. For example, when it snows in the winter and it becomes slippery, more people fall and break hips, legs and arms. To include these seasonal influences, we decided on a run length of one year (52 week = 26 periods). Furthermore, during a year there are 12 weeks with reduced capacity, which differ significantly from regular weeks. So to exclude variances caused by the reduction periods, we decided to decrease the run length to 20 periods of 14 days.

The warm-up period is needed for the simulation to reach a steady state (Law & Kelton, 2000). A ward has already a collection of patients at the beginning of the period and because the simulation starts with empty wards, it is necessary to first fill the wards with patients.

Of all patients, 95 percent have a LOS less than one period. 98 percent of patients have a LOS less than two periods and 99 percent less than three periods. So the warm-up period is expected to be between one and three periods. To determine the warm-up period, twenty independent simulation runs are performed.

Figure 4.1 shows the average utilization of beds of an average nursing ward.

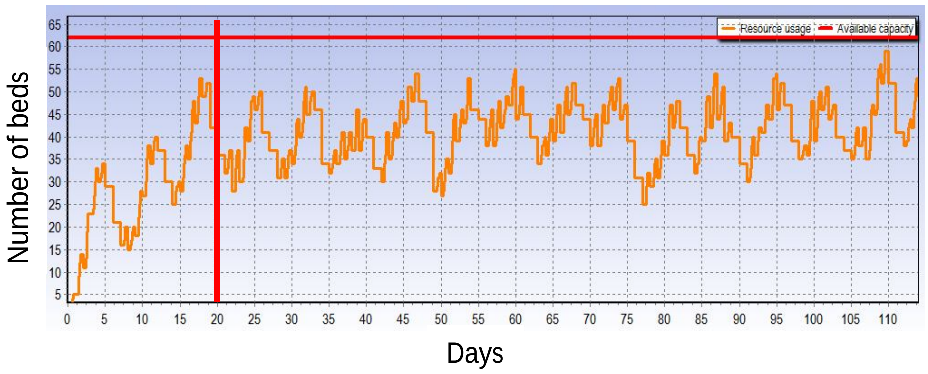


Figure 4.1: Utilization of a ward for 20 runs (print screen from OR-manager)

Figure 4.1 shows that during the first weeks of the run the number of occupied beds is low compared to the other weeks. After 20 days, utilization reaches a steady state and a repetitive pattern starts. The first new period after 20 days is period three and therefore we use a warm-up period of two periods. Therefore each simulation run consists of 22 periods.

In order to get reliable results, multiple runs are required. Each run should use different random numbers, the same initial conditions and reset the statistical counters (Law & Kelton, 2000). We calculate the number of runs with the sequential procedure of Law and Kelton (2000). For a relative error $\gamma = 0.025$ and the confidence level $\alpha = 0.95$, the minimum number of runs necessary is 20. All simulated results are based on 20 runs.

4.2 Grouping surgeries

In the literature several heuristics were proposed for grouping surgeries. Most existing heuristics focus solely on surgery duration, which is insufficient because our goal is to stabilize ward workload. Another point of concern is the gap between constructed groups, and groups that are familiar to OR planners. Most heuristics create groups that become too large and therefore are unrecognizable to OR planners. Also, variance explodes when groups become too large, which harms the performance of the MSS (i.e. only one or two groups per specialty were generated with the method of van Oostrum et al. (2008) and the method of Maruster et al. (2002)). We therefore developed a new heuristic approach for surgical grouping.

The heuristic we propose creates solid, medically and logistically homogeneous groups. Subsection 4.2.1 describes the five steps of the heuristic. This subsection explains the heuristic and in the text boxes the heuristic is illustrated by its application to gynecology. We use gynecology as an example because it has an average case mix in elective surgeries. Subsection 4.2.2 presents the groups that are generated and evaluates the groups, based on the Error Sum of Squares[3] (ESS) and a graphical comparison of the actual surgeries and the chosen distributions.

In Appendix C is a complete overview of the created surgery types included.

4.2.1 Grouping heuristic

Groups should have a medically comparable case-mix (recognizable for OR planners), comparable duration, and comparable LOS. Variance within the groups should be small and groups should be as large as possible, because in a large group, the probability of an arrival in each period is largest. In the heuristic we combine all these characteristics.

To make a clear distinction between surgery, surgical procedure, surgery type, and groups, we explain the differences between them. A surgery is a single surgery. The surgery can consist of multiple interventions and the combination of these interventions is called a surgical procedure. In a surgery type one or multiple surgical procedures are grouped together and are used for planning purposes. Groups are the highest level and contain all surgeries that use the same resources (like X-Ray and wards).

Step 1: Resource-based grouping

The first step of the heuristic is the construction of groups based on required resources. We assume that all surgeries can be performed in all ORs and therefore take the following resources into account: surgeons, X-Ray equipment and wards.

In Gelre Apeldoorn OR days (a combination of an OR on a specific day) are assigned to a specialty, and the specialty plans which surgeon operates that OR day. Therefore we first take into account the specialty and assume that all specialists of the specific specialty are capable to perform all possible surgeries. Second, the use of X-Ray equipment is evaluated. X-Ray equipment has limited capacity and therefore it should be reserved in advance. The third resource is the nursing ward. For clinical (or

[3] Error Sum of Squares (ESS) is defined as: $ESS = \sum_{i=1}^{n}(x_i - \bar{x})^2$ (Ward, 1963)

inpatient) patients, the wards allocated to a specialty are used. All day care (or outpatient) patients recover at the day care ward.

The groups we distinguish consist of patients of a specialty that make use of X-Ray equipment and go to a clinical or day-care ward.

Step 1:

In the 2008 dataset there are 958 Gynaecological surgeries. When the emergency surgeries and reduction periods are excluded, 326 clinical and 154 day-care surgeries remain. 28 of the clinical surgeries and 7 of the day-care surgeries make use of X-ray equipment. We can distinguish four sets of surgeries for Gynaecology:

Name:	Specialty:	X-Ray:	Type of ward:	Surgeries:
GYNA1	Gynaecology	No	Clinical	298
GYNA2	Gynaecology	Yes	Clinical	28
GYNA3	Gynaecology	No	Day	147
GYNA4	Gynaecology	Yes	Day	7
			TOTAL:	480

Step 2: Construction of the first surgery types

To get surgery types that are medically homogenous we group the surgeries of the previous step into types based on surgical procedures.

First, we create a surgery type for each surgical procedure in the set of surgeries performed. The surgical procedures are medically comparable. Second, we describe the surgery type's duration and LOS. We express the surgery duration and LOS with a lognormal distribution for each type. The lognormal distribution is determined by taking the mean and standard deviation of the natural logarithms of the values of all surgeries in the group.

Step 2:

Step 2 is executed for every set of surgeries. In the dataset of Gynaecology there are four sets and we generate 99 groups. On average we have less than five surgeries per group. The results are shown in the table below.

Name:	Specialty:	X-Ray:	Type of ward:	Surgeries:	Types:
GYNA1	Gynaecology	No	Clinical	298	50
GYNA2	Gynaecology	Yes	Clinical	28	18
GYNA3	Gynaecology	No	Day	147	25
GYNA4	Gynaecology	Yes	Day	7	6
			TOTAL:	480	99

OPTIONAL Step 2b: split groups

When a surgery type is not homogenous, it only can be split if there is recognizable difference. For example, when the duration of recovery of some surgical procedure takes 2 or 5 days and there are objective measures to determine the expected value in advance (like the condition of the patient). In the data this is shown by multiple peaks for surgery duration or LOS.

When planners and surgeons recognize such a difference, we can incorporate this manually by changing the surgical code of the specific surgeries. The groups that are split become two groups. Splitting groups does not cause other changes in the heuristic.

Step 3: Find best combinations of groups

Step three combines surgery types in order to find the best fit (the two surgery types that cause the least variance after merging). In order to find the surgical groups that best fit together, we compare the distribution of the surgery duration and length of stay for all groups.

For both surgery duration and LOS, we calculate $E[x]$ of the lognormal distributions determined in step 2, as Equation 4.1 shows. We use the fractional difference to express the size of the difference.

Equation 4.1: Expected value for Lognormal distribution

$$E[X] = e^{\mu+\frac{1}{2}\sigma^2}$$

$E[X]$: $Expected\ value\ for\ the\ lognormal\ distribution$

μ : $Average$

σ : $standard\ deviation$

The fractional difference is calculated as percentage of the smallest expected value of x and the combination of groups which has the smallest percentage difference has the best match.

Step 3:

Step 3 calculates the fractional difference of surgery duration and LOS expressed in $E[x]$ for each combination of surgery types. The table shows first the fractional difference in surgery duration and after the semicolon the fractional difference in LOS. The combinations of groups 2 & 3 and groups 3 & 4 have the smallest value after combining.

	1	2	3	4	5	6
1	x	x	x	x	x	x
2	3.5; 7.7	x	x	x	x	x
3	3.5; 6.8	0.0; 0.1	x	x	x	x
4	3.5; 6.0	0.0; 0.3	0.0; 0.1	x	x	x
5	0.0; 6.5	3.5; 0.2	3.5; 0.0	3.5; 0.0	x	x
6	3.5; 6.3	0.0; 63.0	0.0; 56.0	0.0; 50.0	50; 0	x

Step 4: Combine surgery types

Step 4 combines the surgery types, based on the table of step 3. Because Operating Room is the most expensive resource, we evaluate the surgery duration first, and the LOS second. After tests with different values, we decided to allow a difference for surgery duration and LOS of 30 percent. In this step we now combine all groups which have a difference less than 30 percent, starting with the groups with the smallest difference.

After two groups are merged, we return to step 3.

Step 4:

After the heuristic ran until it reached the selected bounds, 55 groups are left. Many groups only contain one surgery and on average a group contains 9 surgeries.

Name:	Specialty:	X-Ray:	Type of ward:	Surgeries:	Types:	Surgeries in smallest group:
GYNA1	Gynaecology	No	Clinical	298	21	1
GYNA2	Gynaecology	Yes	Clinical	28	10	1
GYNA3	Gynaecology	No	Day	147	19	1
GYNA4	Gynaecology	Yes	Day	7	4	1
			TOTAL:	480	55	

Step 5: Get minimum sized surgery types

The surgery types created in step 4 fit well together. Because we decided that a surgery type should contain surgeries that occur at least twice per period, the minimum number of occurrences is therefore forty times per type. In order to reach this target, we sort the surgery types on occurrence. We combine the surgery type which occurs least with the best matching other type, as calculated in step 3. Step 3 and step 5 are repeated until all surgery types occur at least 40 times.

