Improving elective OR planning at general ORs of Medisch Spectrum Twente

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University of twente, Netherlands

Supervisors:

Dr. ir. E.W. Hans, University of Twente, Enschede, the Netherlands

Dr. ir. J. M. J. Schutten, University of Twente, Enschede, the Netherlands

Cees Schenkeveld, Medisch Spectrum Twente, the Netherlands

Samenvatting

Aanleiding

Medisch Spectrum Twente (MST) is een topklinisch ziekenhuis dat op meerdere locaties in de regio rondom Enschede is gevestigd. Het ziekenhuis omvat zowel algemene operatiekamers (OK's) afdeling, als Thorax OK's. Dit onderzoek focusseert op de algemene OK's. De algemene OK's zijn verdeeld over locatie Enschede en Oldenzaal, waarbij Enschede de planning voor zowel de operaties in Oldenzaal als die in Enschede coördineert. Gedurende de tactische planning wordt de beschikbare OK capaciteit verdeeld over de verschillende specialismen door de uitgifte van OK blokken. Bij het toewijzen van deze OK blokken aan specialismen en tijdens het vullen van deze OK blokken met electieve patiënten wordt tot op heden geen rekening gehouden met de beschikbaarheid van resources, zoals de beschikbaarheid van verpleegbedden. Dit heeft schommelingen in de vraag naar resources tot gevolg en leidt tot resource conflicten. Door deze conflicten dienen regelmatig operationele OK programma's gewijzigd worden, wat leidt tot inefficiëntie en verminderde patiëntvriendelijkheid. Naast een kwalitatieve analyse van het plantraject, toont dit rapport een uitvoerige kwantitatieve analyse van de realisatie van de OK planning. We hebben de resultaten van MST vergeleken met twee benchmarks, gericht op het logistieke resultaat van OK's van diverse Nederlandse ziekenhuizen. Met het oog op de vulling van de OK programma's valt op dat MST een lagere OK bezetting realiseert dan verwacht mag worden aan de hand van de benchmarks.

Eén van de lopende verbeterprojecten binnen het MST is het ontwikkelen van een electief behandel centrum (EBC) voor laag variabele, hoog volume electieve ingrepen in Oldenzaal. Onderdeel van dit plan is een uitbreiding van het OK complex in Oldenzaal van 2 naar 4 volwaardige OK's. Dit rapport neemt de gevolgen van de realisatie van een dergelijk EBC op het resultaat van de OK afdeling en verpleegafdeling mee.

Doel van het onderzoek

Naar aanleiding van de uitgevoerde kwantitatieve en kwalitatieve analyses luidt de doelstelling van het onderzoek als volgt:

"Het presenteren, evalueren en verifiëren van interventies die de OK bezetting verhogen, de variabiliteit in de vraag naar resources verminderen en het verminderen van het aantal keren dat een OK programma wordt gewijzigd voordat het wordt uitgevoerd."

Interventies

Om deze doelstelling te realiseren stellen we een drietal interventies voor:

- Het toepassen van een cyclisch Master Surgical Schedule (MSS) in Oldenzaal.

- Het koppelen van de verwachte vraag naar beddencapaciteit aan het tactisch blokplan in Enschede.
- Het verkorten van de geplande OK duur per operatie.

Cyclisch Master Surgical Schedule (Van Oostrum et al., 2008b)

Qua karakteristieken is EBC Oldenzaal geschikt voor de toepassing van een cyclisch Master Surgical Scheduling benadering. Hierin worden uniforme groepen van operaties vastgesteld, de “Master Slots”. Deze groepen zijn zo uniform mogelijk op zowel medische als logistieke gronden. Vervolgens kunnen deze (lege) sloten worden gepland in het OK programma. Op het moment dat een geschikte patiënt arriveert en een leeg slot beschikbaar is, kan de patiënt direct in dit slot gepland worden. De benadering maakt het mogelijk om op basis van het tactisch programma (zonder dat de daadwerkelijke patiënten bekend zijn) uitspraken te doen over benodigde resources. Bovendien levert deze benadering een framework waarin het mogelijk wordt al in een vroeg stadium patiënten op de OK programma’s te plaatsen en daarmee van een OK datum te voorzien.

Koppel verwachte vraag naar beddencapaciteit aan tactisch blokplan Enschede.

Vanwege het verschil in case mix en een hogere variabiliteit in beschikbare capaciteit en vraag is het voor locatie Enschede niet mogelijk gebruik te maken van een cyclisch MSS. We beperken ons daarom tot het bepalen van een tactische blok planning, waarbij op specialisme niveau wordt gekeken naar het aantal operaties per OK blok en het effect dat een dergelijk aantal operaties heeft op de uitstroom naar de verpleegafdeling. Na het genereren van een beginoplossing, verminderen we de variantie in bedbezetting en workload, door te schuiven met de verschillende blokken.

Verkorten van de geplande OK duur

Onwetendheid over de systematiek op basis waarvan de geplande operatieduur wordt berekend heeft ertoe geleid dat de duur van een operatie structureel overschat werd. Het terugzetten van deze waarden zal moeten leiden tot een verlaging van de afwijking tussen gerealiseerde en geplande tijden. Bovendien zal het verkorten van de geplande operatieduur een verhoging van de OK bezetting tot gevolg hebben. In de huidige situatie, berekent de planningssoftware de verwachte operatieduur aan de hand van een opgegeven kwantiel. Door een hoger kwantiel te kiezen wordt meer rekening gehouden met uitschieters in operatieduren, en wordt de geplande operatieduur groter. Een andere methodiek is het vullen van OK programma’s door uit te gaan van gemiddelde operatieduren, vermeerderd een zogenaamde ‘witte vlek’. Door het plannen van een witte vlek wordt ruimte gereserveerd in het OK programma om fluctuaties in operatieduren op te vangen. We vergelijken het effect van deze twee methodes aan de hand van OK bezetting en kans en hoeveelheid overuren.

Verificatie

Om de aangedragen interventies the verifiëren gebruiken we een simulatiemodel voor het effect op OK bezetting en overuren en een analytisch model voor het effect op de verwachte bedbezetting op verpleegafdelingen. Als input voor beide modellen gebruiken we historische data van de algeme OKs voor het jaar 2008.

Conclusies

- Er is geen significant bewijs dat er door te plannen met behulp van een witte vlek een beter resultaat wordt behaald dan door te plannen met de kwantiel methode. Er is daarom geen reden van de kwantiel methode af te stappen.
- De cyclische MSS benadering zorgt voor een kleine significant verbetering van de OK bezetting ten opzichte van het plannen zonder MSS benadering. De cyclische MSS benadering biedt daarnaast mogelijkheden om het direct inplannen van patiënten te ondersteunen, waardoor de benadering zeer waardevol is voor locatie Oldenzaal.
- Het verschuiven van de case mix als gevolg van het electief behandelcentrum in Oldenzaal levert extra beschikbare capaciteit op in Enschede. Door deze extra capaciteit vooral tegen het weekeinde leeg te laten en in het begin van de week vol te plannen is het mogelijk de variabiliteit op de verpleegafdeling aanzienlijk te verlagen. Voordat een dergelijke interventie echter doorgevoerd kan worden dient allereerst het effect op directe resources worden bepaald, zoals vraag naar personeel, verkoevercapaciteit en instrumentennetten. Een onevenwichtig verdeelde OK capaciteit zal voor deze resources juist tot een hogere variantie leiden.
- De realisatie van een EBC in Oldenzaal levert niet direct een hogere efficiëntie op voor het gehele ziekenhuis. Door de verschuiving van de case mix, wordt de OK bezetting in Oldenzaal weliswaar verhoogd, maar dit gaat ten koste van de OK bezetting in Enschede.

Hoe nu verder?

- Voor wat betreft de gewenste OK bezetting, dient het OK management een afweging te maken tussen de baten van een hogere OK bezetting en de lasten van een hogere kans op overuren.
- Om het cyclisch MSS in Oldenzaal te kunnen implementeren is het noodzakelijk allereerst uniforme groepen van operatietypen te definiëren, aan de hand van zowel logisitieke als medische aspecten. Als overeenstemming is bereikt over deze groepen, kunnen deze groepen vervolgens aan een cyclisch MSS worden toegevoegd, waardoor het mogelijk wordt patiënten die een dergelijke operatie moeten ondergaan direct in de beschikbare sloten te plannen.

Om het cyclisch MSS in Enschede te kunnen toepassen is meer onderzoek nodig naar de mogelijkheden om het cyclisch MSS om te kunnen laten gaan met reductieperioden en seizoensafhankelijk fluctuaties in de vraag.

Summary

Background and scope

Medisch Spectrum Twente (MST) is a top clinical hospital with several locations in the surroundings of Enschede. The hospital has both general operating rooms (OR) departments and Thorax ORs. This research focuses on the general ORs. The general ORs are located in Enschede and in Oldenzaal. Enschede coordinates resource capacity planning for both locations. During tactical OR planning, the tactical planner assigns available OR capacity to various specialties by the distribution of OR blocks. Currently, during the assignment of OR capacity, the tactical planner does not consider the availability of resources, such as equipment or beds. This causes fluctuations in resource demand and leads to resource conflicts. These conflicts regularly cause planners to make changes to OR programs, which leads to inefficiency and decreases patient satisfaction. Besides a qualitative analysis of the planning process, this report also shows an extensive quantitative analysis of the logistic performance of the OR department. We compared the results of MST to the results of other Dutch hospitals, using two existing benchmark studies. In comparison to the benchmarks, MST's OR utilization is lower than what could be expected.

One of the current developments within MST, is the realization of an elective treatment center (Dutch: EBC) in Oldenzaal. The EBC focuses on low variability, high volume, elective surgeries. Part of the plan is to expand the current capacity of location Oldenzaal from 2 to 4 fully functional ORs. This research incorporates the effects of the realization of an EBC on the results of the OR department and wards.

Research objective

Based on the qualitative and quantitative analyses, we came to the following research objective:

"To present, evaluate, and quantitatively verify interventions that increase OR utilization, decrease variability in bed demand of surgical wards, and decrease the number of changes to the OR program before it is being executed."

Interventions

To realize this objective, we propose three interventions:

- Apply cyclic Master Surgical Scheduling (MSS) in Oldenzaal.
- Evaluate the tactical block schedule in Enschede using the projected bed demand at surgical wards.
- Decrease the forecasted surgery durations.

Cyclic Master Surgical Scheduling approach (Van Oostrum et al., 2008b)

EBC Oldenzaal is suitable for applying the cyclic Master Surgical Scheduling approach. The approach starts by defining various clusters of comparable surgery types, the so-called “Master Slots”. These clusters are as uniformly as possible based on medical and logistical characteristics. Before scheduling patients, the empty slots can be assigned to the different OR blocks during tactical planning. The approach enables the planners to evaluate the tactical plan on the demand for resources and the expected utilization of OR capacity (without the knowledge of which patients will arrive). Additionally, the approach offers a framework by which it enables planners to assign patients to available slots during the early stages of the process, thereby offering patients the surgery dates immediately.

Link expected bed demand to tactical block schedule.

The difference in case mix and the increased variability in the availability of capacity of location Enschede prevent the use of a cyclic MSS. In order to be able to comment on the effect of a tactical block schedule on resource demand (of surgical wards), we evaluate the tactical plan by examining general characteristics of each specialty block. Based on empirical distributions for the number of cases per OR block and the length of stay of patients in the surgical ward, we are able to calculate the probability distributions for the number of occupied beds of surgical wards. Based on this probability distribution, we evaluate existing tactical block schedules and decrease expected variability in bed demand by changing the tactical block schedule.

Decrease forecasts of surgery durations

Ignorance on the methodology behind the calculation of the planned surgery durations has led to a structural overestimation of surgery durations. Reducing the forecasted surgery durations leads to a lower deviation between planned and realized surgery durations. Additionally, decreasing the forecasted surgery durations will lead to an increase in OR utilization. The amount by which the forecast can be decreases depends on the desired probability of overtime. Currently, the planning software calculates the planned surgery duration by means of a specified quantile. By choosing a higher quantile, more outliers are included, and the planned surgery durations increases. A different methodology is to schedule surgeries using its expected surgery durations and adding an amount of “planned slack” to cope with uncertainty. We evaluate the effect of both methods on OR utilization and the probability and amount of overtime.

Computational verification

To verify the proposed interventions, we use a simulation model for the effect on OR utilization and an analytical model for the effect on bed capacity of surgical wards. As input for these models, we use historical data of the general ORs in 2008.

Conclusions

- There is no significant statistical evidence that logistical performance increases by using planned slack instead of the quantile method. Therefore, we find no reason for replacing the currently used methodology.
- The cyclic MSS approach, that schedules master slots using list scheduling, leads to minor, but significant benefits compared to scheduling without master slots in Oldenzaal. Also, the possibility of enabling the direct scheduling of patients makes the approach valuable for location Oldenzaal.
- The implementation of the EBC in Oldenzaal changes the case mix for both locations. The extra capacity in Oldenzaal increases flexibility in the tactical schedule in Enschede, since the required capacity in Enschede decreases. By reducing available OR capacity towards the end of the week instead reducing capacity evenly over the week, it is possible to decrease variability in bed demand of surgical wards. However, before actually implementing such a tactical schedule, the availability of other resources has to be examined, such as the demand for recovery capacity, and instruments. More OR capacity towards the beginning of the week creates more variability in the demand for these direct resources.
- The realization of an EBC in Oldenzaal does not cause increased OR utilization for the entire hospital. Although the shift in the case mix does improve efficiency in Oldenzaal, efficiency in Enschede decreases.

Further research

- OR management should decide which level of OR utilization is desirable, thereby making the trade-off between OR utilization and overtime (probability).
- Before implementing a cyclic MSS in Oldenzaal, uniform clusters of surgery types have to be formed, based on logistic and medical characteristics. When these clusters are defined, they can be assigned to Master Slots, which enables scheduling patients immediately after they finished pre operative screening (POS).
- To be able to use the cyclic MSS approach in Enschede, further research is required on the possibilities of introducing reduction periods and demand fluctuations in the model.

Voorwoord

Beste lezer,

Hier voor je ligt een voor mij belangrijk verslag. Ik rond er namelijk mijn masteropleiding Industrial Engineering & Management mee af. Het onderwerp waarop ik afstudeer is het plannen van OK capaciteit in het Medisch Spectrum Twente. Als je mij 20 jaar geleden had gevraagd waar ik later zou kunnen komen te werken had ik waarschijnlijk het ziekenhuis als één van de eerste dingen uitgesloten. Ik had vroeger namelijk nog wel eens de neiging om bij het binnengaan van een ziekenhuis gevaarlijk wit weg te trekken, om te vallen en dan vervolgens op een brancard ergens in de gang weer bij te komen.

Neem dan het onderwerp van mijn onderzoek: “OK planning”. Mensen die mij kennen, weten dat ik erg goed ben in het opstellen van planningen. Ironisch genoeg heb ik nog wel eens moeite om me aan mijn eigen, doorgaans wat optimistische, planning te houden.

Maar goed, hoe kwam ik hier dan wel bij? Eén van de laatste vakken van mijn master was het vak: “Optimization of Healthcare Processes 2”. Nadat ik mijn bacheloropdracht bij een machinefabriek had uitgevoerd, leerde ik tijdens dit vak een hele andere omgeving kennen. Na het vak met veel plezier gevolgd te hebben, kwam ik via Erwin Hans en Frans Wolbers uiteindelijk terecht bij het MST.

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Gerwen Apenhorst
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1. Introduction

This first chapter describes the motivation for this research. It globally describes how developments in society and the health care industry force Medisch Spectrum Twente (MST) to improve their processes in order to provide the high quality of care it wishes to offer. This chapter describes problems that prevent MST from achieving an efficient operating room (OR) planning. Finally, we define the objective of the research presented in this report and formulate the corresponding research questions.

1.1 Background

Recent developments in the social system in the Netherlands have forced health care providers to examine their logistic processes. Dorsten (2005) describes two changes that have major impact on the way health care is organized. First, the annual budget depends on actual production instead of the available capacity. This implicates that on average the revenues from performing certain treatments should outweigh the cost price for this treatment. A second development is the introduction of negotiable Diagnosis-Treatment-Combinations (Dutch: DBC). A low cost price improves MST's position in negotiation with health insurance organizations. Additionally, for a small part of these negotiable DBCs, providing the best costs/quality ratio can result in exclusive contracts with health insurers. The percentage of DBCs that is negotiable has grown from 10% in 2005 (Van Dorsten, 2005) to 31% in 2010 (Nederlandse Zorgautoriteit, 2010). The Dutch healthcare authority has advised the ministry of Health to expand the negotiable part of the DBC to 50% in 2011 (Nederlandse Zorgautoriteit, 2010). These developments increase the importance of offering high quality care against competitive prices.

Both developments increase the importance of optimizing the utilization of expensive resources such as ORs. MST distinguishes between general and thoracic ORs. The thoracic ORs are physically separated from the general ORs and are dedicated to thoracic surgery. The general ORs are used by several independent specialties sharing resources such as OR time, OR personnel, equipment, and recovery space. While many different parties are involved in the planning and scheduling process, even more parties depend on the outcomes of the OR schedule. Therefore, improving OR planning and scheduling not only concerns the OR with all involved parties, but also downstream functions (e.g. recovery, ICU, and wards).

1.2 Context description

MST is one of the largest non-academic hospitals in the Netherlands. Its core business is to offer curative care for the Twente region. With locations in Enschede and Oldenzaal, MST has a service area of approximately 264,000 people. The entire organization consists of approximately 4,000 employees, among which 200 medical specialists. Besides basic care, MST also delivers topclinical care and is one of the 11 trauma centers in the Netherlands (Medisch Spectrum Twente, 2008). Cardoen et al. (2008) indicate that the operating theatre is the most important revenue and cost centre in an hospital . Improving processes concerning the ORs will therefore affect the performance of the entire organization. In 2008, MST's general ORs treated little over 15,000 elective patients and approximately 1,300 emergency patients during regular working hours.

In 2008, a reorganization changed the organizational structure of MST. The organization is now functionally divided into multiple departments. This means that each surgical speciality is organized in its own department and is therefore responsible for its own performance. Medical specialists however are often not employed by the hospital, but are organized in separate partnerships. This makes it more difficult to direct them.

1.3 Problem description

Various specialties share the general ORs. Each specialty makes production agreements with health insurance organizations. Based on these agreements they request OR capacity. The distribution of this OR capacity is centrally organized. After an OR committee assigns blocks to different specialties, the specialties individually assign surgeons to specific blocks. Each specialty organizes the actual patient scheduling individually (decentral planning approach). The general focus lies with creating a schedule according to a specialist's or specialty's preferences, without considering the availability of shared resources. Variability in both the arrivals of patients as well as the durations of surgeries, however, complicates the scheduling process. To cope with the variability in arrival process of patients, most specialties postpone the actual scheduling of patients until the last possible moment. General surgery, for example, completes the OR schedule only one week prior to the surgery. Neurosurgery postpones the completion of the schedule even further until one day before surgery.

Although MST uses a software package to support planners, the usage of this software remains limited to a digital plan board and data collection tool. The software does not offer tools to optimize a schedule or to prevent or identify resource conflicts. In order to make sure that ORs are not over- or under- scheduled and to avoid resource conflicts, an OR committee weekly evaluates next week's program. This is the first time in the process that a coordinating party examines the OR utilization and availability of resources on an integral level. Since neurosurgery does not complete its schedule until one day before surgery, the OR committee does not take into account the resource usage of neurosurgical surgeries. Instead, a part of the resource capacity necessary for neurosurgery is reserved. The day before execution of the program, the day-coordinator reevaluates the complete program.

In case the OR committee identifies research conflicts in next week's program, planners have to adjust the OR program. Other causes for changes in the OR program are: insufficient consideration of the occurrence of semi-urgent and emergency patients, cancellations by patients, and ad hoc changes due to decisions of a specialist. Since several (supporting) departments rely on the weekly OR planning evaluated by the OR committee, every change in the program during the last week has to be communicated to the appropriate departments. The more changes occur, the more work the central planner gets and the more the planning and preparations of supporting functions and subsequent departments change. Besides the effects on efficiency, last minute changes also increase the probability of “wrong patient” or “wrong location” errors and thereby deteriorating patient safety.

The short period between the approval of the OR committee and the actual time of surgery, combined with the occurrence of last minute changes in the schedule, complicates the coordination and control of material requirement planning and resource capacity planning of supporting functions. Since the OR schedule is known only shortly before surgery, it is difficult to proactively reserve capacity, for example in the surgical wards. Variability in surgery duration and length of stay of clinical patients increase the variability in downstream processes even further. Peak demand in surgical wards can even force wards to declare admission stops, resulting in the cancellation of surgeries.

Health insurance organizations recently added the role of mediator to their tasks. This makes the patient, who is in this case the customer, more knowledgeable. In case of long or unknown access times, the patient is more likely to go to another hospital to undergo the procedure. A disadvantage of postponement is that it is generally impossible to provide a patient with an operation date at the moment this patient announces him- or herself at the admission office. If another hospital is able to provide the patient with a suitable surgery date, MST looses patients and thereby revenues. However, scheduling further in advance raises other problems. By increasing the period between the time a patient is scheduled and the actual time of surgery, the possibility of disturbances increases. Additionally, the disturbances are no longer solely caused by the occurrence of semi-urgent or emergency patients, but also by scheduled clinical patients with higher priorities.

Problem statement

We summarize the problems described in this section as follows:

Despite the available planning software and historical data, MST does not use mathematical tools to improve OR utilization. Additionally, the OR schedule is created without sufficiently taking into account resource demand at supporting and downstream departments (e.g. surgical wards), causing variability. This variability leads to capacity problems and can even cause admission stops. Last minute changes in the OR program underpin this effect but also decrease efficiency and negative effect patient safety. Due to postponement of actual patient scheduling, various specialties are not able to provide the patient with a date of surgery until one week before surgery. Long access times and unclearness about surgery dates increase the probability of patients “shopping” around in other hospitals.

1.4 Research objective

This research focuses on the logistical aspect of the problems presented in Section 1.3. The main question to be answered therefore is: What interventions do we propose to improve OR planning of the general ORs and how do these interventions influence the identified problems? We therefore define the objective of this research as follows:

> *"To present and evaluate interventions that improve the utilization of the general ORs, while reducing variability in resource demand for surgical wards and decreasing the number of changes in the OR program before the schedule is actually processed in the ORs"*

1.5 Research questions

In order to attain the research objective, we formulate several research questions. Each question corresponds to a chapter in this report.

What is the current performance of OR planning?
Chapter 2 gives an overview of the current situation. First, it describes the primary process from the physician's initial consult until the moment the patient is dismissed from the ward. Next, the chapter describes the organization of the planning function, based on interviews with several participants in the process and personal observations. Using historical data for the general ORs in 2008, we conduct a quantitative analysis. After calculating various key performance indicators (KPIs), we comment on the performance of MST and compare this performance to that of other hospitals using the benchmarks of Van Hoorn & Wendt (2008) en Plexus Medical Group (2007). Chapter 2 answers the following sub-questions:

- What is the primary process?
- How are resource capacity planning and in particular patient scheduling currently organized and which actors can be identified in the process?
- How do MST's general ORs perform when compared to other hospitals?

For which of the identified problems do we design interventions?
Limitations on time and resources prevent us from elaborating on all problems identified. In order to be able to demarcate the scope, Chapter 3 presents the problem analysis. We specify causal relations of problems identified during interviews with employees of various departments and personal observations. Using a problem bundle, we identify the underlying core problems. We elaborate on the causal relations between problems. MST has initiated a number of projects to deal with various problems. We describe which projects are currently executed and how these projects relate to this research. Additionally, we comment on the expected effect of future developments on logistic

performance of the general ORs. After we demarcate the scope of this research, we conclude by stating which problems we target and which problems are left for further research. Chapter 3 therefore provides answers to the following sub-questions:

- Which problems do we observe with respect to OR planning?
- How do these problems relate to each other and what causes can be identified?
- What developments do we expect to influence the primary process of the logistic performance of the general ORs?
- Which key problems do we include in this research and which are left for further research?

How does this research relate to the literature concerning OR planning on a tactical and operational level?

Chapter 4 describes relevant literature on robust OR scheduling on both the tactical as well as the operational level. Relevant literature does not limit its scope to the effect of OR planning on the operating theatre, but also considers the effect the OR program has on supporting and subsequent departments. We comment on the similarities and differences between the situation of MST and the situations described in the literature. Chapter 4 concludes by stating which interventions are proposed in literature for situations similar to that of MST. Chapter 4 answers the following sub-questions:

- What literature addresses OR scheduling on a tactical and operational level and takes into account the effects of OR planning on subsequent or supporting departments?
- How do the situations described in the literature relate to that of MST?
- Which interventions, derived from the literature, are applicable to OR planning in MST?