If there are surgery types left which occur less than forty times (for example, when seldom X-Ray equipment is used on day care patients), we combine those surgery types, with surgery types of other groups.

Step 5:

When the heuristic finished, all surgery types contain of least forty surgeries. There are eight surgery types left and the average occurrence is 60 times. Group GYNA4 occurred 7 times and is therefore too small to plan. Therefore we decided to combine GYNA3 and GYNA4 into GYNA5. Day-care patients are, independent if they use X-Ray equipment, planned in one of the three surgery types of Gyna5. When a surgery from this group uses X-Ray, the availability needs to be verified.

Name:	Specialty:	X-Ray:	Type of ward:	Surgeries:	Types:	Surgeries in smallest group:
GYNA1	Gynaecology	No	Clinical	298	4	44
GYNA2	Gynaecology	Yes	Clinical	28	1	28
GYNA5	Gynaecology	-	Day	154	3	43
			TOTAL:	**480**	**8**	

4.2.2 Groups and quality of the groups

This subsection discusses the results for Gynecology. Table 4.1 shows the eight surgery types created. Three types are day-care patients and five types are clinical patients. In the row 'X-Ray', the percentage of surgeries is shown that make use of X-Ray equipment. In this subsection, we focus on two groups, surgery type III (Day-Care) and VI (long-stay). These groups are representative for other groups and for other specialties.

Table 4.1: Result after grouping for Gynecology

***) (D = outpatient; L = inpatient)**

Type name:	I	II	III	IV	V	VI	VII	VIII
Type*:	D	D	D	L	L	L	L	L
X-Ray:	2%	9%	4%	0%	0%	0%	0%	100%
Size:	64	43	47	44	67	134	53	28
Av. Duration:	36.53	48.37	59.91	49.91	73.75	112.71	152.94	101.8
Max LOS:	0.54	0.50	0.42	2.79	11.08	9.08	38.83	6.9
Av. LOS:	0.35	0.37	0.39	1.03	3.07	2.89	4.81	3.0
Mu Duration:	3.55	3.86	4.06	3.89	4.27	4.70	4.98	4.6
Sigma Duration:	0.32	0.19	0.25	0.22	0.23	0.24	0.31	0.4
Mu LOS:	-1.08	-1.02	-0.95	-0.09	0.95	0.96	1.18	1.0
Sigma LOS:	0.28	0.21	0.13	0.48	0.58	0.44	0.89	0.5

The types are all distinctly different and contain at least 40 surgeries, except group eight. This group of long stay patients makes use of X-Ray equipment and has no more patients. Apparent in Table 4.1 are the negative values for μ for the LOS. These values are negative, which in a two parameter lognormal distribution means that the median is below one. Also apparent is the small difference in the length of stay between some types, like II and III, or V and VI. This can be explained because in the heuristic duration is higher valued than LOS and some types have a rather large difference in duration, but a comparable LOS.

In Figure 4.2 the two parameter lognormal distribution is shown for the duration and LOS of type III. Both are compared to the actual values. Figure 4.3 shows the two parameter lognormal distribution for surgery duration and LOS of type VI, compared to the actual values.

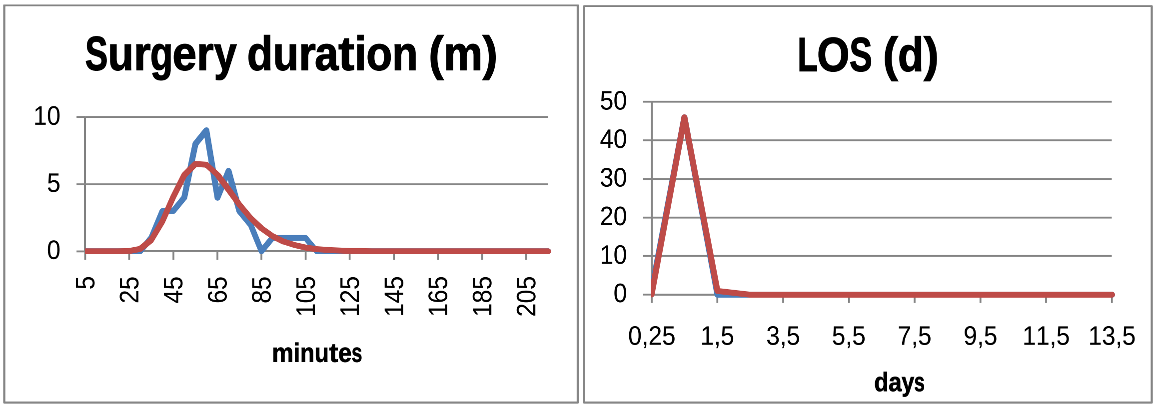


Figure 4.2 Frequency of surgery duration and LOS 2008 for surgery type III

The blue lines are actual values and the red lines are the approximation of the distributions (n=134)

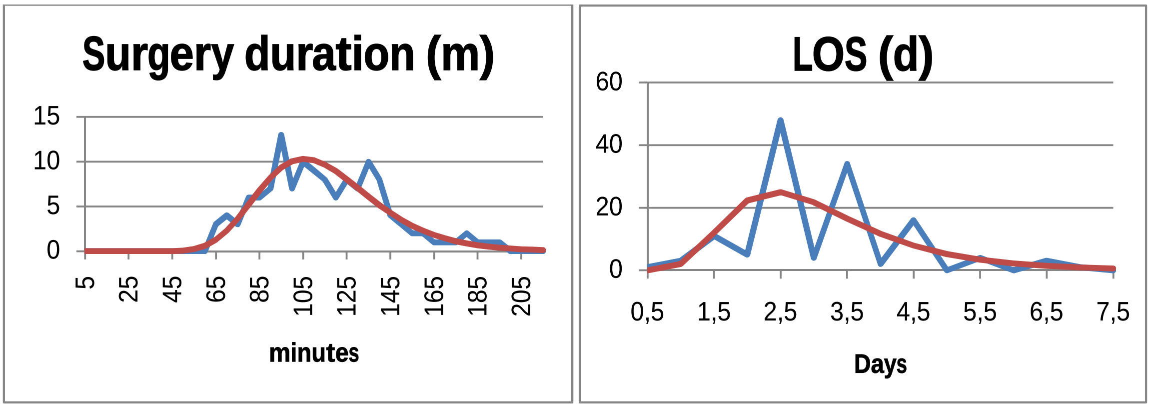


Figure 4.3 Frequency of surgery duration and LOS 2008 for surgery type VI

The blue lines are actual values and the red lines are the approximation of the distributions (n=47)

Figure 4.2 and Figure 4.3 shows that the two parameter lognormal distributions approach the retrieved surgery duration and LOS. Additional to the visual check, we quantitatively compared the quality of the solutions. Table 4.2 shows the Error Sum of Squares (ESS) (Ward, 1963), which we have chosen as measure. The table shows the situation of no groups (only plan a specialty) compared to the current planning of surgical procedures (not feasible in an MSS) and to the constructed surgery types. This measure ranges from zero (no variance), to a high value when all surgeries are in one group.

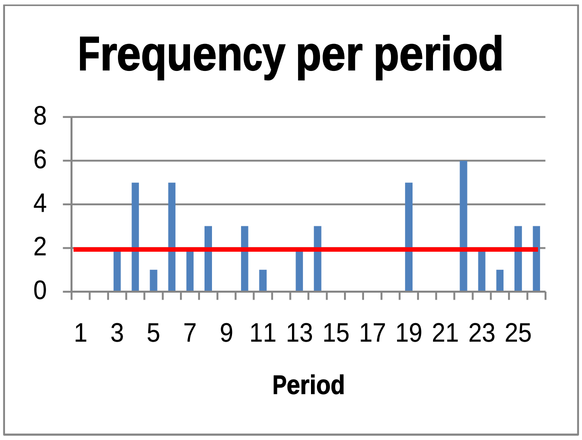
Table 4.2: Performance grouping (for gynecology) when all surgeries are in one group ('No groups'), when every surgical procedure is one group ('surgical procedures') and after the grouping heuristic ('Surgery types')

	No groups	Surgical procedures	Surgery types
ESS duration:	949,003.07	181,712.93	185,486.59
ESS LOS:	3,100.09	367.76	570.47
Num surgeries per group	470.0	7.6	58.8
Number of groups:	1	62	8

Table 4.2 shows that the ESS for the duration after executing the grouping heuristic, increases with 2% compared to the current situation. The ESS for the LOS increases with 55%. We conclude that the increase in variance of duration of 2% is not significant. The increase in variance of LOS is huge, but does not cause any problems because it allows us to plan the utilization of the wards, which was impossible with the surgical procedures. Therefore, these groups are good.

Frequency of surgical groups

Another check for the quality and usability of the groups is the frequency table. For a stable planning it is necessary that surgeries are available when they are planned. For example, when surgery A is planned, but there is no patient who needs to undergo surgery A, the schedule will be disrupted. Figure 4.4 shows the frequency tables for surgery types III and VI. The numbers of surgeries of the particular type performed, per period (two weeks), are shown.



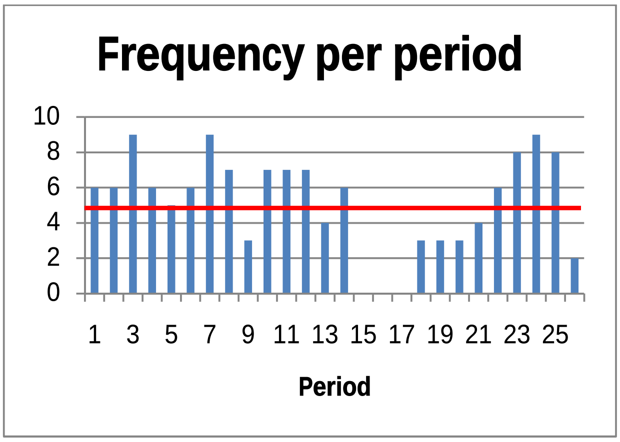


Figure 4.4: Frequency table 2008 (Left: surgery type III; Right: surgery type VI)

Realized frequency for surgery types III & VI over 26 periods of 2 weeks in 2008. The red line is the trend line. Reduction periods are: 5; 9; 15; 16; 17; 18; 21; and 26. (III: n=47 and VI: n=134)

Figure 4.4 shows a similar pattern as for the other groups. We considered this pattern as stable. The manager patient logistics of Gelre Apeldoorn (interview with Eelco Bredenhoff on November 2010) expects that the differences are mainly caused by the reduction periods and disturbances in the planning after the reduction periods. There is no clear trend visible in the tables.