What are the strengths and weaknesses of the proposed interventions?

Chapter 5 discusses both the interventions derived from the literature as well as the interventions we propose with respect to the specific situation of MST. We discuss the expected strengths and weaknesses of each proposed intervention. We elaborate on how the interventions affect the number of changes in OR schedule and comment on the expected effect on robustness and logistic performance. Finally we test each of these interventions on the possibility of actually implementing them in MST. The chapter concludes by describing which interventions we investigate quantitatively. Chapter 5 provides answers to the following sub-questions:

- How do we apply the interventions found in the literature to MST?
- Which interventions address the specific situation of MST?
- What are the expected strengths and weaknesses for each intervention?
- Which interventions do we propose to investigate quantitatively?

How do the proposed interventions improve the planning function based on quantitative criteria?

Chapter 6 presents the quantitative analysis. First, it describes which type of model we use to quantitatively compare the proposed interventions. We define assessment criteria on which to evaluate the possible solutions based on interviews with both medical as well as managerial experts within MST. We validate the model using data of 2008. After defining experimental settings, Chapter 6 presents the results of the quantitative evaluation of the proposed interventions. Based on these results and the predefined assessment criteria, we compare the interventions with the current situation. Finally we state which interventions we propose as a solution for MST based on the quantitative analysis. Chapter 6 deals with the following sub-questions:

- What model do we use to quantitatively evaluate the proposed interventions?
- What assessment criteria do we use?
- What experimental settings do we use?
- How does the model compare to reality?
- What are the results of the quantitative analysis?
- Which solution do we suggest?

What issues do we expect when implementing the proposed solution?

Chapter 7describes the issues corresponding to the implementation of the solution we propose.

Finally, Chapter 8 covers the conclusions, discussion, and suggestions for further research.

2. Context analysis

This chapter describes the context of this research. Section 2.1 describes the primary process from the physician's initial consult until the moment the patient is discharged from the ward. In Section 2.2, we describe the design of the planning function from the moment the patient and physician agree on the necessity of surgery until the moment the patient is actually in the OR. Section 2.3 shows the characteristics of MST in terms of general statistics on the number of ORs, the case mix, and the specialties assigned to the general ORs. We compare these statistics to those of other hospitals. In Section 2.4, we compare the performance of MST to that of Dutch university hospitals (Van Hoorn & Wendt, 2008) and regional hospitals, including top clinical hospitals (Plexus Medical Group, 2007) by means of a predefined set of key performance indicators.

2.1 Process description

The steps a patient has to take before undergoing surgery depend on the urgency of the surgery. We therefore distinguish elective surgeries and emergency surgeries.

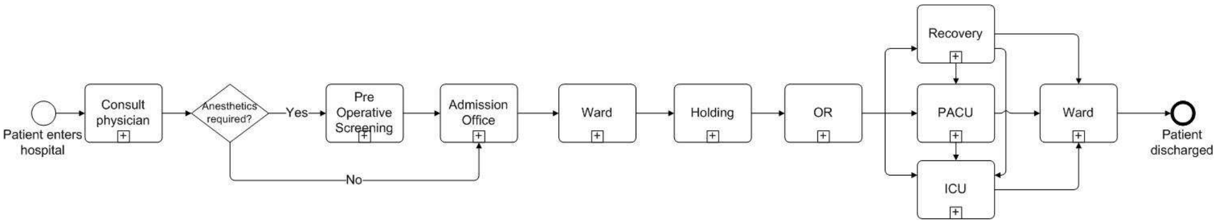

Figure 1 Process description from a patient's first arrival at the hospital until the discharge from the surgical ward after recovering from surgery. (The '+' symbol indicates that the activity is a combination of various activities. For more information, see Appendix A.)

Elective surgery

Figure 1 shows the pathway a patient follows when undergoing elective surgery. After referral by a general practitioner (GP) or another specialist, an elective patient visits the outpatient clinic. If necessary, this first consult leads to one or more follow up appointments and may require one or more diagnostic tests. After the physician and the patient agree that the patient will undergo surgery, the patient visits preoperative screening (POS). During preoperative screening, an anesthesiologist determines the patient's physical condition and informs the patient of the type of anesthesia that will be used during surgery. If necessary a nurse provides the patient with information on the admission and how the patient should prepare for the surgery (e.g. temporarily interrupt medicine usage). Outpatients that do not need anesthetics do not visit POS (e.g. eye surgery). After POS, the admission office puts the patient on the waiting list. The access time between the preoperative screening and the actual surgery depends on the patient's condition, the size of the waiting list, the availability of surgeons and resources, and the type of surgery. When the patient is scheduled for surgery, the patient is admitted at a surgical ward. The nurses prepare the patient for surgery and transport the patient to the OR's holding area. In the holding area, OR assistants start with anesthetic preparations, after which they transport the patient to the OR. Here, the OR assistants continue preparing the patient and arrange the materials, equipment, and instruments required for surgery. After the anesthesiologist induces anesthetics, the surgeon can start the surgery. When the surgeon has completed the surgery, the patient is transported to the recovery room, the post anesthetic care unit (PACU), or the intensive care (ICU). Generally, patients go to the general recovery. In case extensive care is required, the patient visits either the PACU or the ICU, depending on the period of time the patient is expected to require intensive care. After the patient has recovered sufficiently, nurses return the patient to the ward. When the patient's condition has improved adequately, the specialist discharges the patient.

Emergency surgery

The process for emergency patients is somewhat different from that of elective patients. It generally does not start at the outpatient clinic. There are various possibilities for an emergency patient to start the process. Patients can enter the hospital via the emergency room (ER), but it is also possible that the physical condition of a patient that is already admitted to the hospital suddenly deteriorates. The most important difference between the processes of elective patients and that of emergency patients is the access time before a patient is scheduled for surgery. The more critical the patient's condition is, the shorter the access time. In order to decrease the access time for emergency patients, several steps might be skipped. Depending on the urgency of the patient, the patient's physician and the OR's day coordinator may choose to transport a patient directly to the OR, thereby skipping preoperative steps, such as POS and admission at a surgical ward.

2.2 Description of planning function

The OR program determines when a patient receives surgery, in which OR, and by which specialist the surgery is performed. This program is leading when considering the demand for resources such as equipment, instruments, and OR personnel. Furthermore the OR program determines the utilization of supporting and succeeding departments, such as recovery, ICU, and wards. In order to examine which factors play a role in generating the OR program, we describe how MST organizes the planning function. For this purpose, we use the hierarchical framework for healthcare planning and control of Van Houdenhoven et al. (2007). With respect to resource capacity planning, Van Houdenhoven et al. distinguish four hierarchical managerial levels depending on the period of time in which decisions are made and the characteristics of these decisons. Figure 2 shows the framework.

	Medical planning	Resource capacity planning	Material coordination	Financial planning
Strategic	Research and treatment methods	Case mix planning, layout planning, capacity dimensioning	Supply chain and warehouse design	Agreements with insurance companies, investment plans
Tactical	Definition of medical protocols	Allocation of time and resources to specialties, rostering	Supplier selection, tendering	Determining and allocating budgets, annual plans
Operational offline	Diagnosis and planning of an individual treatment	Patient scheduling, workforce planning	Puchasing, determining order sizes	RNG billing
Operational online	Diagnosing emergencies and complications	Monitoring emergency coordination	Rush ordering	Billing complications

Managerial areas

Hierarchical decomposition

Figure 2 Hierarchical framework for hospital planning (Van Houdenhoven et al., 2007).

2.2.1 Strategic planning

The strategic level concerns long term decisions, which have a large impact on resource capacity planning for a long period of time, such as case mix planning, layout planning, and capacity dimensioning. Layout planning and capacity dimensioning are highly relevant due to MST's long term accommodation plan (Medisch Spectrum Twente, 2007). MST plans to realize a new accommodation, which includes the realization of a new operating theatre. This makes the decision on the number of ORs and the type of ORs very applicable. Another aspect of the plan is to dedicate the ORs in Oldenzaal to high volume, low variability elective surgery types. This development has major impact on resource capacity planning, as it will affect both the OR schedule for location Oldenzaal as well as for location Enschede.

Another aspect of planning on the strategic level is case mix planning. Each specialty annually negotiates target production volumes with the board of directors. After making production agreements with health insurance organizations, the board of directors translates these agreements into functional budgeting (FB) parameters. These parameters contain production agreements concerning the number of first visits to the outpatient clinic, the number of admissions, and the number of outpatients. Based on these parameters, supporting and facilitating departments, such as the OR department, receive production targets.

2.2.2 Tactical planning

Decisions on the tactical level depend on the decisions made on the strategic level. The number of ORs and the types of ORs serve as input for tactical resource capacity planning. Theoretically, the expected case mix serves as input for the distribution of OR time to the various specialties. However, the budget agreements that the board of directors communicates to the OR department are not specific enough to be translated into the required OR time per specialty.

Every three months, the OR committee evaluates the OR usage of the previous period and develops a four-weekly repeating schedule in which specific blocks are assigned to specific specialties, the tactical block plan. In practice however, there is little difference between succeeding schedules. The distribution of OR time over the various specialties has evolved over time. Changes in the tactical OR division have a large impact on outpatient clinic schedules. Especially small specialties rely on a rather static tactical planning, since there is no possibility of switching clinic duties and OR programs with collegues within the same partnership. With the new operating theatre however, the available resource capacity changes. Since the current tactical plan is no longer suitable for the new OR configurations, a new tactical plan is required. This forces specialties to accept changes to the tactical plan and creates an oppurtunity to improve the tactical plan.

After the central OR committee allocates the blocks to the different specialties, the allocation of specialists to the specific blocks is either performed by the specialists themselves during a partnership meeting, or by the unit manager of the admission office (in case of for general surgery).

Besides allocating blocks to specialties for the treatment of elective patients, reserved OR time is required to take care of emergency patients. In order to avoid each emergency patient causing the schedule to run into overtime, MST uses one dedicated trauma OR. This trauma OR is part of the OR program of the trauma surgeons (general surgery). The OR committee allows planners to use the period between 8:30 AM and 12:00 AM for high urgency elective patients, leaving four hours for the treatment of emergency patients. Gynecology reserves slack on their own programs to deal with emergency C-sections.

2.2.3 *Operational planning*

According to van Houdenhoven et al. (2007) the operational planning can be divided into an online stage and an offline stage. MST however divides the operational planning into three stages, as displayed in Figure 3.

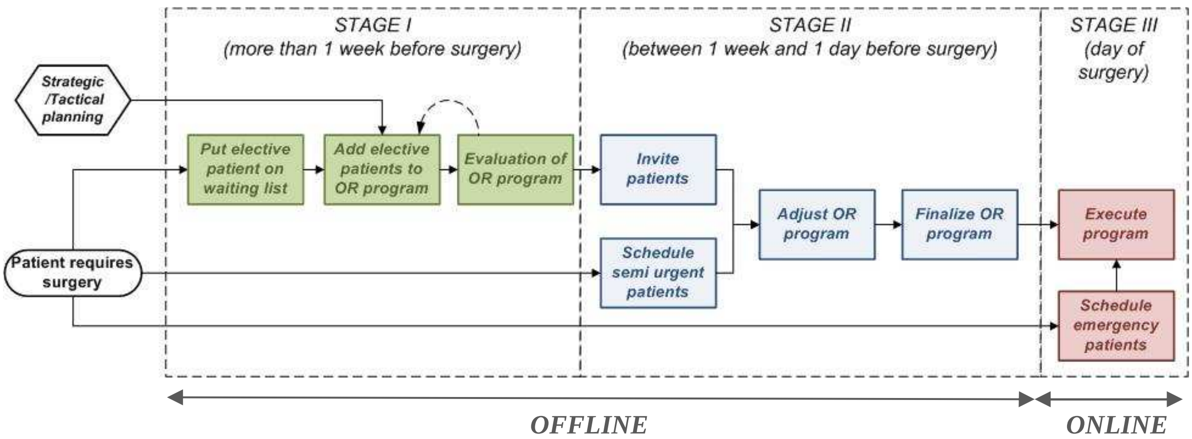

Figure 3 Stages in operational resource capacity planning

In the *first stage*, either the specialist's secretary or the central admission office adds patients to the specialists' OR programs. Some specialties choose to perform a part of the planning process themselves, while other specialties outsource patient planning to the central admission office entirely. The absence of a standardized process makes it difficult to manage the way patients are being scheduled on an integral level. Additionally a lack of transparency on how each specialty constructs the OR program causes confusion between subsequent departments on responsibilities. This leads to inefficiencies in the system as a whole. For a detailed description on how each specialty organizes operational offline resource capacity planning, we refer to Appendix A. After each specialty has completed its OR program, the medical manager and the OR's day coordinator screen the programs for resource conflicts and evaluate the size of each program. In case of resource conflicts or size issues, the initial planner receives instructions to apply the necessary changes, after which the medical manager approves the program. As from this moment, the OR program is fixed The time between adding patients to the program and the screening of the program differs per specialty. Especially when different specialties have to use the same shared resource, problems can occur. In order to prevent these kinds of capacity problems, planners work according to several guidelines for the maximum number of surgeries of certain types. This however does not guarantee resources being used efficiently. If, for example, two specialties are allowed to use only one X-ray machine, while one of them has in fact a demand for two machines, while the other does not have any demand, resources are not used as efficiently as possible.

The week between approval of the program and the actual day of the surgery can be identified as the *second stage*. During this second stage, semi urgent patients are added to the OR programs. Several departments depend on the OR program in planning their activities, such as wards, procurement, the central sterilization department, and other supporting services. After the OR committee approves the program, these departments start planning, reserve resources, and place surgery specific orders. At this point, changes in the OR program affect many different parties. In order to be able to inform all appropriate stakeholders, the central planning department is responsible for monitoring the schedule. If someone wants to change something in the approved program, he or she informs the central planner. During the entire stage, the OR's day coordinator is responsible for monitoring resource availability and acting if a resource conflict arises. One day before surgery the OR assistant on duty performs a final capacity check, after which the anesthesiologist on duty assigns anesthesiologists to different OR programs. Generally one anesthesiologist serves two ORs simultaneously. The second stage ends the moment the central planner's shift ends the day before surgery.

The *third stage* is similar to the operational online level. The responsibility of the OR schedule shifts towards the day coordinator. Besides monitoring the active OR schedule, he or she is responsible for all emergency patients that need to receive surgery within 24 hours. Just like the OR planner, the day coordinator informs all relevant parties in case an emergency patient has been announced. In principle, OR time is reserved in the schedule of the trauma OR. However, it is possible that the nature of an emergency surgery restricts the number of possible ORs suitable to perform a specific surgery. If this is the case, it is possible that the day coordinator decides to give a suitable free OR the status of trauma OR, either temporarily or for the remainder of the day. If no free OR is available, an emergency patient can intervene in an elective program on a suitable OR. In these cases, the day coordinator discusses with the appropriate surgeons when and where to schedule the emergency patient and which changes in the sequence of surgeries are necessary to treat the emergency patient within the required amount of time.

2.3 Descriptive statistics

The general operating theatre of MST consists of 15 ORs, 11 in Enschede and 4 in Oldenzaal. Both locations are centrally coordinated in Enschede. In 2008, little over 16,300 surgeries were performed during regular OR opening hours, divided over 3026 realized OR-days[1]. The year 2008 consisted of 252 regular days (365 days – weekends and irregular days, such as holidays). Safety issues in Oldenzaal caused four ORs to be closed from August 14 until August 31. On September 1, two of these ORs were reopened and remained available until the end of the year. If we take all of this into account, a total of 3560 OR-days were available during the year. Table 1 shows that Oldenzaal focuses on outpatients, while Enschede admits both outpatients as well as inpatients. Additionally, Oldenzaal generally does not treat emergency patients.

Table 1 Number of cases in 2008 (partly) during regular working hours ***(Data: ORSuite, general ORs, 2008)***

	Enschede	Oldenzaal	Total
Available ORs	11	4	15
OR-days	2524	502	3026
Outpatients	3474	3464	6938
Inpatients	7472	606	8078
Emergency patients	1268	31	1299
Total Nr. of Patients	12214	4101	16315

2.3.1 Elective patients

Table 2 shows the total number of elective surgeries performed by various specialties in 2008. General surgeons perform over 35 percent of all surgery time. General surgery consists of vascular surgeons, gastro-enterology/oncology surgeons, and trauma surgeons. Besides surgery types that can be assigned to each of these subspecialties, a number of surgery types cannot be categorized. We therefore introduce a general category. A small number of surgeries are executed by surgeons from different specialties. We summarize these surgeries in the category: combinations. Figure 4 shows that the six largest specialties account for 80 % of all surgical cases.

[1] A realized OR-day is a combination of a date and an OR on which at least one surgery is performed that started within regular OR opening hours or half an hour before.

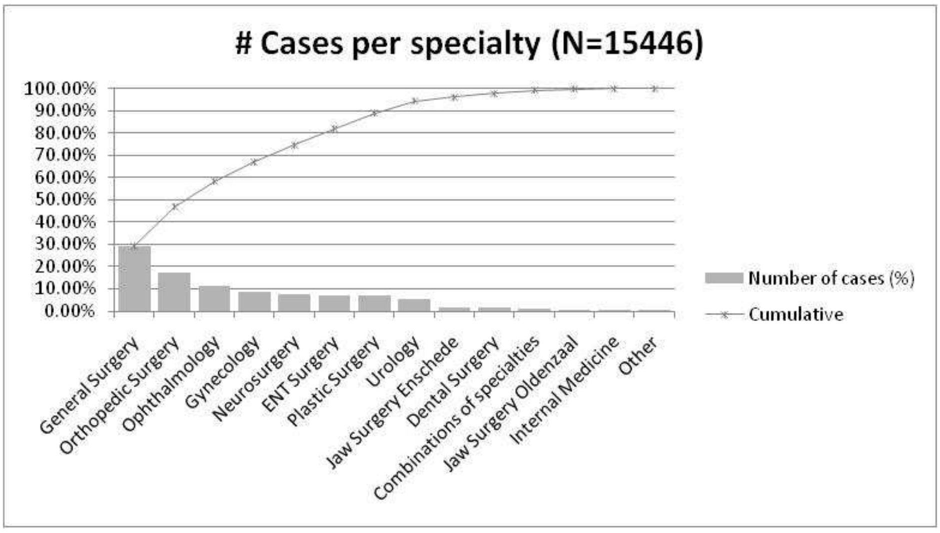

Figure 4 Pareto diagram of number of cases per specialty in 2008 (N=15446). (*Data: ORSuite, general ORs, 2008*)

Table 2 Descriptive statistics elective surgeries per specialty *(Data: ORSuite, general ORs, 2008)*

Specialty	N	Number of cases (%)	Total surgery duration (%)	Mean surgery duration (min.)	SDEV surgery duration (min.)	CV
General Surgery	4533	29.3%	35.1%	88.23	66.81	0.76
Gastro-Enterology/Oncology	*1903*	*12.3%*	*14.6%*	*87.63*	*64.44*	*0.74*
General	*1058*	*6.8%*	*6.8%*	*73.35*	*36.05*	*0.49*
Vascular	*800*	*5.2%*	*9.2%*	*131.76*	*99.51*	*0.76*
Trauma	*772*	*5.0%*	*4.4%*	*64.97*	*33.71*	*0.52*
Orthopedic Surgery	2691	17.4%	16.1%	68.44	35.86	0.52
Ophthalmology	1749	11.3%	4.8%	31.35	13.79	0.44
Gynecology	1368	8.9%	7.2%	60.41	38.67	0.64
Neurosurgery	1196	7.7%	9.8%	93.02	69.25	0.74
ENT Surgery	1111	7.2%	5.6%	57.61	40.84	0.71
Plastic Surgery	1068	6.9%	8.6%	91.61	59.51	0.65
Urology	861	5.6%	5.6%	74.39	68.84	0.93
Jaw Surgery Enschede	270	1.7%	1.8%	74.02	43.96	0.59
Dental Surgery	251	1.6%	2.0%	90.12	38.32	0.43
Jaw Surgery Oldenzaal	70	0.5%	0.3%	43.56	14.43	0.33
Internal Medicine	51	0.3%	0.1%	33.27	11.24	0.34
Combinations	210	1.4%	3.0%	160.54	114.88	0.72
Other	17	0.1%	0.1%	45.65	26.65	0.58
Total	**15446**	**100%**	**100%**			

Table 2 also shows the differences between specialties when it comes to surgery duration. The variability in surgery duration differs between the specialties. The coefficient of variation for ophthalmology is small when compared to other specialties, which can be expected since eye surgery concerns a large number of relatively ‘standard’ procedures. Differences between surgeries do not only occur between specialties, but also between different types of surgeries within the same specialty. The coefficient of variation for treating a carpal tunnel syndrome for example is 0.17, while the coefficient of variation for removing a medium to large tumor is 0.93. Appendix H presents descriptive statistics of surgery durations per specialty per surgery type and includes additional data, such as length of stay (LOS).

2.3.2 Semi-urgent versus emergency patients

Semi-urgent and emergency patients differ in the phase in which they are scheduled and the person or department responsible for scheduling the surgery. Emergency patients have to receive surgery within 24 hours, while semi urgent patients need to be scheduled within one week. This means that emergency patients have to be scheduled online, while semi-urgent surgeries can be scheduled in the second phase of the operational offline scheduling. In each phase, however, time has to be reserved to cope with the occurrence of these non-elective patients. MST’s planning tool does not distinguish between semi-urgent and emergency patients. In order to comment on the percentage of semi urgent and emergency patients, we introduce a custom indicator. The difference between the date of the first registration of a patient and the actual date of surgery indicates whether a surgery is urgent. In calculating this indicator for 2008, we observe negative values. We assume these surgeries are emergency surgeries. Since the surgery has to be performed immediately, there is no time or no person available to register it in the planning software right away.

Definition 2.3.1: Custom indicator for the urgency of an emergency patient U:

$$U = T_s - T_r$$

Where T_s is the time of surgery (realized) and T_r is the time of the initial registration of the patient in the OR planning software.

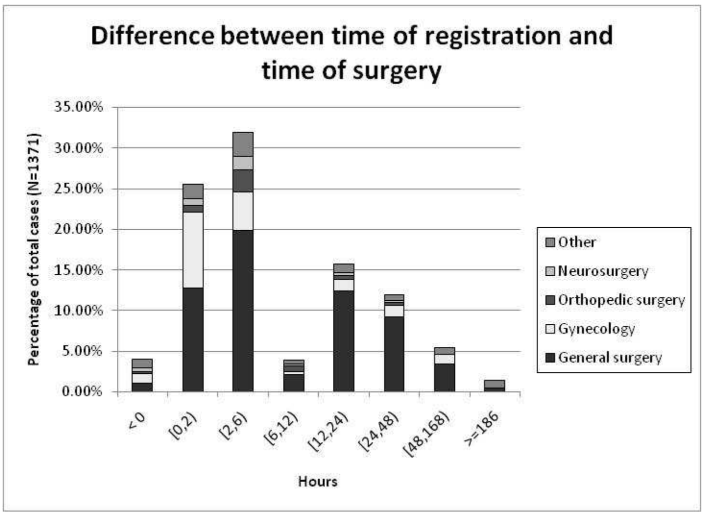

Figure 5 Time between surgery and registration in "ORSuite" (used as an indicator for urgency of emergency patients), N=1371 ***(Data: ORSuite, general ORs, 2008)***

Figure 5 shows that 80% of the patients labeled as emergency patients receive surgery within 24 hours after registration. General surgery (61%) and Gynecology (20%) treat the largest amount of emergency patients (for further information, see Appendix G). Figure 5 shows a decrease in the number of emergency patients that receive treatment between six and twelve hours after registration. Most patients arrive during the day. If immediate surgery is required, this will show in the first two categories of Figure 5. The trauma OR is partially reserved for emergency patients. General surgery is allowed to use half of the trauma OR's capacity for (high priority) elective patients. If immediate surgery is not required, emergency patients are preferably scheduled after these elective patients. If there is no capacity available in the current schedule, specialists generally postpone surgery until the next day. This explains the gap in the number of surgeries between 6 – 12 hours after registration.

Table 3 shows the descriptive statistics for the number of emergency patients per weekday. The expected number of patients per day slightly increases during the week. The coefficient of variation shows that variability does not increase during the week.