4.2.3 The heuristic in pseudo code

To illustrate the heuristic we summarize the seven steps using pseudo code:

1. *Create surgery types based on the surgical procedures and go to step 2*
2. *Determine Lognormal distribution for each surgery type and go to step 3*
3. *Calculate for each combination of surgery types the distance between expected value for the surgery duration and the LOS and store in the array "compare" and go to step 4*
4. *In the first iteration, perform step **a** and **b** and then go to step 5:*
    a. *Sort the array "compare" in ascending order on distance of surgery duration and LOS and go to step 5*
    b. *Sort the array "compare" in ascending order on the group size and distance of surgery duration and LOS in ascending order and go to step 5*
5. *Select two surgery types to compare. Evaluate the first row of the array "compare" :*
    a. *If the difference in row 1 < than the maximum allowed difference, go to step 6*
    b. *If the difference in row 1 > larger than the maximum allowed difference, and the group size is < than the minimum group size, go to step 6*
    c. *In all other situations go to step 7*
6. *Combine the surgery types in the first row of the array "compare" and update the array "compare". Evaluate the first row of the array "compare":*
    a. *If the difference in duration and LOS <= than the maximum allowed, return to step 4a*
    b. *If the difference in duration and LOS > than the maximum allowed, return to step 4b*
7. *Show the end results*

4.2.4 Conclusions

The heuristic we applied is closely related to the heuristic developed by van Oostrum (2008). To determine which surgery types to combine, Van Oostrum calculates the change in ESS for surgery duration and for LOS. The change in ESS, combined with the change in dummy volume determines the best combination.

We disregard the dummy volume and in our heuristic we don't make a choice in importance of the duration or LOS. Therefore our grouping policy produces better understandable results and is less influenced by the user. Unfortunately it was not possible to compare both heuristics quantitatively.

4.3 Validation

We validated the simulation in two ways. First, we compared the results of the simulation with the results of the realization of 2008. Second, we discussed the results with the manager patient logistics (interview with Eelco Bredenhoff on November 29th, 2010) and concluded that the simulation shows a recognizable representation of reality. Table 4.3 shows the realization of 2008 and the results of the simulation.

Table 4.3: results simulation compared with 2008 realization

	2008	
	Realization	Simulation
MSS coverage	n.a.	n.a.
OR utilization	84.2%	84.3%
OR overtime	3.6%	4.2%
OR levelling	n.a.	9.4%
Ward utilization	98.6%	107.6%
Ward leveling (utilization)	19.4%	12.1%
Ward leveling (adm+dis)	31.8%	20.0%
X-ray over utilization	1.8%	0.3%
Cancelled surgeries	n.a.	7.9%
Delayed surgeries	n.a.	27.8%

Table 4.3 shows that the OR utilization in the simulation approaches the actual utilization. An explanation for the higher overtime in the simulation is human influence. In reality a more accurate estimation is made for the time necessary to finish the surgery. Therefore, less overtime is generated.

We do not have an explanation for the higher values on ward utilization in the simulation. The LOS per specialty approaches the actual LOS and also the case-mix is comparable. An explanation for the lower values for ward leveling in the simulation is that we did not take into account emergency patients arriving after closing time of the OR.

The lower over-utilization for X-Ray equipment in the simulation is explained by the fact that we ignore the use of X-Ray equipment in surgical procedures that seldom occur. As a result, we generate fewer patients that make use of X-Ray equipment than in practice.

Currently, the percentage of cancelled surgeries is unknown. In the simulation we had to generate 11,997 patients to have 11,052 elective patients served at the OR.

4.4 Planning policies and scenarios

To find the best performing MSS, we test multiple versions under different conditions. We test three versions of an MSS, respectively: MSS optimized on OR utilization, MSS optimized on ward utilization and MSS optimized on count of admissions and discharges.

We test the MSSs for two scenarios: the 2008 situation and the 2011 situation. Also, we test the difference in performance for the current (fixed) allocation and an optimized (free) allocation of specialties to ORs. We do not resize the total allocated time per specialty. Figure 4.5 summarizes the different tests we perform.

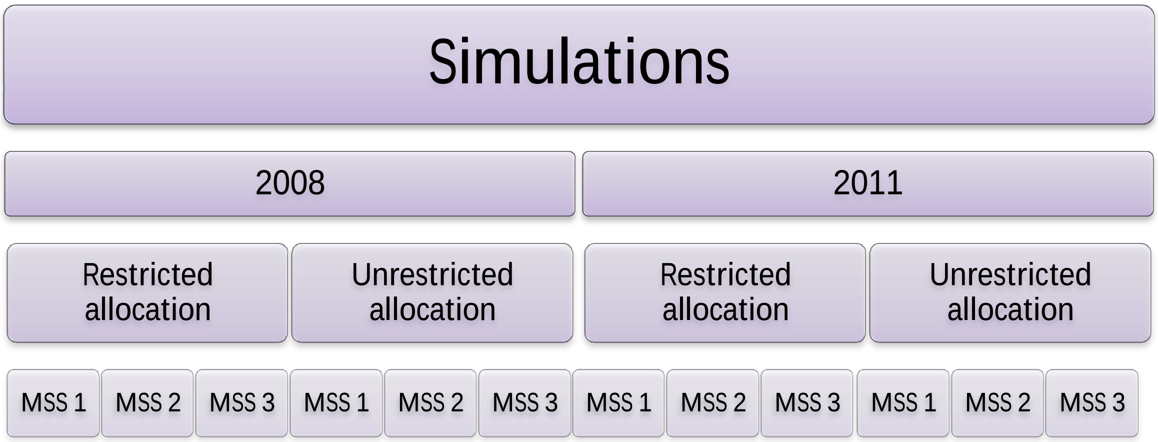


Figure 4.5: Graphical representation of the planning policies investigated in the simulation

Subsection 4.4.1 describes the two scenarios. Subsection 4.4.2 describes the allocation of ORs. Subsection 4.4.3 describes the three planning policies.

4.4.1 Scenarios

We investigate two scenarios: the situation in 2008 and the situation in 2011. There are three big differences between both scenarios. First, in 2008 about 11,000 elective patients were treated. In the 2011 scenario 14,000 elective patients are expected at an actual OR. Second, in 2008 only 8 ORs were available, while currently, there are 10 ORs operational. Third, because there are more patients and more ORs, the allocation of specialties to ORs is different.

For the 2011 scenario, we generated 16,000 patients to serve 14,000 elective patients. The number of patients is retrieved from the production plan of 2011.

4.4.2 Allocation of specialties to ORs

Specialties are allocated to an OR. First, we investigate the performance when using an MSS in the current allocation of specialties to ORs (restricted). This allocation corresponds with the availability of surgeons. Second, we investigate performance when we optimize the allocation of specialties to ORs (unrestricted). The number of ORs per specialties stays constant, but the day on which the OR is available to a specialty differs.

4.4.3 Planning policies

We test three versions of an MSS, all constructed by the simulation program. Table 4.4 shows the three available options for optimization: On OR standard deviation, on ward utilization and on ward admissions and discharges. For all three options a heuristic is performed which randomly select two surgeries and swaps them if it reduces the standard deviation.

Table 4.4: Planning policies

Planning policy	Optimization
MSS 1	Optimization on standard deviation of OR utilization
MSS 2	Optimization on standard deviation of ward utilization
MSS 3	Optimization on standard deviation of admissions and discharges

5 Results

This chapter presents the results of the simulations. Section 5.1 presents the results of the simulations for the 2008 scenario. Section 5.2 presents the results of the simulations in the 2011 scenario. Finally, Section 5.3 discusses the results of the sensitivity analyses we performed.

5.1 Simulations in the 2008 scenario

In this section we discuss the performance per planning policy. For each planning policy we discuss the performance when the allocation of specialties to ORs is restricted to the current schedule and when it is optimized. Table 5.1 shows the results for the 2008 scenario with restricted allocation and with unrestricted allocation of specialties to ORs. For both interventions the three MSSs are compared with the current planning policy.

Table 5.1: Results for scenario 2008

Current : Uses current planning policy
MSS 1 : Uses MSS, optimized on utilization of OR
MSS 2 : Uses MSS, optimized on utilization of ward
MSS 3 : Uses MSS, optimized on admissions and discharges at the ward

	2008							
	Restricted allocation				Unrestricted allocation			
	current	mss 1	mss 2	mss 3	current	mss 1	mss 2	mss 3
MSS coverage	**n.a.**	81.5%	81.7%	81.2%	**n.a.**	81.5%	81.2%	81.1%
OR utilization	**84.3%**	83.3%	84.5%	84.7%	**84.6%**	84.0%	84.4%	83.3%
OR overtime	**4.2%**	4.6%	4.2%	4.3%	**4.2%**	4.3%	4.3%	4.5%
OR levelling	**9.4%**	9.2%	9.5%	9.2%	**9.4%**	9.5%	9.1%	10.0%
Ward utilization	**107.6%**	106.5%	108.0%	108.4%	**107.7%**	109.7%	109.3%	106.8%
Ward leveling (utilization)	**12.1%**	11.8%	10.7%	12.3%	**12.4%**	11.9%	11.9%	11.7%
Ward leveling (adm+dis)	**20.0%**	23.4%	18.9%	20.1%	**20.4%**	16.5%	13.5%	14.9%
X-ray over utilization	**0.3%**	0.2%	0.5%	0.2%	**0.3%**	0.3%	0.5%	0.4%
Cancelled surgeries	**7.9%**	10.7%	8.0%	8.0%	**7.8%**	6.8%	7.2%	8.4%
Delayed surgeries	**27.8%**	26.8%	27.9%	28.1%	**27.3%**	28.1%	27.2%	27.0%

In 2008 11,000 elective surgeries and 580 emergency surgeries were performed. Only emergency surgeries performed during the opening hours of the OR department are included.

5.1.1 Results MSS 1

MSS 1 is optimized on utilization of the OR. Therefore we expect this MSS to perform well on the OR measures. Surprisingly, Table 5.1 shows that MSS 1 (with restricted allocation) performs worse of all MSSs for OR utilization, OR overtime and cancelled surgeries in the 2008 scenario. However, MSS 1 performs best on OR leveling. This is expected as MSS 1 aims for approaching the end time of the OR. The low utilization probably originates from the increased percentage of cancelled surgeries. This also explains the low percentage of resource conflicts for X-Ray equipment and delayed surgeries. MSS 1 scores moderately on leveling of ward utilization and low on ward utilization and leveling of admissions and discharges.

With unrestricted allocation of OR time for specialties to ORs, the performance on OR measures of MSS 1 is similar to the restricted allocation. The ward measures improve, especially the leveling of admissions and discharges improves with 7 percentage points.