Table 3 Descriptive statistics for the number of emergency patients per weekday within regular OR opening hours *(Data: ORSuite, general ORs, 2008)*

	Monday	Tuesday	Wednesday	Thursday	Friday
Mean	4.33	4.75	5.38	5.35	5.62
St. dev.	1.74	2.20	2.12	1.90	2.29
Median	5.00	5.00	5.00	5.00	5.00
CV	0.40	0.46	0.39	0.36	0.41

2.3.3 Repetitiveness of the OR program

Inherent to health care, it is generally impossible to predict whether patient X is going to need surgery type Y in, for example, six months time. Nevertheless a part of the entire case mix remains fairly stable throughout the year. So although it remains unclear which patients should be treated in six months time, we are able to predict the number of surgeries of type Y that have to be performed during a certain period. Since MST does not collect demand information, we assume the number of realized surgeries per year equals annual demand. If we assume demand for a specific surgery type remains stable throughout the year, the number of surgeries per planning cycle equals the number of patients per year divided by the annual number of planning cycles. To relax the assumption of a stable demand per planning cycle and to correct for the fact that it is not possible to perform a fractional number of surgeries per cycle, we round down the number of surgeries per cycle to the nearest integer. This gives a measure for the minimal number of surgeries per planning cycle. For example, a surgery type that occurs on average 1.8 times per planning cycle is rounded down to 1 surgery per planning cycle. We define the repetitiveness of the OR program a surgery type as the sum of the rounded average number of surgeries per cycle divided by the sum of the average number of surgeries per cycle is defined as the repetitiveness of a surgery type.

Definition 2.3.2 *The repetitiveness of the OR program is:*

$$R = \frac{\sum_{j=1}^{S} \left\lfloor \frac{N_j}{C} \right\rfloor}{\left(\frac{\sum_{j=1}^{S} N_j}{C} \right)}$$

Where N_j is the annual number of surgeries of type j=1,..,S and C is the number of planning cycles per year.

Table 4 shows the measure for the repetitiveness for all inpatients, and outpatients for 2008. More information about the repetitiveness per surgery type can be found in Appendix J.

Table 4 Repetitiveness of the OR program (Data: ORSuite, general ORs, 2008)

	Nr. Elective Patients	Repetitiveness
Inpatients	8208	54%
Outpatients	7218	70%
Total	**15426**	**62%**

2.4 Performance

Logistic performance indicators, as defined by Van Hoorn & Wendt (2008) provide measures for the performance of the general ORs. Appendix B shows the definitions of these indicators. This section presents the analysis of MST's performance in 2008. For a complete overview of MST's performance on all performance indicators, we refer to Appendix C.

2.4.1 Time registration

In order to be able to compare MST's performance to that of other hospitals, we need not only use the same definitions for the performance indicators, the moments in time that are being registered during surgery also have to be aligned.

During a surgery session, an OR assistant registers the time stamps of six different points of care:

1. Arrival at OR/preparation
2. Start anesthetics
3. End anesthetics
4. Start incision
5. End of surgery
6. Departure OR

The time between the first two time stamps is used to prepare the patient, the patient charts, and necessary equipment. After the anesthesiologist finishes inducing the anesthetic, the OR assistant registers the third timestamp. Before the surgeon starts with the first incision, the OR team performs a final check. The OR assistant registers the moment the surgeon starts with the first incision as the fourth timestamp. The last two registered times correspond to the moment the surgeon places the last stitch and the moment the patient departs from the OR. The time a patient arrives at the holding and the moment he or she leaves the recovery room are not registered in "ORSuite", the OR planning tool. Therefore, we cannot comment on the patient's waiting time in the holding. Figure 6 shows how the six time stamps relate to the session period in the model for time registration described by Van Houdenhoven et al. (2006) This model is the same model used in the OR benchmark by Van Hoorn & Wendt (2008), which we use to compare MST's results to those of other hospitals.

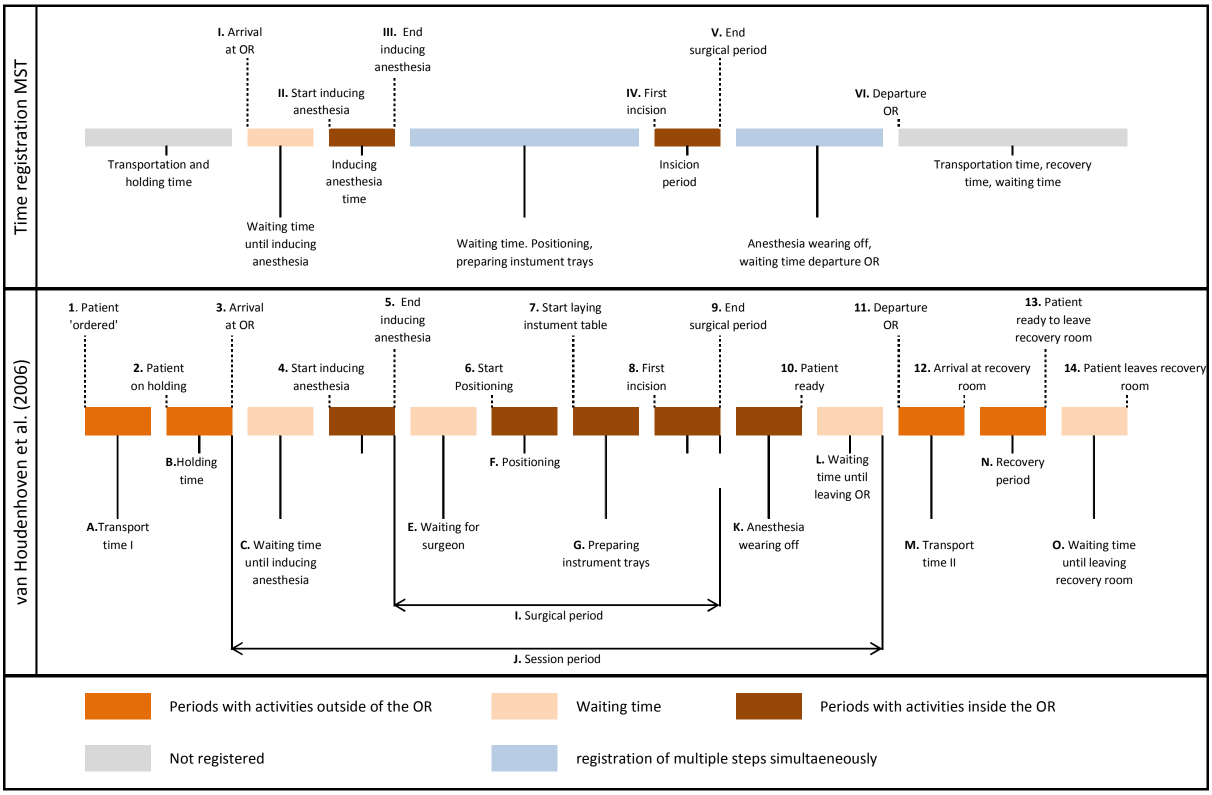

Figure 6 time registration model MST vs time registration model of van Houdenhoven et al. (2006)

In the data analysis, we use the time between the patient's arrival and departure as the surgery duration. We calculate the changeover time as the time between the departure of a patient and the arrival of the next.

2.4.2 Utilization

We calculate the net utilization over the OR-days on which at least one surgery is performed within regular working hours. The net utilization of MST over 2008 is 82.17%, which is comparable to the results of the five top-ranked Dutch University Medical centers (UMCs) in the period from 2005 to 2007 (Van Hoorn & Wendt, 2008). Comparing MST to these UMCs without considering the thoracic ORs cannot be fully justified. The characteristics of MST in terms of case mix, does not resemble those of the UMCs. Therefore we also use the benchmark performed by Plexus in 2005 (Plexus Medical Group, 2007) as a second frame of reference. This benchmark includes hospitals that have a case mix similar to that of MST. A disadvantage of this benchmark however, is that the definitions of the proposed parameters are not clearly presented. Additionally, the period in which the actual measurement took place is four weeks, whereas the benchmark among UMCs considers data of several years.

Comparing the average duration of surgeries in the general ORs of the MST with the average duration of a surgery in the UMCs, we see that there is a large difference (see Table 5). The case mix differs from that of MST. Next to the ‘regular’ surgeries, UMCs also perform difficult high-risk surgeries with relatively high probability of complications. Therefore, we expect MST’s case mix to be less complex and have less variation in surgery durations than that of UMCs. Less variation in surgery types and surgery durations leads to a more predictable OR program. Therefore, we expect MST to outperform the UMCs in terms of utilization, overtime, “early ending vacancy duration” and “deviation from planning”. Table 5 shows that this is in fact the case for all but utilization.

Table 5 MST compared to university medical centers (Hoorn & Wendt, 2008 *(Data: ORSuite, general ORs, 2008)*

	University Medical Centers[2]			MST
	Max	Min	Average	
Average session time (min)	156	105	125	75
Net utilization (%)	84	77	81	82
Overtime duration (min.)	75	46	55	39
Overtime frequency (%)	47	35	42	34
Early ending vacancy duration (min)	88	55	64	48
Early ending vacancy frequency (%)	60	47	52	64
Deviation from planning (absolute) (%)	36	30	33	25
Deviation from planning (average) (%)	22	9	15	-9
Average time late starts (min)	31	18	25	13
Late start frequency (%)	92	46	71	90

The net utilization of location Oldenzaal is lower than of location Enschede (respectively 80.6% and 82.5%), which seems remarkable at first sight. A possible explanation is that the case mix in Oldenzaal consists of more but smaller surgeries; changeovers represent a larger part of the available time. The measure for the gross norm utilization supports this explanation (respectively 95.5% and 90.6%).

The Plexus benchmark compares the results of 25 regional and 16 top clinical hospitals, whose case mix is more comparable to MST than that of the UMCs. Appendix F shows the list of participating hospitals. In Section 2.3, we have shown that 3560 OR-days are available over 2008. This means that over the entire year 1,708,800 minutes of surgery time is available. This however does not mean that the various specialties use all available time. Reduction periods, undistributed sessions (closed ORs), returned sessions, and shortage of personnel cause empty session blocks. Over 2008, specialties used a total 1,433,280 minutes, accountable for 84% of all available time. Appendix E shows the distributed sessions per day in minutes. Figure 7 shows how the available capacity is utilized using the definition posed by the Plexus Medical Group. In calculating the sum of surgery durations of elective and emergency patients, we use the entire surgery time of all operations that are at least partly performed during regular time. Figure 7 shows that MST uses only 64% of all available capacity for elective patients, while the average of the benchmark is 76%. Since the percentage of distributed OR time is

[2] Data of eight university medical centers in 2007

comparable to the average of the benchmark, we conclude that the utilization of capacity in the general ORs of MST is below average.

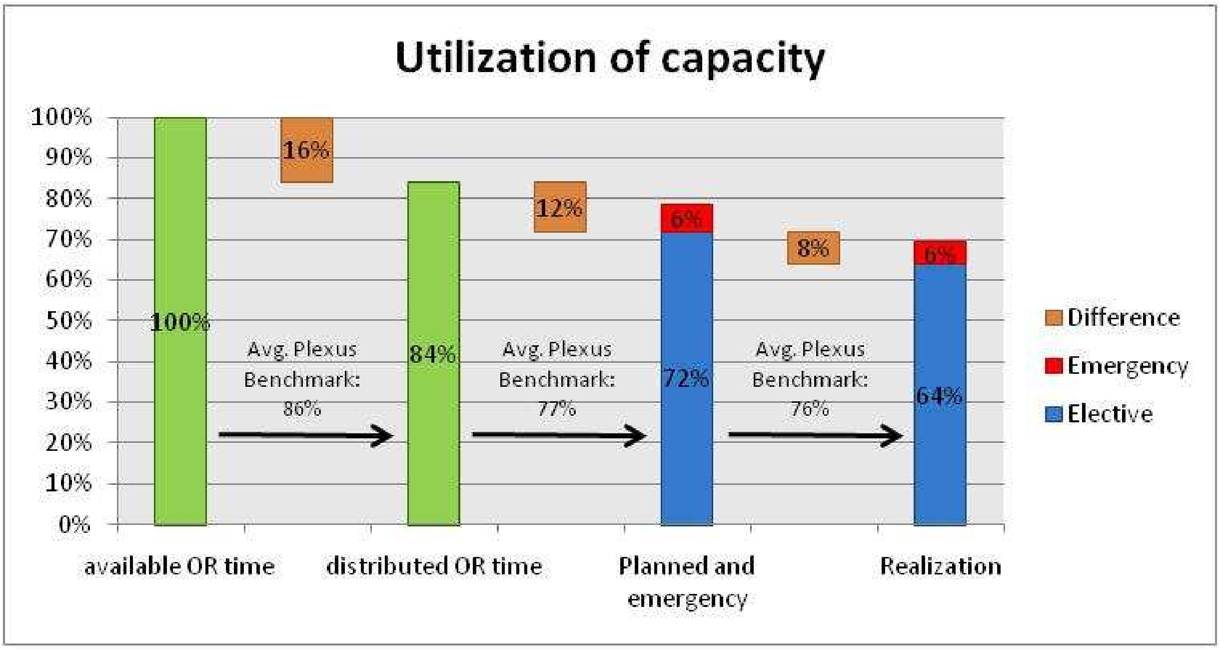

Figure 7 Utilization of capacity, definitions from Plexus Medical Group (2007), *(Data: ORSuite, general ORs, 2008)*.

2.4.3 Deviation from planning

Table 5 shows that the average and absolute deviation from planning for MST are less than the deviation from planning of the UMCs. The difference between the case mix of a UMC and MST explains the larger deviation of the UMCs. The larger case mix variability of the UMCs makes it difficult to predict surgery durations. It is remarkable however that, in contrast to all UMCs, MST's average deviation from planning is negative. A negative deviation from planning indicates that surgery durations are structurally overestimated.

Average deviation from planning (daily)

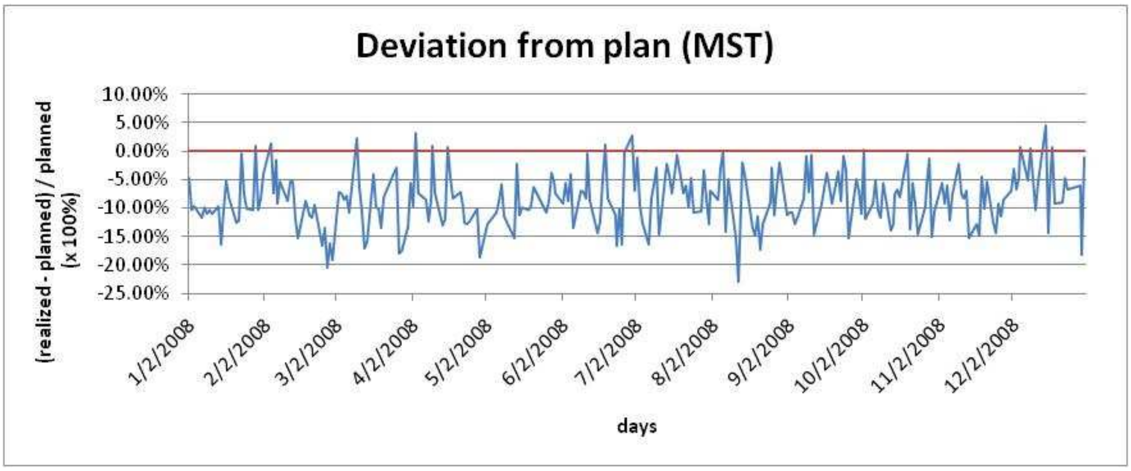

Figure 8 Deviation from plan. Difference between sum of realized surgery durations and sum of planned surgery durations per day (negative values represent overestimated surgery durations). (*Data: ORSuite, general ORs, 2008)*

MST uses planning software that forecasts surgery durations based on historical data. We expect the use of historical data in forecasting surgery durations to result in an average deviation from planned surgery durations that fluctuates around zero or at least converges to zero over time. Figure 8 however shows that the daily deviation from planning for 2008 is structurally below zero and remains fairly stable over time. Figure 9 supports these findings by showing a positive skew in the distribution of the deviation from planned surgery durations per surgical case. This indicates that planners schedule surgeries based on overestimated surgery durations. Structurally overestimating surgery durations prevents planners from efficiently filling an OR program.

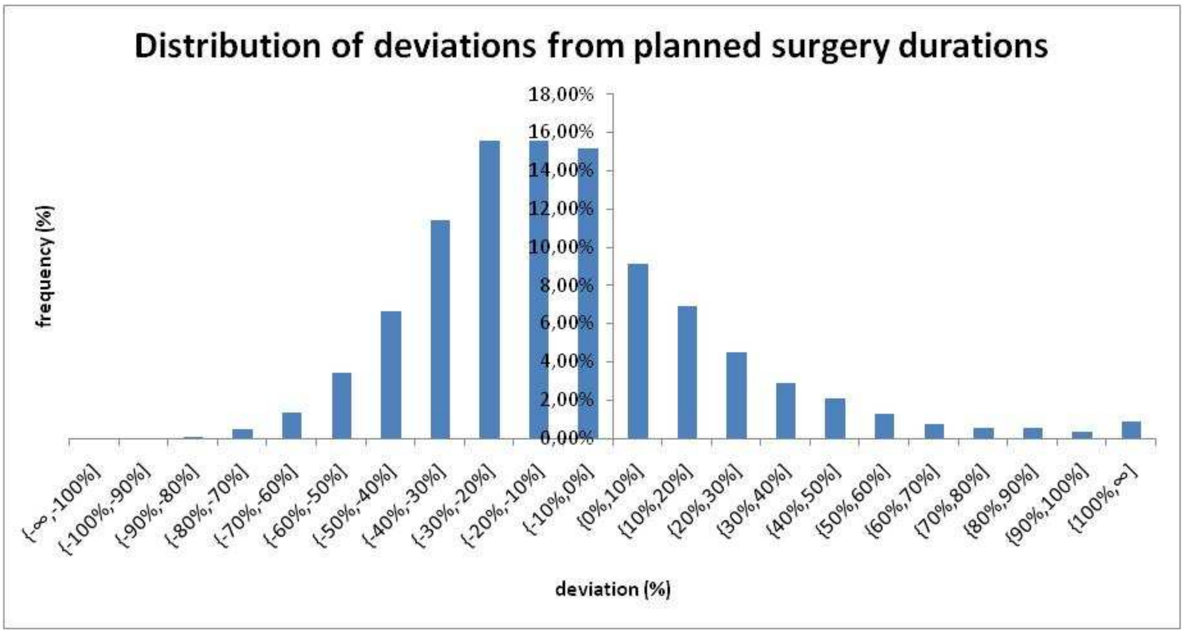

Figure 9 Difference realized surgery duration and planned duration, (negative values represent overestimated surgery durations), N=16290. (Data: ORSuite general ORs, 2008)

Surgery duration includes incision time as well as time for preparing the patient, and time for inducing anesthetics by an anesthesiologist (see Figure 6). In order to find out which part of the surgery causes these negative deviations, we examine the incision times. The incision time represents the largest part of the surgery duration. Table 6 shows that the deviation from planning for incision times is even more negative than the deviation for surgery durations. This shows that the overestimation of incision times is the primary cause for the overestimated surgery durations, which is consistent with the preliminary data of 2009. The lack of a learning effect in forecasting surgery durations rejects the hypothesis that the deviation is caused by the warm up period of the relatively new planning software.

Table 6 Key performance indicators for deviation from plan. (Data ORSuite general ORs, 2008)

	Average deviation from plan:	Absolute deviation from plan:
Surgery durations	-8,6% (N=16290)	24,7% (N=16390)
Incision times	-10,5% (N=16258)	32,8% (N=16386)

MST's planning software forecasts surgery durations using historical data for the combination of a surgeon and a surgery type. In order to take variability into account, a percentile value is used to predict the surgery duration. If for example the percentile was set to 70% for a period of 1 year, this means that of all comparable surgeries the specific surgeon has performed during this year, 70% took less than the predicted surgery time. A disadvantage of this method is that slack can only be reserved for each individual surgery instead of calculating slack for the combination of surgeries on a specific day in a specific session block (or OR-day). Until December 2009, it was unclear to MST how this quantile method generated forecasts for the surgery durations. As a result, the settings were set to the 90 percent quantile, resulting in the structural overestimation of surgery durations. As a result, planners and specialists lost confidence in the values calculated by the planning system and therefore manually adjust the values to the incision times estimated by the physicians during the first consult at the outpatient clinic.

Appendix I shows more information about the observed differences between planned and realized surgery durations. Moreover, Appendix I contains additional information on the relation between deviation from planning and the starting time of a surgery.

2.4.4 *Late starts*

A "late start" occurs when the first surgery within regular hours starts after the planned start OR block. The frequency in which late starts occur in MST resembles the UMC that has the highest percentage late starts. The average time an OR remains unused in case of a late start is however smaller than that of the UMCs (see Table 5). Figure 10 shows that more than 60% of all first sessions start within 10 minutes from the start of regular working hours.

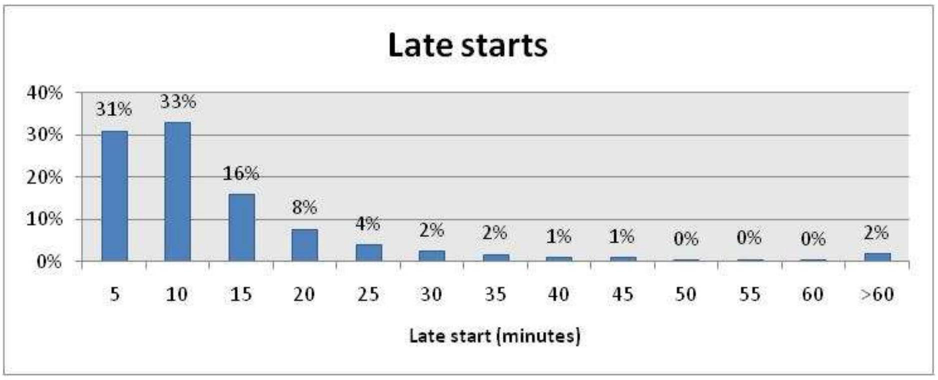

Figure 10 Late starts (N=2699) ***(Data: ORSuite, general ORs, 2008)***

At MST, anesthesiologists serve two ORs at the same time. This means that at the start of the day, one of the ORs has to wait until the anesthesiologist has completed inducing anesthetics in the other OR, considering that both ORs start at the same time. This waiting affects the data in two possible ways. If patients arrive at both ORs simultaneously, it results in a longer interval between the arrival of the patient at the OR and the moment the anesthesiologist starts inducing anesthetics (first two registered time stamps). Another possibility is the postponement of the patient's arrival and subsequent preparations. The latter has an effect on the number of late starts. Sessions generally start at 8:00 AM. ORs 6 and 11 are exceptions. OR 11 is generally used as trauma OR. Regular working hours for the trauma OR are from 8:30 AM until 4:30 PM. The first half of 2008, ENT surgery started their sessions on OR 6 at 10:00 AM, the second half of the year ENT also started at 8:00 AM, as did the other specialties *(data: MST Blokplan, 2008)*.

2.4.5 Cancellations

Cancellations of surgeries can either be a reason to change an OR schedule or be the result of changes in an OR schedule. Table 7 shows the number of surgeries that were both planned and subsequently cancelled during 2008. Overall, 3202 surgeries that were planned during regular working hours were cancelled. This means that in 2008 17.6% of all surgeries during regular hours were cancelled.

Table 7 Number of surgeries in elective hours that were both planned and cancelled in 2008 ***(Data: ORSuite, general ORs, 2008)***

Time between planned surgery and cancellation	Nr. Cancellations	Nr. cancellations / (Nr. Cancelations + Nr. Planned cases)
cancellations > 1 wk	576	3.7%
1 wk > cancellations >= 24H	1917	11.3%
24H > cancellations >= 12H	217	1.4%
12H > cancellations >= 1H	287	1.9%
1H > cancellations >= 0H	73	0.5%
cancellations < 0H	133	0.9%
Total	**3203**	**17.6%**

The actual time and date at which the decision is made to cancel a surgery is not recorded. Therefore, we take the time and date that a surgery is removed from "ORSuite" as an indicator for the cancellation date. This also explains why it is possible that 133 surgeries seem to be cancelled after their planned surgery date. Seventy-five percent of these surgeries are removed from "ORsuite" within the next 24 hours.