5.1.2 Results MSS 2

MSS 2 is optimized on the leveling of ward utilization. Table 5.1 shows this MSS has the lowest overtime and a moderate utilization. MSS 2 only performs less on OR leveling. MSS 2 performs best on both ward leveling indicators, with reductions of 1.4 percentage points on utilization leveling and 1.1 percentage points on leveling of admissions and discharges.

When the allocation is unrestricted, the performance on leveling increases further. OR utilization and overtime are similar, but the OR leveling improves with 0.4 percentage points. Ward performance on the leveling of utilization deteriorates, but remains better than with the current planning policy. The leveling of admissions and discharges improves with 6.9 percentage points.

5.1.3 Results MSS 3

MSS 3 is optimized on the leveling of ward admissions and discharges. Table 5.1 shows that this MSS performs well on OR overtime and leveling. On the ward leveling indicators, this MSS performs similar to the current situation.

When the allocation is unrestricted, the performance on the OR measures deteriorates. OR utilization decreases 1.3 percentage points. The leveling of utilization of the wards improves with 0.7 percentage points and the leveling of admissions and discharges with 5.5 percentage points.

5.2 Simulations in the 2011 scenario

In this section we discuss the performance per intervention. For each intervention we discuss the performance when the allocation of specialties to ORs is restricted to the current schedule and when it is optimized. Table 5.2 shows the results for the 2011 scenario with restricted allocation and with unrestricted allocation of specialties to ORs. For both interventions the three MSSs are compared with the current planning policy.

Table 5.2: Results for scenario 2011

Current: Uses current planning policy
MSS 1: Uses MSS, optimized on utilization of OR
MSS 2: Uses MSS, optimized on utilization of ward
MSS 3: Uses MSS, optimized on admissions and discharges at the ward

	2011							
	Restricted allocation				Unrestricted allocation			
	current	mss 1	mss 2	mss 3	current	mss 1	mss 2	mss 3
MSS coverage	**n.a.**	83.2%	82.8%	82.9%	**n.a.**	82.9%	82.8%	82.4%
OR utilization	**88.7%**	88.3%	89.0%	89.0%	**88.6%**	90.1%	89.1%	89.3%
OR overtime	**6.4%**	6.4%	6.2%	6.1%	**6.4%**	6.4%	6.1%	6.3%
OR leveling	**7.7%**	7.8%	8.1%	8.2%	**7.7%**	7.8%	7.9%	8.0%
Ward utilization	**134.5%**	136.1%	136.9%	136.6%	**135.2%**	137.1%	135.3%	138.0%
Ward leveling (utilization)	**15.8%**	15.5%	13.0%	13.2%	**15.7%**	11.2%	12.2%	12.2%
Ward leveling (adm+dis)	**20.4%**	20.3%	13.2%	13.4%	**20.2%**	11.9%	10.9%	15.0%
X-ray over utilization	**0.5%**	0.6%	0.5%	0.4%	**0.5%**	0.3%	0.3%	0.5%
Cancelled surgeries	**14.6%**	13.0%	11.2%	10.8%	**14.3%**	11.4%	11.4%	10.7%
Delayed surgeries	**25.2%**	25.8%	26.5%	26.6%	**24.7%**	25.9%	26.2%	26.1%

Important to note in Table 5.2 is the high utilization of the wards, all far above 100%. This is due to an increase in the number of patients (11,000 in 2008 versus 14,000 in 2011) while the capacity of the (simulated) wards remained the same.

5.2.1 Results MSS 1

Table 5.2 shows that MSS 1 performs similar to the 2008 scenario. On the OR measures MSS 1 performs comparable to the current planning policy. Ward leveling on admissions and discharges in the 2011 scenario is similar to the current planning policy, while in the 2008 scenario this measure deteriorated by 3.4 percentage points. An explanation is the increased OR capacity, which increases the freedom to swap surgeries and optimize the performance.

For the unrestricted simulations, the OR utilization shows an improvement of 1.5 percentage points. The ward measures improve significantly, especially the ward leveling of admissions and discharges improves with 8.3 percentage points. Both are an improvement compared to the 2008 scenario.

5.2.2 Results MSS 2

Table 5.2 shows that the improvements of MSS 2 are similar to those in the 2008 scenario. OR utilization stays comparable. Ward leveling on utilization improves with 2.8 percentage points and on admissions and discharges it improves with 7.2 percentage points. These improvements are even larger than in the 2008 scenario.

For the unrestricted simulations, the OR measures show similar improvements compared to the current planning policy. Compared to the current planning policy, the ward leveling on utilization improves with 3.5 percentage points and on admissions and discharges with 9.3 percentage points. These improvements are larger than in the 2008 scenario.

5.2.3 Results MSS 3

Table 5.2 shows that the performance of MSS 3 in the 2011 scenario is better than in the 2008 scenario. In the 2011 scenario, OR utilization is comparable to the current planning policy, while it deteriorated in the 2008 scenario. Compared to the current planning policy, the ward leveling on utilization improves with 2.6 percentage points and on admissions and discharges with 7 percentage points. These improvements are larger than in the 2008 scenario.

For the unrestricted situation, the OR utilization is again comparable. This is contrary to the 2008 scenario, where OR utilization deteriorated in the unrestricted situation. The leveling of ward utilization improves with 3.5 percentage points, comparable to the 2008 scenario. The leveling of ward admissions and discharges improves with 5.2 percentage points, which is lower than in the 2008 scenario.

5.3 Sensitivity analyses

In this section we test the stability of the found results by changing some parameters. We test on increasing the standard deviation of the LOS and on changing the volume of dummy surgeries[4]. Subsection 5.3.1 presents the results for increasing the standard deviation. Subsection 5.3.2 presents the results for rounding the number of MSS slots. Subsection 5.3.3 gives the conclusions of the sensitivity analysis.

Table 5.3 shows the results for the sensitivity analyses. We have chosen to investigate MSS 2 with fixed allocation. When the results are stable with restricted allocation, the results are also stable with the unrestricted allocation. We chose the 2011 scenario, because that is current situation, in which the MSS might be implemented.

Table 5.3: Results for sensitivity analyses in the 2011 scenario

MSS 2: Uses MSS, optimized on utilization of ward with restricted allocation of specialties to ORs

	mss 2	SD +10% mss 2	SD +20% mss 2	mss round down mss 2	mss round up mss 2
MSS coverage	82.8%	82.9%	82.6%	78.7%	86.5%
OR utilization	89.0%	88.9%	88.7%	89.1%	88.8%
OR overtime	6.2%	6.1%	6.2%	6.3%	6.1%
OR leveling	8.1%	8.1%	8.2%	7.8%	8.1%
Ward utilization	136.9%	136.4%	136.0%	136.2%	136.7%
Ward leveling (utilization)	13.0%	13.2%	14.8%	13.8%	13.2%
Ward leveling (adm+dis)	13.2%	12.8%	16.1%	13.8%	13.8%
X-ray over utilization	0.5%	0.7%	0.6%	0.5%	0.4%
Cancelled surgeries	11.2%	11.1%	11.5%	11.4%	11.4%
Delayed surgeries	26.5%	26.1%	25.8%	26.3%	26.3%

[4] Surgeries that not fit into the MSS.

5.3.1 Increasing standard deviation of the Length Of Stay

First, we test the stability of the solution when the standard deviation of the LOS increases, what e.g. happens if the groups are not well determined. Table 5.3 shows that performance deteriorates when standard deviation of the LOS increases, but even when it increases with 20%, MSS 2 still outperforms the current situation.

5.3.2 Dummy surgeries (round MSS slots)

A dummy surgery is a surgery which does not fit in the MSS. In the tested solutions, we calculated the number of MSS slots by dividing the expected annual number of surgeries by the number of periods, and we rounded this to the nearest integer. For some surgery types we will have more slots than necessary, and for other types, we do not have enough slots available.

We test two situations. First we round the number of MSS slots down, so there are not enough MSS slots to cover all surgeries of a surgery type. Second, we round the number of MSS slots up, which will gives us too much MSS slots.

Table 5.3 shows that in both situations performance is similar to the performance of the MSS which is round to the nearest integer. By rounding the number of MSS slots, only the coverage rate of the MSS is influenced.

5.3.3 Conclusions

We conclude that the MSS also works when the surgery types are of low quality, but that with improving the quality of the surgery types, performance of the MSS increases. The number of surgeries which cannot be captured by the MSS is not important for performance of the ORs and wards.

6 Conclusions and recommendations

The goal of this study was to: "*... investigate recurring OR planning policies that help stabilize ward workload, and lead to an acceptable level of OR utilization for Gelre Apeldoorn.*" To reach this goal, we investigated three different planning policies, all versions of an MSS.

Section 6.1 answers the research questions. Section 6.2 proposes a solution to reach the research goal. This section also elaborates on the sensitivity of the results. Section 6.3 gives our recommendations for further research and tips for implementation.

6.1 Answers to the research questions

In this section we answer the research questions.

RQ 1: What is proposed in the literature for planning of Operating Rooms?

The literature describes various planning policies. A Master Surgical Schedule (MSS) is presented as a suitable planning policy for cyclic OR planning. An MSS offers the opportunity to improve both the performance of the OR department and of the nursing wards.

RQ 2: Which performance indicators express performance of the wards and OR department?

Based on the literature and interviews, we selected nine performance indicators to evaluate the performance of different planning policies. For the OR performance we use: utilization, overtime, leveling of end times, X-ray overutilization, cancelled surgeries and delayed surgeries. For ward performance we use: utilization, leveling of utilization and leveling of admissions and discharges.

RQ 3: What is the current situation at Gelre Apeldoorn?

Currently, surgeries are planned using a first come first served method. Surgeries are only planned in OR time allocated to the specialty.

RQ 4: How to evaluate different planning policies?

To evaluate different planning policies, we created a simulation model based on data-analysis and interviews. For simulating, we used the simulation program "OR-manager". We used the simulation model to simulate two scenarios: 2008 and 2011.

RQ 5: How to construct surgery types for planning purposes?

An MSS requires a set of surgery types for planning. We developed a heuristic to create these surgery types. We developed this heuristic ourselves, in order to create groups that are recognizable to OR planners.

RQ 6: Is the simulation model valid?

The simulation model was validated by comparing the simulation results with the realization of 2008 and by discussing it with planning experts in the hospital.

RQ 7: Which planning policies should be evaluated?

We evaluate an MSS. Three improvement heuristics are available in the simulation software: optimization on OR utilization, optimization on ward utilization and optimization on ward admissions and discharges. We tested these three versions under the current allocation (restricted) of specialties to ORs and in an unrestricted situation.

RQ 8: What is the performance of the proposed planning policies?

Implementing an MSS shows improvements on ward measures without deteriorating the OR performance, compared to the current planning policy. Improvements on ward measures range up to 10 percentage points in both scenarios (2008 and 2011).