The largest part of all cancelled operations are called off in the period between evaluation and approval of the weekly schedule by the medical manager and day coordinator (every Wednesday a week before surgery) and the actual day of surgery. Because the admission office starts inviting after the OR program is approved, every patient that is unable to be present on the proposed date, results in a cancellation. Figure 11 shows that indeed most surgeries that are cancelled during the last week before surgery, are cancelled upon request of the admission office. Requests for cancellation by the admission office can, however, have various reasons. When the admission office invites a patient for surgery and the patient does not want to undergo surgery anymore, the admission office reports this change to the central planning department. The request for cancellation can be recorded as "request from admission office", but also as “patient no longer wants surgery”. The same holds for when a surgeon asks the admission office to remove a certain surgery from the OR schedule. In order to come to a conclusion on the actual reasons for cancellation, we advise to register cancellation reasons more specifically.

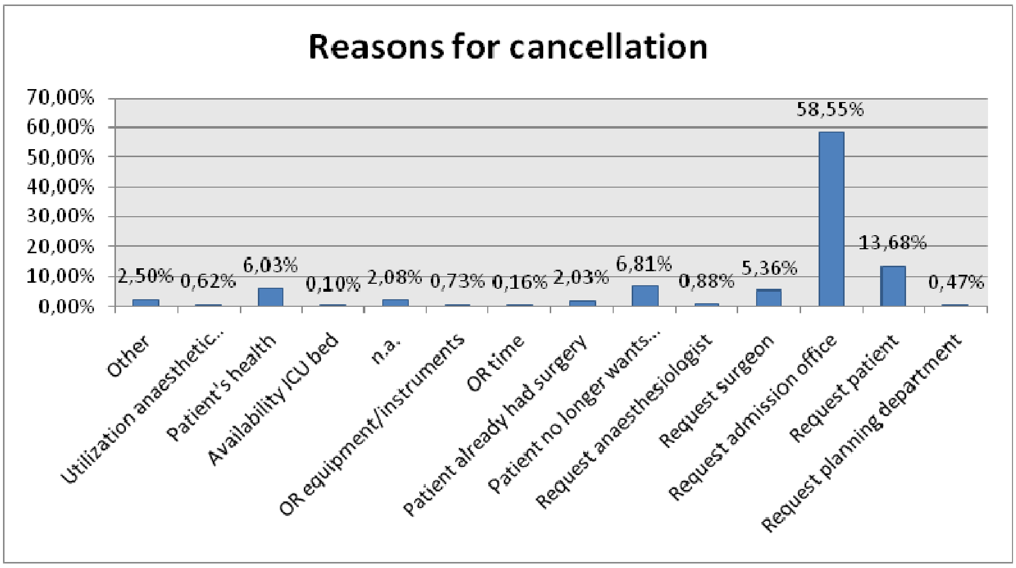

Figure 11 Reasons for cancelling surgery within period between one week before surgery and 24H before surgery (N=1917) ***(Data: ORSuite, general ORs, 2008)***

2.4.6 Variability in patients per day

Table 8 shows the average number of patients per day for the two locations. The variability in Oldenzaal is larger. This can be explained by the fluctuating number of available ORs in Oldenzaal. When one out of four ORs is closed, the effect on variability is larger than if one out of eleven ORs is closed. In Enschede, the coefficient of variation for outpatients exceeds that of emergency patients. This means that there is more variation in the number of outpatients than there is in the number of emergency patients. In fact, the coefficient of variation for emergency patients resembles that of inpatients. For an extensive overview of the number of elective patients per specialty and per location, we refer to Appendix D

Table 8 Descriptive statistics for number of patients per day: average, standard deviation, and coefficient of variation ***(Data: ORSuite, general ORs, 2008)***

	Enschede			Oldenzaal		
	average	**st.dev.**	**C.V.**	**average**	**st.dev.**	**C.V.**
Inpatients	29.65	5.33	0.18	2.40	2.72	1.13
Outpatients	13.71	4.90	0.36	13.66	8.28	0.61
Emergency patients	12.12	2.08	0.17	0.12	0.36	2.96
Total	48.39	7.83	0.16	16.19	8.84	0.55

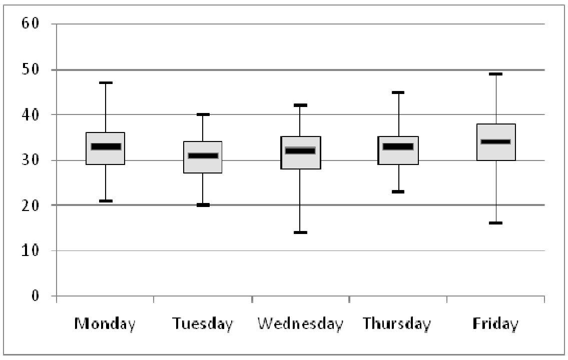

Figure 12 Box plot of number of surgeries on clinical patients per weekday ***(Data: ORSuite, general ORs, 2008)***

Figure 12 shows the spread of the number of surgeries per weekday. The average number of surgeries slightly increases from Tuesday to Friday. The average number of surgeries is largest on Friday, but the spread in the number of surgeries on Friday is also largest. Although the number of surgeries per weekday seems relatively stable, we see large differences when looking at specific specialties. Most surgical specialties have dedicated wards. The number of patients per day directly influences the number of admissions in these wards. The ward that shows most fluctuations in bed occupancy is the neurosurgical ward. Part of these fluctuations can be explained by the division of blocks during the tactical planning. Figure 13 shows a box plot of the number of patients per weekday for neurosurgery. The number of surgeries per weekday depends on the availability of session time for the specific specialty. The box plot shows that on Thursday the number of surgeries is larger than on other weekdays. Figure 14 shows that neurosurgery receives 960 minutes of surgery time on Thursday, while on other days generally 480 minutes are available. This explains the increase in number of surgeries every Thursday.

2.4.7 Bed utilization in surgical wards

Figure 15 shows the balance between the number of admissions and the number of discharges for neurosurgery over 2008. The number of patients increases on Wednesday. Neurosurgical patients are generally admitted one day in advance. Figure 15 shows an increase in number of neurosurgical admissions on Wednesday, which is in accordance with the increase of OR capacity on Thursday.

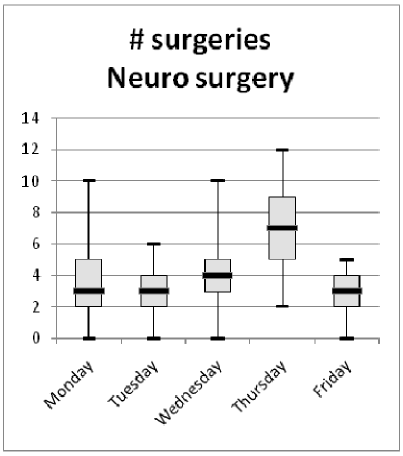

Figure 13 Box plot of the number of surgeries per weekday for neurosurgery *(Data: ORSuite, general ORs, 2008)*

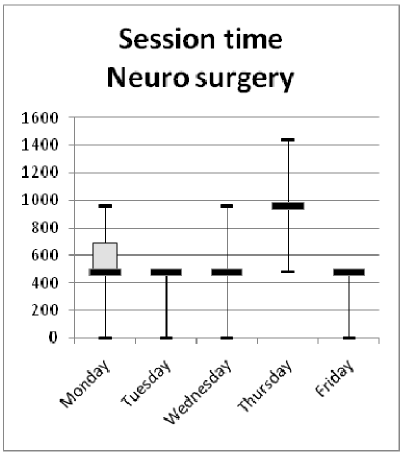

Figure 14 Box plot of the available session time per weekday for neurosurgery in minutes *(Data: ORSuite, general ORs, 2008)*

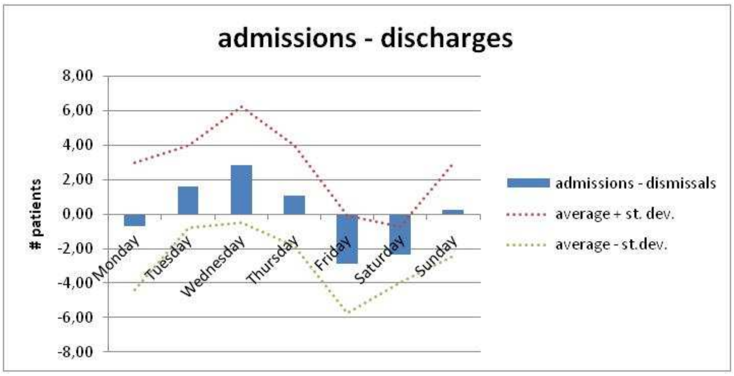

Figure 15 Balance between number of admissions and number of discharges per weekday for neurosurgerical ward, (average +/- standard deviation) *(Data: MST neurosurgery 2008)*

The bed utilization at the wards does not solely depend on the number of admission per day. Also, the length of stay of a patient is an important parameter. This length of stay depends on the physical condition of the patient, but also on the type of surgery. The OR program determines which types of surgeries are performed on which day. Therefore the OR program for a large part determines the bed utilization of subsequent wards. However, during tactical and operational planning, MST’s planners do not take the expected effect the OR program has on bed utilization into account. This results in large fluctuations in bed occupancy. For more information on these fluctuations in bed utilization of the neurosurgical ward, we refer to Appendix D.3.

2.5 Conclusion

MST’s long term accommodation plan (Dutch: LTHP) both leads to logistic challenges as well as opportunities for change. On a strategic level decisions about the number of ORs and the use of these ORs have a large impact on resource capacity planning on the tactical and operational level.

The current tactical block plan is the result of incremental changes over a period of many years. Changes in this schedule directly influence the availability of specialists and thereby the clinic rosters. Especially, relatively small specialties that operate in multiple hospitals and are less flexible in swapping OR blocks or clinic duties, show resistance against major changes in the OR block assignment. In creating and adjusting the current tactical block plan, the demand for resources of supporting and downstream departments is not taken into account, resulting in a high variability in for example bed utilization in surgical wards. The realization of a new accommodation with a different number of ORs and with specific ORs dedicated to outpatients inevitably causes the block plan to change. This need for change creates an opportunity to come up with a plan where resource capacity planning on an integral level is considered.

Operational offline resource planning is organized by each specialty individually. Each specialty plans differently, which complicates the control on a higher hierarchical level and leads to inefficiencies in the way the business process is organized. During the operational offline phase, planners are not aware of possible resource conflicts. The OR committee or the OR assistant on duty identifies occurring resource conflicts in the second operational offline phase or in the worst case in the operational online phase, resulting in (last minute) changes to the OR program.

On examining the performance of the entire OR theatre, we see that MST underperforms in term of late start frequency, and utilization. The late start frequency can be explained by anesthesiologists serving two ORs simultaneously. At the start of the program, one of the two ORs has to wait until the anesthesiologist is available. Since all ORs theoretically start at the same time, this results in a high "late start frequency". With respect to the net OR utilization, MST's performance is comparable to that of UMCs, while comparable regional hospitals outperform MST's performance.

Data on planned and realized surgery durations from 2008 and 2009 indicate that the technique used to forecast surgery durations overestimates surgery durations. This structural overestimation of surgery durations prevents an efficient use of OR capacity and thereby decreases utilization.

Almost 18% of all planned surgeries are cancelled. In order to be able to decrease the number of cancellations, the reasons for cancellations have to be specified. When we examine the reasons for cancellations, we see that almost 60% of the surgeries are cancelled due to a request from the admission office. This description includes a broad variety of reasons for cancellation (e.g. request from surgeon, request from patient, resource conflict). In order to improve the number of cancellations more specific registration of reasons for cancellations is necessary.

3. Problem analysis

This chapter describes the problem analysis. We identify the different problems observed during data analysis, interviews with different actors, and personal observations. Section 3.1 presents the causal relations between these problems and identifies the core problems. Section 3.2 compares the problems we identified with current improvement projects within MST. Finally, in Section 3.3, we determine the scope of this research and present the problem that will be our key concern during the remainder of this research.

3.1 Causal relations

In order to show the causal relations between observed problems, we create a problem bundle. A problem bundle starts with the identified problems and works back into the causal chain until it shows the core problem. Figure 16 shows the problem bundle for the problems we identified with respect to the general ORs of MST.

By means of this problem bundle, we identify seven core problems, which we describe in the remainder of this section.