MSS 2 performs best in both scenarios and both allocation policies (restricted and unrestricted). The leveling of ward utilization improves with 1 to 4 percentage points and the leveling of admissions and discharges improves with 1 to 10 percentage points.

6.2 Main conclusion

Our research that investigated recurring OR planning policies shows that an MSS with unrestricted allocation of specialties to ORs, optimized on ward utilization, performs best (MSS 2). On average for both scenarios, the leveling of the utilization of the wards declines with 22%, while leveling of the admissions and discharges declines with 26%. In order to reach these improvements, we made 12 swaps. Appendix D shows these swaps. We expect a decline in the maximum number of beds in use on one day of 6%, which equals 13 beds. See 0 for the calculations.

Figure 6.1 shows the effect of the introduction of an MSS on the number of beds in use.

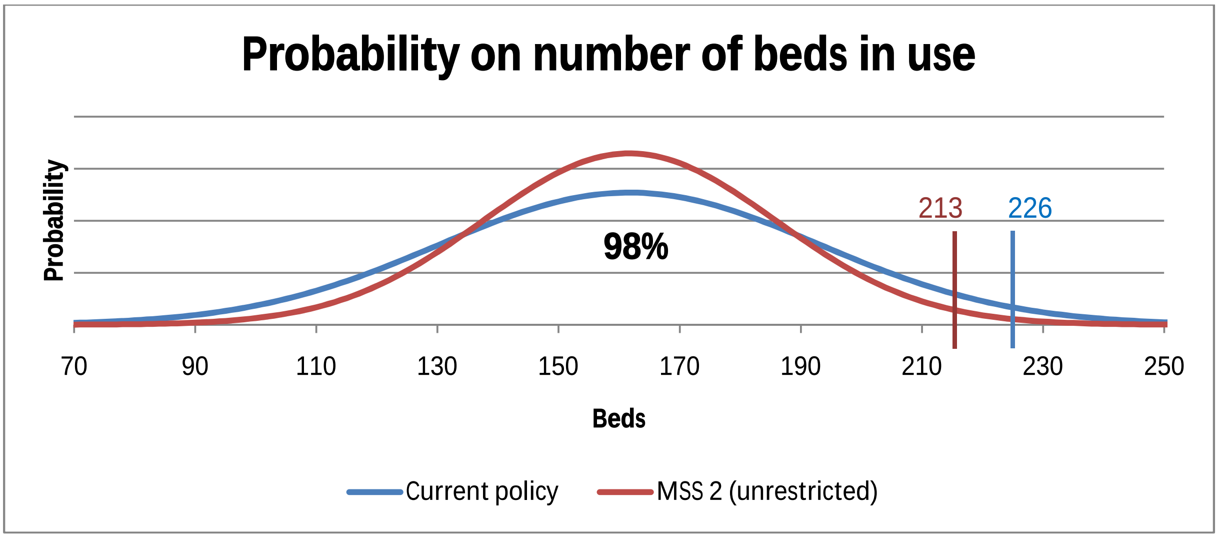


Figure 6.1: Probability on number of beds in use for surgical specialties

The blue vertical line shows the 98% confidence interval for the current planning policy at 226 beds. The red vertical bar shows the 98% confidence interval for the introduction for the unrestricted MSS 2 at 213 beds.

As Figure 6.1 shows, the 98% confidence interval for the number beds in use is 226 beds with the current planning policy. This means that in 98% of the days fewer beds are needed to serve all patients. When we use MSS 2 (unrestricted), the 98% confidence interval declines with 13 beds to

213 beds. The reductions are smaller than we expected for three reasons. First, performance is deteriorated by emergency patients, who arrive with a high variation. Second, we calculate performance over all specialties, while in reality multiple specialties are combined at one ward. A busy day for one specialty can therefore be compensated with a quiet day for another specialty (the pooling effect). Third, the optimization of the MSS is complex. It is a multi objective optimization, where the importance between the different objectives is arbitrary. We expect that more improvements are possible with a more sophisticated heuristic like simulated annealing[5].

6.3 Recommendations

Subsection 6.3.1 gives some recommendations about the data recording. Subsection 6.3.2 gives some recommendations for swapping the allocation of specialties to ORs. Subsection 6.3.3 gives some recommendations about the use of an MSS and for implementation at Gelre Apeldoorn. Subsection 6.3.4 gives some recommendations for further research.

6.3.1 Data recording

We recommend Gelre Apeldoorn to pay continuous attention to the process of data recording. It is of major importance to gather reliable data about surgery duration and LOS in order to construct a reliable MSS. One suggestion to improve the recording is to increase awareness of the importance of reliable data. For example by taking random samples, where performance in the database is compared with the actual measures. The differences show where people work with wrong procedures, don't use the procedures or where procedures not match with the process. This can be included in the safety round ("veiligheidsronde"), which is regularly performed.

We also recommend to increase insight and awareness of medical employees (at OR and wards) to the importance of reliable data. Unaware of their actions, they sometimes deteriorate data. For example, when the registration of a discharge is done hours after the physical discharge, the data becomes less reliable.

6.3.2 Make swaps in the schedule of specialists

In the best performing MSS, we found an optimal allocation of specialties to OR days. To change the current schedule into the optimal schedule, we need 12 swaps (see: Appendix D). We suggest investigating these swaps on their attainability.

6.3.3 Use of a Master Surgical Schedule

We recommend Gelre Apeldoorn to implement an MSS (MSS2), with the current (restricted) allocation of specialties to ORs. This will reduce workload of the wards significantly and without deteriorating the OR performance. After introducing an MSS the capacity needed for 98% of the days decreases with 6% to 213 beds. Also, introducing an MSS allows outpatient wards to plan surgeries, which helps improving customer satisfaction.

---

[5] Simulated Annealing (SA) is a global optimization strategy. It is designed to find the global optimum instead of a local optimum, by accepting under certain conditions worse solutions. For a short (non-scientific) introduction to SA see: http://en.wikipedia.org/wiki/Simulated_annealing.

We recommend an MSS with restricted (to the current) allocation, because the implementation mainly consider the OR planners. This is a small group which is more aware of the planning issues. This will simplify the implementation.

For implementation we suggest three steps, freely based on the resistance interference strategy of Kotter and Schlesinger (1979): Awareness, Corporation and Feedback.

Awareness

First step is to raise awareness among the medical staff and the OR planners about the need for this change. The OR planners are already aware of the necessity of reducing variability and they see the potential of the introduction of an MSS.

The medical staff also sees the necessity of process improvements. Numerous project are already started to increase efficiency at outpatient wards and to improve the flow between the outpatient wards and the OR department.

Corporation

The second step is corporation. The medical staff must be convinced of the importance of the introduction of an MSS. Difficulties that the specialists and OR personnel possibly have are amongst others:

1. Fear for a limited mix of surgeries on an OR day (in order to maintain their license for all surgeries, they have to perform these surgeries a minimal number of times per year)
2. Fear that it is not possible to capture all surgeries in a surgery type
3. Fear to lose flexibility in the adaptability of the schedule

The first difficulty is invalidated by two reasons. An MSS works with surgery types, which consist of multiple surgeries. Also, during a day multiple surgery types are planned, so during an OR day a surgeon performs different surgeries.

The second difficulty is solved by putting more effort in the process of creating the surgery types. In our simulations we were able to cover 85% of the surgeries with the MSS. We recommend for Gelre Apeldoorn to add as much surgeries to a surgery type as possible, in order to create a stable group. Specialists and planners should be involved to be sure that the surgeries are medically comparable and that all resources are covered.

The third difficulty is a right fear. Currently, it often happens that specialists change their schedule on the spot for many reasons. The performance of the MSS is seriously undermined when this happened. Therefore, specialists need to be keener on their agenda and make less last minute changes.

When the specialists and planners are involved during the construction phase of the MSS, they become more aware of the system and that will improve their corporation.

Feedback

To help improving the MSS, feedback from the stakeholders is an important tool. The outpatient wards and planning department should give feedback on the quality of the surgery types and the fit of surgeries into the MSS. The OR department should give feedback on the planning, the estimation of surgery durations and the use of resources (like X-Ray, tools and ORs). Finally, the wards should give feedback on the influence on workload and on the moments in the schedule where the most problems occur. All this information can be used to further improve performance of the MSS.

It is also important to give feedback to the stakeholders. When they do not receive feedback, corporation will decline and it becomes harder to gain all benefits from the MSS.

6.3.4 Further research

For further research, we suggest investigating the influence of emergency surgeries, other improvement heuristics for the MSS and the inclusion of outpatient wards. In this subsection we discuss these suggestions.

Urgent and emergency surgeries

Urgent and emergency surgeries cause major variance at the OR and wards. Due to their nature, the number and type of urgent and emergency surgeries varies highly. Currently, Gelre Apeldoorn plans slack time for urgent and emergency surgeries at the OR. We suggest investigating the arriving urgent and emergency surgeries for possible recurring surgery types. If it is possible to take into account these surgeries or deal differently with them, variance can further be reduced.

Improvement heuristics for the MSS

We measure performance of the MSS on multiple objectives, but during the optimization, we only take one performance indicator into account. We suggest test a combination of optimization objectives. For example, first optimize on number of admittance and discharges at the wards and second optimize on utilization of the wards.

We optimize our planning by a simple swap heuristic. When a swap of two surgeries gives a better or equal solution, the swap is accepted. In this heuristic it is possible that we are now jammed in a local optimum. Therefore, we suggest investigating the benefits of implementing a more sophisticated heuristic like simulated annealing (SA). Simulated annealing allows worse solutions with a certain probability in order to escape from local optimums.

Outpatient wards

It is of major importance to have a stable mix of surgeries in surgery types, while using an MSS. When not enough, or too much, patients of a particularly surgery type arrive during a period at the hospital, the performance will deteriorate.

We suggest investigating the influence of the outpatient wards to the arrival pattern of the OR. This can be done by prioritizing specific patient groups or creating consulting hours for specific patient groups. When it is possible to stabilize the arrival pattern of patients at the OR department, the MSS will become more stable and reliable and therefore the benefits increase.

7 References

Bagirov, A. M., & Churilov, L. (2003). An optimization-based approach to patient grouping for acute healthcare in Australia. *Lecture notes in computer science*, 20-29.

Beliën, J., & Demeulemeester, E. (2007). Building cyclic master surgery schedules with leveled resulting bed occupancy. *European Journal of Operational Research, 176*, 1185-1204.

Beliën, J., Demeulemeester, E., & Cardoen, B. (2009). A decision support system for cyclic master surgery scheduling with multiple objectives. *Journal of Scheduling, 12*(2), 147-161.

Boer, F., & Beuzekom, M. v. (2009, June 16). Personeelstekort OK. *Medisch Contact,* 1100.

Cardoen, B., Demeulemeester, E., & Beliën, J. (2010). Operating room planning and scheduling: A literature review. *European Journal of Operational Research, 201*, 921-932.

Centraal Bureau voor de Statistiek. (2010). CBS - Statline. Retrieved November 18, 2010, from http://www.cbs.nl

El-Darzi, E., Abbi, R., Vasilakis, C., Gorunescu, F., Gorunescu, M., & Millard, P. (2009). Length of stay-based clustering methods for patient grouping. *Studies in computational Intelligence, 189*, 39-56.

Gelre Ziekenhuizen. (2010). Gelre ziekenhuizen krijgt erkenning als topklinisch ziekenhuis. Retrieved July 19, 2010, from http://www.gelreziekenhuizen.nl/Internet_Channel/19563/Gelre_ziekenhuizen_krijgt_erkenning_als_Topklinisch_Ziekenhuis.html

Hans, E., Houdenhoven, M. v., & Hulshof, P. (2010). A framework for Hospital Planning and Control: WORKING PAPER.

Hans, E. W., Wullink, G., Houdenhoven, M. v., & Kazemier, G. (2008). Robust Surgery Loading. *European Journal of Operational Research, 185*, 1038-1050.

Jun, J., Jacobson, S., & Swisher, J. (1999). Application of Discrete-Event Simulation in Health Care clinics: A Survey. *Journal of the Operational Research Society, 50,* 109-123.

Kotter, J. P., & Schlesinger, L. A. (1979). Choosing strategies for change. *Harvard Business Review, 57*(2), 106-114.

Law, A. M., & Kelton, W. D. (2000). *Simulation modeling and analysis* (Third ed.): McGraw-Hill.

Maruster, L., Weijters, T., Vries, G. d., Bosch, A. v. d., & Daelemans, W. (2002). Logistic-based patient grouping for multi-disciplinary treatment. *Artificial Intelligence in Medicine, 26*, 87-107.

Ommen, A.-M. v. (2010). Medewerkers tevredenheidsonderzoek Gelre Apeldoorn. *Gelrevue,* 6-8.

Plexus. (2009). *Eindrapportage OK-benchmark*: Plexus.

van Oostrum, J. M., Bredenhoff, E., & Hans, E. W. (2008). Managerial implications and suitability of a Master Surgical Scheduling approach.

van Oostrum, J. M., Houdenhoven, M. v., Hurink, J. L., Hans, E. W., Wullink, G., & Kazemier, G. (2008). A master surgery scheduling approach for cyclic scheduling in aperating room departments. *OR Spectrum, 30*(2), 355-374.

van Oostrum, J. M., Parlevliet, T., Wagelmans, A. P. M., & Kazemier, G. (2008). *A method for clustering surgical cases to allow master surgical scheduling.* Paper presented at the ORAHS 2008, Toronto.

Vanberkel, P. T., Boucherie, R. J., Hans, E. W., Hurink, J. L., & Litvak, N. (2009). *A Survey of Health Care Models that Encompass Multiple Departments*.Unpublished manuscript, Enschede, The Netherlands.

Ward, J. H. (1963). Hierarchical grouping to optimize an objective function. *Joural of the American Statistical Association, 58*(301), 236-244.

Appendix A. Data analyses

During 2009 and 2010 the major information systems of Gelre Apeldoorn were replaced. Before July 2009 Gelre Apeldoorn used ChipSoft for planning and registration at the OR department and DCC/ARS for registration at the wards. In July 2009 the software package SAP is introduced at the wards and since July 2010 SAP is also used at the OR department.

Due to the migration to SAP, data about the nursing wards for 2009 and 2010 is not as reliable as earlier data according to the involved departments. Because the current case mix is expected to be equal to the case mix in 2008, we have chosen to use 2008 data. Important to notice is that information about the wards is expected to be valid until July 2009, and information about surgeries is valid until July 2010.

Data processing

Each surgical procedure is recorded in the hospital database. In 2008 a total of 24,427 surgical procedures were performed. A surgery can consist of multiple surgical procedures and involve multiple surgeons. Therefore, data has to be processed in several steps to be used.

The first step was to combine all surgical procedures performed during one surgery. The second step was to rename, for each specialty, the surgeries that consisted of identical surgical procedures. The third step was to link surgical data, with data of the nursing department. Both were registered in different databases until July 2010. Therefore it was necessary to combine surgical data (duration, priority, specialty, type, and patient number [ChipSoft]) with information about the Length of Stay (LOS) of the patient [KeyView], via the patient numbers. Surgical data of 2008 was combined with length of stay data of 2007, 2008, and 2009, because patients treated at the OR in 2008, can be admitted in 2007 or discharged in 2009.

Of all performed surgeries, it was possible to link 99.2 percent to an LOS. The remaining surgeries have an unknown LOS. Of the surgeries that were impossible to link, 22 percent consisted of activities that were not performed at in actual OR (like inserting drips), cancelled surgeries and registration errors. As it was unclear where the errors originated, we omitted these surgeries from the dataset.

The fourth step was to link the use of X-Ray equipment to the surgeries. From the list of X-Rays performed and the patients under research, it was possible to link 98 percent of all performed X-ray scans with a surgery. The scans that were unable to link are all registration errors and it is too complicated to individually combine them. After omitting these, the resulting dataset contains 18,239 surgeries.

The fifth step was to omit 2,042 surgeries which are not performed in an OR. After removing those, the database consists of 16,197 surgeries with known LOS. In the last step, surgeries performed during one of the reduction periods were omitted. The final database consists now of 11,799 elective surgeries for 40 regular weeks during 2008.

General Surgery

General surgery is a large specialty, with specific subspecialties. During the planning process these subspecialties are important. Therefore the specialty for General Surgery is divided into four specific subspecialties. These subspecialties are General Surgery, Oncologic Surgery, Vascular Surgery, and Gastroenterological surgery.

A.1 Analysis of past years

The 2008 case mix is expected to be usable for this study, because there were no big changes in medical staffing. Due to the comparable case mix, the pattern of surgery duration, LOS and surgery count is expected to be stable. Figure 7.1 shows the number of surgeries performed, the total surgery duration and the sum of the length of stay, per period. We chose for a two week interval because Gelre Apeldoorn works with a cyclic schedule of two weeks. Built-in variance due to the current planning is not eliminated.

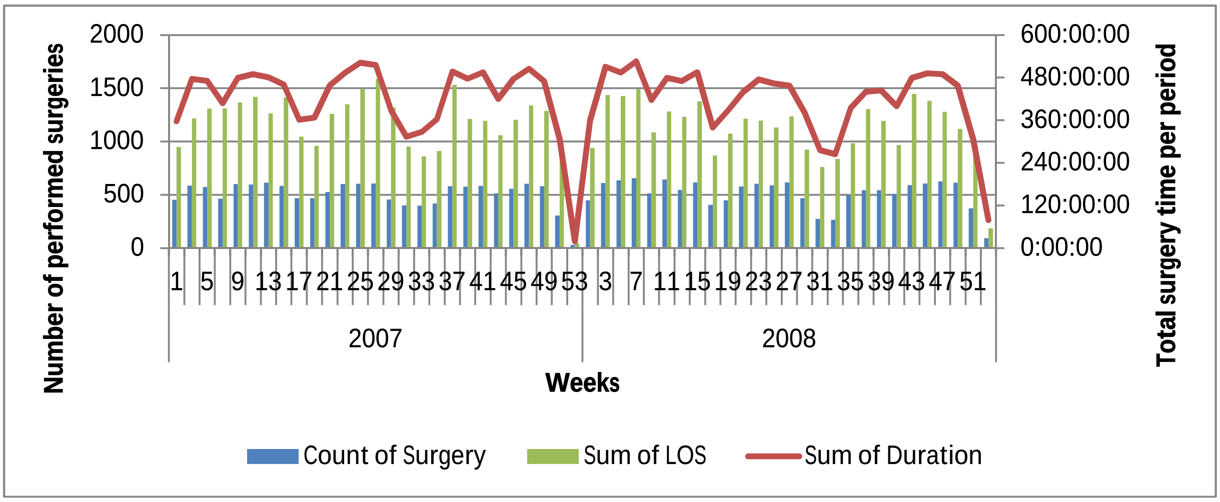


Figure 7.1: Number of surgeries, sum of LOS and sum of duration, per two weeks for all elective surgeries over 2007 & 2008 for all specialties (n= 15,998 [2007], n=16,197 [2008])

[Source: KeyView and ChipSoft]

Figure 7.1 shows a repetitive pattern over the years 2007 and 2008. The declines in Figure 7.1 are during reduction periods. Therefore we chose to focus on regular periods and consider the pattern in Figure 7.1 stable. Figure 7.2 shows the average LOS and surgery duration per patient.

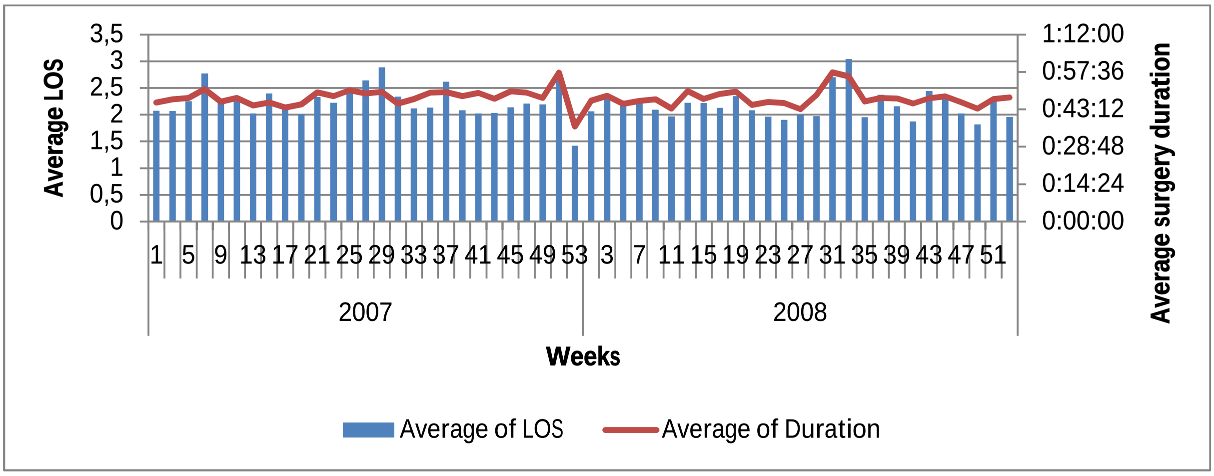


Figure 7.2: Average LOS and duration per two weeks for elective surgeries over 2007 & 2008 for all specialties (n= 15,998 [2007], n=16,197 [2008])

[Source: KeyView and ChipSoft]

Figure 7.2 shows that the average surgery duration and average LOS are also stable over 2007 and 2008. There are only some minor disturbances around New Year and reduction periods. This can be explained because in these periods there are other types of surgeries performed due to holidays and reduced capacity. Patients like to postpone less urgent surgeries until they are back from their holidays. The histograms per specialty are printed in Figure 7.2, and show a comparable trend.

After evaluation of Figure 7.1 and Figure 7.2, we conclude that except for the reduction periods, surgery duration and LOS is stable over the years, and it is therefore appropriate to use 2008 data in this study.

Appendix B. Simulation settings

In the table in this appendix are the settings given which are used in the simulation.

	Option:	Value:
1	Number of periods	20
2	Number of days per period	14
3	Start of working day	0.333333
4	Length of working day (minutes)	480
5	Outpatient OR costs / year	350000
6	Dedicated Inpatient OR costs / year	400000
7	Generic Inpatient OR costs / year	500000
8	Emergency OR costs / year	400000
9	Expected number of patients / year	16280
10	Maximum number of waiting weeks	2
11	Anesthesia Assistant costs / year	60000
12	Anesthetist costs / year	170000
13	Surgery Assistant costs / year	60000
14	Anesthesia Assistants per inpatient/emergency OR	1,1
15	Anesthetists per inpatient/emergency OR	0,5
16	Surgery Assistants per inpatient/emergency OR	2,4
17	Anesthesia Assistants per outpatient OR	1
18	Anesthetists per outpatient OR	0,25
19	Surgery Assistants per outpatient OR	1
20	Scenario name	Gelre_Ronald
21	Use advanced interface features instrument trays	TRUE
22	Elective surgeries may start before planned start	TRUE
23	Nr of ORs that can deal with emergencies	2
24	Nr of simulation runs	20
25	Default surgery startup time	0
26	Default surgery cleaning time	2
27	Delayed elective surgeries may move to another OR	FALSE
28	Elective surgeries may move to another available and suitable OR	FALSE
29	Elective surgeries may not move to another available and suitable OR	TRUE
30	Cancel elective surgeries that have not been performed on their planned day	FALSE
31	Cancel emergency surgeries that have not been performed on their arrival day	FALSE
32	Cancel semi-emergency surgeries that have not been performed on their arrival day	FALSE
33	All patients are available at the start of the day	TRUE
34	outpatient surgeries must be performed in outpatient ors	FALSE
35	Use appointment slots	FALSE
36	Write detailed simulation output in Excel files	FALSE
37	Schedule lunchbreak	FALSE
38	Schedule lunchbreak after	0.541667
39	Schedule lunchbreak before	0.541667
40	Use no-show	TRUE
41	Emergency surgeries may be performed in any type of OR	TRUE
42	Semi-urgent surgeries may be performed in any type of OR	TRUE
43	do not start elective surgeries if more than x% is outside working hrs	35

44	do not start (semi) emergency surgeries if more than x% is outside working hrs	100
45	enable do not start elective surgeries if more than x% is outside working hrs	TRUE
46	enable do not start (semi) emergency surgeries if more than x% is outside working hrs	FALSE
47	surgeries cannot last into the next day (i.e. are stopped at midnight)	TRUE
48	allow overtime	TRUE
49	surgery with an mss slot may only be performed in the mss slot	FALSE
50	close empty ors after planning	FALSE
51	use casemix	TRUE
52	fill capacity	FALSE
53	waiting list	FALSE
54	percentage capacity	100
55	initial weeks of waiting list	1
56	Number of warm-up periods	2
57	Option regarding which arrivals to consider	0
58	job priority rule	due date
59	job selection rule	descending
60	or selection rule	best fit

Appendix C. Surgery Types

//ID	SpecID	P1 (min.)	P2 (min.)	DistrType	Percentage	Surgery type	Long name	Short name	Ward	Distribution LOS	P1 (min)	P2 (min)
1	6	40.70	24.78	LOGNORMAL	13.33%	o	Obstetrics & Gynaecology	GYNA	10	LogNormal	562.79	318.56
2	6	52.17	23.58	LOGNORMAL	8.96%	o	Obstetrics & Gynaecology	GYNA	10	LogNormal	577.71	279.74
3	6	65.83	35.22	LOGNORMAL	9.79%	o	Obstetrics & Gynaecology	GYNA	10	LogNormal	592.35	217.87
4	6	114.06	73.95	LOGNORMAL	5.83%	i	Obstetrics & Gynaecology(X-Ray)	GYNA_XRAY	3	LogNormal	4875.44	3868.51
5	6	54.38	26.98	LOGNORMAL	9.17%	i	Obstetrics & Gynaecology	GYNA	3	LogNormal	1676.32	1322.09
6	6	80.57	40.94	LOGNORMAL	13.96%	i	Obstetrics & Gynaecology	GYNA	3	LogNormal	4992.76	4427.71
7	6	123.60	64.95	LOGNORMAL	27.92%	i	Obstetrics & Gynaecology	GYNA	3	LogNormal	4714.24	3523.74
8	6	170.17	102.39	LOGNORMAL	11.04%	i	Obstetrics & Gynaecology	GYNA	3	LogNormal	7284.62	8706.99
9	10	25.03	24.85	LOGNORMAL	6.71%	o	Eye surgery(X-Ray)	OOGH_XRAY	10	LogNormal	512.80	406.49
10	10	64.11	60.60	LOGNORMAL	1.78%	i	Eye surgery	OOGH	9	LogNormal	1620.72	2532.32
11	10	7.69	7.33	LOGNORMAL	7.19%	o	Eye surgery	OOGH	10	LogNormal	382.72	258.38
12	10	8.49	5.33	LOGNORMAL	5.55%	o	Eye surgery	OOGH	10	LogNormal	283.27	139.64
13	10	25.20	18.97	LOGNORMAL	75.84%	o	Eye surgery	OOGH	10	LogNormal	506.45	345.01
14	10	59.73	45.93	LOGNORMAL	2.93%	o	Eye surgery	OOGH	10	LogNormal	533.66	360.95
15	13	61.81	52.19	LOGNORMAL	7.08%	i	Urology(X-Ray)	UROL_XRAY	7	LogNormal	2545.79	2924.68
16	13	40.52	25.41	LOGNORMAL	26.13%	i	Urology	UROL	7	LogNormal	3100.64	3522.58
17	13	64.62	36.97	LOGNORMAL	25.05%	i	Urology	UROL	7	LogNormal	3481.29	3200.31
18	13	183.05	126.35	LOGNORMAL	7.62%	i	Urology	UROL	7	LogNormal	14698.03	14059.37
19	13	32.22	20.12	LOGNORMAL	14.88%	o	Urology	UROL	10	LogNormal	579.45	333.62
20	13	47.20	25.04	LOGNORMAL	9.44%	o	Urology	UROL	10	LogNormal	552.34	312.61
21	13	63.90	41.28	LOGNORMAL	9.80%	o	Urology	UROL	10	LogNormal	593.81	302.74
22	11	79.01	54.00	LOGNORMAL	3.68%	i	Orthopaedic(X-Ray)	ORTH_XRAY	2	LogNormal	4757.55	4999.30

23	11	36.46	22.30	LOGNORMAL	3.30%	o	Orthopaedic(X-Ray)	ORTH_XRAY	10	LogNormal	522.25	259.83
24	11	39.11	22.54	LOGNORMAL	2.89%	i	Orthopaedic	ORTH	2	LogNormal	2243.68	3318.96
25	11	48.96	23.57	LOGNORMAL	2.84%	i	Orthopaedic	ORTH	2	LogNormal	2623.77	4456.58
26	11	59.36	31.85	LOGNORMAL	3.68%	i	Orthopaedic	ORTH	2	LogNormal	2414.81	2389.00
27	11	63.58	34.10	LOGNORMAL	3.72%	i	Orthopaedic	ORTH	2	LogNormal	5026.81	8053.42
28	11	73.29	41.05	LOGNORMAL	2.37%	i	Orthopaedic	ORTH	2	LogNormal	3875.14	6194.22
29	11	78.07	44.58	LOGNORMAL	9.87%	i	Orthopaedic	ORTH	2	LogNormal	6869.45	5534.16
30	11	91.06	47.56	LOGNORMAL	12.80%	i	Orthopaedic	ORTH	2	LogNormal	7693.63	7435.66
31	11	103.10	62.43	LOGNORMAL	5.40%	i	Orthopaedic	ORTH	2	LogNormal	5227.02	5498.52
32	11	113.55	54.22	LOGNORMAL	2.98%	i	Orthopaedic	ORTH	2	LogNormal	4534.44	7069.61
33	11	152.87	87.34	LOGNORMAL	2.79%	i	Orthopaedic	ORTH	2	LogNormal	12259.53	15159.65
34	11	25.88	14.38	LOGNORMAL	4.47%	o	Orthopaedic	ORTH	10	LogNormal	492.47	285.16
35	11	32.94	19.87	LOGNORMAL	10.84%	o	Orthopaedic	ORTH	10	LogNormal	549.23	268.03
36	11	34.01	17.83	LOGNORMAL	20.80%	o	Orthopaedic	ORTH	10	LogNormal	554.51	279.98
37	11	40.48	23.07	LOGNORMAL	3.49%	o	Orthopaedic	ORTH	10	LogNormal	544.01	303.74
38	11	45.72	17.39	LOGNORMAL	1.91%	o	Orthopaedic	ORTH	10	LogNormal	596.23	360.41
39	11	62.49	35.82	LOGNORMAL	2.19%	o	Orthopaedic	ORTH	10	LogNormal	698.22	385.94
40	7	109.12	110.85	LOGNORMAL	9.36%	o	Oral surgery(X-Ray)	KAAK_XRAY	10	LogNormal	1012.00	990.07
41	7	130.01	126.51	LOGNORMAL	10.34%	i	Oral surgery	KAAK	8	LogNormal	2555.54	4655.67
42	7	58.12	41.88	LOGNORMAL	80.30%	o	Oral surgery	KAAK	10	LogNormal	591.77	301.70
43	1	14.54	10.81	LOGNORMAL	3.25%	o	Anaesthetics(X-Ray)	ANES_XRAY	10	LogNormal	520.74	169.40
44	1	21.93	16.03	LOGNORMAL	3.15%	o	Anaesthetics(X-Ray)	ANES_XRAY	10	LogNormal	523.98	163.42
45	1	29.21	34.54	LOGNORMAL	3.52%	i	Anaesthetics	ANES	6	LogNormal	13234.45	18696.14
46	1	120.94	98.50	LOGNORMAL	2.19%	i	Anaesthetics	ANES	6	LogNormal	2535.08	2513.21
47	1	15.77	12.88	LOGNORMAL	46.03%	o	Anaesthetics	ANES	10	LogNormal	524.93	164.31
48	1	16.04	12.71	LOGNORMAL	14.67%	o	Anaesthetics	ANES	10	LogNormal	543.18	152.29
49	1	18.16	12.62	LOGNORMAL	2.24%	o	Anaesthetics	ANES	10	LogNormal	542.87	228.13
50	1	21.36	14.54	LOGNORMAL	3.09%	o	Anaesthetics	ANES	10	LogNormal	540.95	165.72

51	1	25.97	18.33	LOGNORMAL	2.19%	o	Anaesthetics	ANES	10	LogNormal	472.43	170.11
52	1	28.46	19.66	LOGNORMAL	14.99%	o	Anaesthetics	ANES	10	LogNormal	486.85	148.05
53	1	30.72	20.74	LOGNORMAL	4.69%	o	Anaesthetics	ANES	10	LogNormal	482.69	130.87
54	8	37.35	42.60	LOGNORMAL	6.26%	i	ENT(X-Ray)	KNO_XRAY	4	LogNormal	1588.87	1809.87
55	8	49.60	29.29	LOGNORMAL	17.63%	i	ENT	KNO	4	LogNormal	1779.24	1883.25
56	8	54.11	27.21	LOGNORMAL	4.72%	i	ENT	KNO	4	LogNormal	1685.22	3180.90
57	8	75.18	38.33	LOGNORMAL	6.55%	i	ENT	KNO	4	LogNormal	2266.41	2485.80
58	8	110.22	54.49	LOGNORMAL	4.82%	i	ENT	KNO	4	LogNormal	1918.20	1143.56
59	8	114.76	52.68	LOGNORMAL	4.72%	i	ENT	KNO	4	LogNormal	1851.06	1127.16
60	8	166.11	86.18	LOGNORMAL	5.78%	i	ENT	KNO	4	LogNormal	2165.20	1510.89
61	8	11.29	9.36	LOGNORMAL	41.71%	o	ENT	KNO	10	LogNormal	978.92	364.80
62	8	43.98	38.42	LOGNORMAL	7.80%	o	ENT	KNO	10	LogNormal	717.44	389.80
63	12	57.23	53.45	LOGNORMAL	8.70%	o	Plastic Surgery(X-Ray)	PLCH_XRAY	10	LogNormal	1156.19	1869.19
64	12	61.88	38.64	LOGNORMAL	7.51%	i	Plastic Surgery	PLCH	5	LogNormal	4894.32	8442.01
65	12	87.93	48.54	LOGNORMAL	7.63%	i	Plastic Surgery	PLCH	5	LogNormal	2097.20	1988.69
66	12	145.16	87.05	LOGNORMAL	8.70%	i	Plastic Surgery	PLCH	5	LogNormal	4742.75	6964.81
67	12	27.63	14.59	LOGNORMAL	7.75%	o	Plastic Surgery	PLCH	10	LogNormal	542.78	267.72
68	12	31.86	20.59	LOGNORMAL	8.34%	o	Plastic Surgery	PLCH	10	LogNormal	531.68	273.52
69	12	35.97	29.24	LOGNORMAL	5.13%	o	Plastic Surgery	PLCH	10	LogNormal	538.78	283.99
70	12	36.23	22.63	LOGNORMAL	6.44%	o	Plastic Surgery	PLCH	10	LogNormal	566.39	243.94
71	12	38.72	29.00	LOGNORMAL	10.73%	o	Plastic Surgery	PLCH	10	LogNormal	552.55	300.39
72	12	48.85	29.27	LOGNORMAL	5.96%	o	Plastic Surgery	PLCH	10	LogNormal	585.00	253.38
73	12	53.05	33.49	LOGNORMAL	7.15%	o	Plastic Surgery	PLCH	10	LogNormal	575.99	314.77
74	12	53.54	31.43	LOGNORMAL	6.79%	o	Plastic Surgery	PLCH	10	LogNormal	569.10	273.14
75	12	72.16	44.57	LOGNORMAL	9.18%	o	Plastic Surgery	PLCH	10	LogNormal	620.41	281.02
76	9	84.14	48.87	LOGNORMAL	100.00%	i	Neurosurgery	NEUR	9	LogNormal	3907.45	3655.55
77	2	115.70	87.61	LOGNORMAL	3.08%	i	General surgery(X-Ray)	CHIR_XRAY	1	LogNormal	6823.40	9674.93
78	2	51.90	38.32	LOGNORMAL	3.95%	o	General surgery(X-Ray)	CHIR_XRAY	10	LogNormal	627.49	374.57

79	2	47.01	29.77	LOGNORMAL	3.28%	i	General surgery	CHIR	1	LogNormal	4339.54	7415.67
80	2	66.08	40.55	LOGNORMAL	3.48%	i	General surgery	CHIR	1	LogNormal	2449.96	2326.46
81	2	78.41	43.96	LOGNORMAL	3.48%	i	General surgery	CHIR	1	LogNormal	10774.19	18172.10
82	2	90.51	49.41	LOGNORMAL	3.75%	i	General surgery	CHIR	1	LogNormal	7044.64	10226.52
83	2	92.12	49.36	LOGNORMAL	7.77%	i	General surgery	CHIR	1	LogNormal	4467.74	8732.79
84	2	103.01	61.70	LOGNORMAL	10.78%	i	General surgery	CHIR	1	LogNormal	2566.55	3050.98
85	2	117.76	61.46	LOGNORMAL	3.01%	i	General surgery	CHIR	1	LogNormal	9198.16	14518.30
86	2	171.54	102.50	LOGNORMAL	8.24%	i	General surgery	CHIR	1	LogNormal	12871.84	18970.76
87	2	29.64	18.70	LOGNORMAL	4.29%	o	General surgery	CHIR	10	LogNormal	639.76	431.08
88	2	40.47	26.42	LOGNORMAL	6.23%	o	General surgery	CHIR	10	LogNormal	603.49	353.62
89	2	42.03	25.70	LOGNORMAL	6.36%	o	General surgery	CHIR	10	LogNormal	601.21	372.65
90	2	43.11	23.49	LOGNORMAL	5.09%	o	General surgery	CHIR	10	LogNormal	669.99	406.97
91	2	47.33	25.34	LOGNORMAL	4.55%	o	General surgery	CHIR	10	LogNormal	611.91	358.48
92	2	55.90	30.96	LOGNORMAL	3.35%	o	General surgery	CHIR	10	LogNormal	677.44	374.16
93	2	62.76	39.42	LOGNORMAL	3.22%	o	General surgery	CHIR	10	LogNormal	691.61	348.00
94	2	75.39	45.83	LOGNORMAL	11.25%	o	General surgery	CHIR	10	LogNormal	617.33	336.38
95	2	100.26	58.51	LOGNORMAL	4.82%	o	General surgery	CHIR	10	LogNormal	735.56	413.47
96	3	124.73	89.45	LOGNORMAL	53.61%	i	Oncologic surgery	ONCO	1	LogNormal	9105.49	12955.36
97	3	248.38	156.52	LOGNORMAL	33.13%	i	Oncologic surgery	ONCO	1	LogNormal	15017.24	14960.09
98	3	51.48	35.34	LOGNORMAL	13.25%	o	Oncologic surgery	ONCO	10	LogNormal	602.69	395.30
99	5	121.79	85.61	LOGNORMAL	34.15%	i	Gastroentrological Surgery	GAST	1	LogNormal	7884.13	8326.26
100	5	244.49	153.38	LOGNORMAL	47.97%	i	Gastroentrological Surgery	GAST	1	LogNormal	17849.62	21226.54
101	5	29.92	23.93	LOGNORMAL	17.89%	o	Gastroentrological Surgery	GAST	10	LogNormal	603.37	401.16
102	4	105.18	68.40	LOGNORMAL	13.28%	i	Vascular Surgery	VAAT	1	LogNormal	5057.97	8711.24
103	4	222.98	148.21	LOGNORMAL	26.84%	i	Vascular Surgery	VAAT	1	LogNormal	12769.53	15594.64
104	4	56.68	34.55	LOGNORMAL	12.99%	o	Vascular Surgery	VAAT	10	LogNormal	531.26	338.78
105	4	72.95	45.25	LOGNORMAL	34.18%	o	Vascular Surgery	VAAT	10	LogNormal	518.50	292.95
106	4	100.53	51.64	LOGNORMAL	12.71%	o	Vascular Surgery	VAAT	10	LogNormal	562.47	267.27

Appendix D. Swaps in scenario 2011

Table 7.1 shows the swaps made in the 2011 scenario, optimized on utilization of the wards, with unrestricted allocation of specialties to ORs.

Table 7.1: Swaps in scenario 2011

Index	Specialty	From day:	To day:
1	General surgery	0	7
2	General surgery	2	10
3	Orthopaedics	0	1
4	Orthopaedics	0	9
5	Vascular surgery	1	9
6	ENT	3	11
7	Gynaecology	7	11
8	Plastic surgery	8	0
9	Plastic Surgery	9	10
10	Anaesthetics	9	2
11	Eye surgery	10	0
12	Oncologic surgery	11	8

Appendix E. Calculations of maximum capacity

In this appendix we explain how we calculated the savings in the bed utilization. We express the savings in the maximum capacity that is necessary to suffice demand with 99% certainty. We use the capacity utilization (98.6% of 164 beds) and the leveling of bed utilization of 2008 (19.4%). We assume that the number of beds in use is normal distributed, with mean 161.7 (0.986×164) and sigma 31.4 ($[0.986 \times 164] * 0.194$). After implementing an MSS, we expect that the standard deviation of utilization declines with 20%.

Table 7.2 shows the values of our calculations.

Table 7.2: Calculation of maximum necessary capacity of the nursing wards

	Current policy	MSS 2	Savings
Capacity	164	164	0%
Mean	161.7	161.7	0%
St. Dev	31.4	25.1	20%
Capacity necessary with 99% reliability interval (in beds)	226 beds	213 beds	6%

According to the normal distribution, the number of beds necessary, under the current planning policy, is 226. In 2008 the maximum number of beds in use on one day was 221.

When the capacity and the average utilization do not change, while the leveling is reduced with 22%, then we expect a reduction on the maximum number of beds used, of 7%. Table 7.2 shows that 7% reduction equals to 17 beds.