- Planning without considering availability of resources
- False assumptions on methodology of forecasting surgery durations
- Deterministic planning of stochastic processes
- Postponement of patient scheduling
- Equal starting times of parallel OR sessions that require the same anesthetist
- Inefficient business process design of planning function
- IT support OR scheduling insufficient

3.1.1 Planning without considering availability of resources

Planning without considering availability of resources has both a tactical as well as an operational component. The distribution of OR time among the different specialties has a large influence on the usage of specialty specific resources. Examples of these specialty specific resources are wards, but also specialty specific equipment, or instruments. The current tactical planning in MST has evolved over the years to what it is today. This means that in creating the tactical planning, the OR committee does not particularly take into account the impact the tactical planning has on resource demand. This leads to peaks in resource demand, for example, a large number of admissions on a specific ward, the utilization of a certain piece of equipment, or even the need for OR personnel.

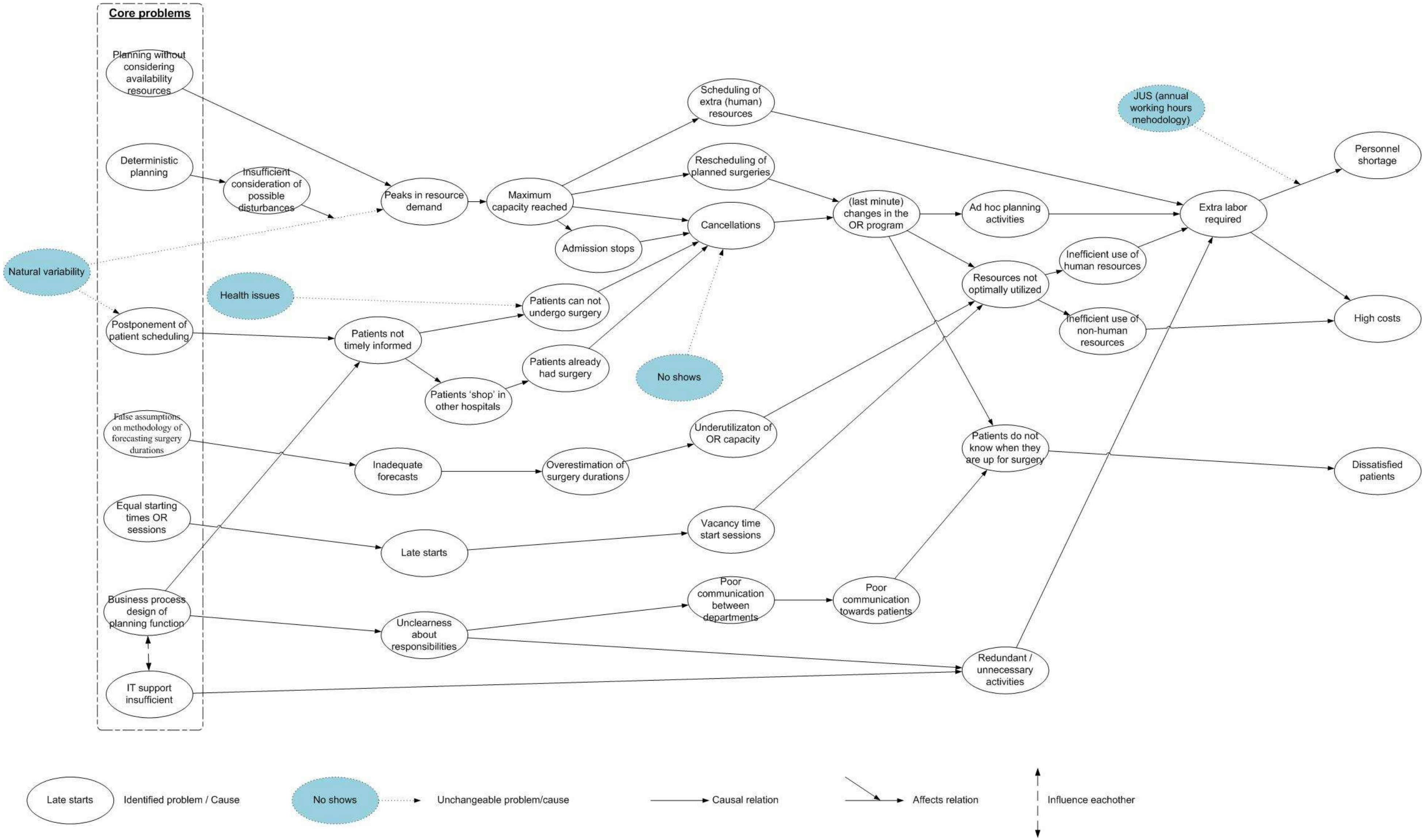

Figure 16 Problem bundle (Causal relations)

During operational offline planning, planners load the surgical program by adding patients to a specialist's block. By doing so, the planners determine which elective surgeries will be performed in the OR. During the creation of the operational offline schedule, planners do not receive feedback on the availability of resources. Section 2.2 already described that some specialties make agreements on the maximum number of daily surgeries of a certain type. Although this agreement partially solves the problem of over-scheduling certain resources, in some cases it does not suffice, while in other cases it is too stringent. Due to practical reasons, it is impossible to include all resources in the agreements. Furthermore, if a certain specialty's demand for a certain shared resource drops, these agreements can even cause a drop in resource utilization. Additional difficulty in assigning these resources to specialties is the different specialties using another time horizon to schedule patients.

If the peak in resource demand becomes too large, demand exceeds the capacity. Depending on the type of resource and the level of exceeding capacity, either extra personnel is scheduled, surgeries are rescheduled, or an admission stop needs to be announced. Both admission stops and rescheduling of planned surgeries lead to changes in the OR program. These changes result in extra labor costs due to additional planning activities as well as uncertainty for patients. This eventually leads to unsatisfied patients. The temporary deployment of extra personal to increase capacity has both a direct as well as an indirect negative effect. Scheduling additional personal directly leads to an increase in labor costs. Indirectly, it has a negative effect on the future availability of personnel. The "annual working hours quota" states that every employee works a specified number of hours per year. The hours for an additional shift are subtracted from this quota, thereby increasing the possibility of personnel shortage in the end of the year.

3.1.2 False assumptions on methodology of forecasting surgery durations

The current planning software gathers a substantial amount of information such as historical surgery durations, incision times, preparation times, and arrival rate of emergency patients. The current software package calculates expected surgery durations that can be used for scheduling surgeries. Unawareness of the actual methodology behind these forecasts has led to wrong settings for the forecasting algorithm. This resulted in a structural overestimation of surgery durations. Experienced planners acknowledge this misfit and therefore manually adjust the incision times or surgery durations. Even when considering the estimated surgery durations that have been corrected by these planners, the forecasting durations remain too cautious. The overestimated surgery durations prevent planners from efficiently filling available OR capacity.

3.1.3 Deterministic planning of stochastic processes

Another core problem is the deterministic planning of stochastic processes. Surgery durations as well as the arrival rate of (semi-)emergency patients are stochastic variables. Disturbances, such as surgeries that exceed their expected durations, unexpected complications, or the occurrence of emergency patients, cause problems if the buffer is insufficient. Free OR space, personnel on call, and empty slots in the OR schedule are all examples of buffering for variability. For MST, insufficient consideration of variability causes peak demand for resources which subsequently lead to changes in the OR program or even cancellations of surgeries. This results in negative effects on personnel availability, costs and patient satisfaction.

3.1.4 Postponement of patient scheduling

Postponement is one way to deal with the variability in the arrival process of patients. Various specialties postpone the moment at which they invite patients for surgery, in order to reduce the probability of disturbances until this patient is up for surgery. Neurosurgery even invites patients only one day before surgery. Although postponement decreases the period in which disturbances may occur and thereby reduce the probability of changes in an established OR program, it also has a number of negative effects.

Due to the late term on which the OR schedule is published, supporting and successive departments receive demand information on short notice. This complicates ordering supplies, rostering staff, and making work schedules in advance.

Postponement also causes patients to remain uninformed about surgery dates. Developments in the organization of the entire healthcare sector make it possible for patients to shop around. Health insurers reinforce this phenomenon by exercising the role of mediator. Patients provided with insufficient information therefore have a larger probability of going to another hospital. This not only causes a loss of possible revenues for MST, but also causes the need to remove a planned patient from the schedule, since the patient received surgery elsewhere. Postponement therefore affects both patient satisfaction as well as the costs.

Informing the patient on last notice also increases the possibility of patients having scheduled other important appointments, which they are not willing or able to cancel. The subsequent cancellation of the surgery leads to changes in the OR schedule, leading to additional activities for planners and thereby increasing costs.

3.1.5 Equal starting times of OR sessions using a two-tables system

Section 2.4 showed that the frequency of late starts for MST is high, even when compared to UMCs. Vacancy time at the start of an OR-day negatively influences the utilization of OR time. Empty ORs during regular hours indicate that costly resources are not optimally used. An explanation of the vacancy time at the start of the day is the fact that almost all sessions start at the same time. Since an anesthesiologist serves two ORs, similar starting times imply that one of the two has to wait for the anesthesiologist to finish inducing anesthetics.

3.1.6 Business process design of planning function

Section 2.1 described how the design of the planning function differs between specialties. Over time, every specialty has formed its own routines for patient scheduling. These routines strongly differ between specialties and thereby complicate the work of central departments. Succeeding departments do not know what the other departments do, resulting in unclearness of responsibilities. This unclearness affects both the information flows towards patients as well as the number of redundant and unnecessary activities. Succeeding departments partly redo each other’s work to prevent mistakes. These redundant activities require time that could have been used more effectively, thereby leading to unnecessary overhead.

3.1.7 Insufficient IT support of OR scheduling

Different specialties use different software packages to facilitate patient scheduling. Many of these packages are not compatible with each other. This causes subsequent departments entering similar types of information in different systems, leading to inefficient administrative tasks. The way patient scheduling is organized for ENT surgery is an example of this incompatibility of different systems. The ENT surgery secretary first enters the patient information into an Excel spreadsheet. Next, the patient visits POS after which the central admission office enters this information into the waiting list registration system. The central admission office sends this information to the ENT secretaries by fax. They enter the patient information into the consult planner, which they use for surgery scheduling. The output from this system is then sent back to the admission office by fax, after which the staff member of the admission office literally cuts and pastes the OR schedule in the proper sequence using the information from the fax and their own printout from the waiting list registration system. Subsequently the OR secretaries enter the patient and surgery information into the OR planning software.

Not only the incompatibility of supporting IT system causes problems, also the flexibility and the functionality of the IT systems do not support the business processes. In order to increase system functionality, users 'abuse' features by assigning new meaning to certain fields. For example the admission office uses the urgency status in the waiting list registration system to indicate whether a patient can be added to an OR program, or if he or she has to visit POS first. The user then enters the actual urgency of the patient into a user defined memo field. Since the memo field of the waiting list registrations system has no link to the OR planning software, it is not possible to attain information on patient priorities from the OR planning software. Such improvisations to adjust the system to the user’s needs, complicates linking different systems and results in loss of information.

3.2 Active projects and future developments within MST

Market mechanisms have forced MST to reexamine the way care is organized. This has lead to six main subjects of change (Medisch Spectrum Twente, 2008, 2009b):

- Organizational change
  - Decentralization of control by means of functional units responsible for their own performance (RVEs), in order to create a more flexible organization where departments can be evaluated on their own results.
- Chain of care (ketenzorg)
  - Increase collaboration between MST and primary care providers with respect to the care of chronic patients and the provision of services for research and diagnostics.
- Investment in IT
  - Replacement of paperwork by digitalization and automated support for patient logistics and patient safety.
- Accomodation (LTHP)
  - Realization of an accommodation that is in line with the vision and goals of the MST.
- Business Process Redesign (BPR)
  - Redesign of patient logistics, reduction of costs, and improving quality and safety.
- Safety Management System (Dutch: VMS)
  - Improve patient safety, prevent avoidable damage (part of national program: "Avoid harm, work safe").

Except for "chain of care", all subjects of change somehow influence the OR planning. Decentralized control leads to an optimization of processes within each RVE. This however does not necessarily mean that the performance of the entire organization also improves. Each specialty, organized in individual RVEs, organizes the planning function in its own way (see Appendix A). This complicates the implementation of a generic planning methodology, especially since most RVEs are reluctant to change their planning processes. The introduction of IT to support the planning function forces some RVEs to adjust their planning function, while others still hold on to their own methodology.

The realization of the new accommodation also has an impact on the OR complex. The number of ORs as well as the way these ORs are used will change. The location in Enschede now consists of eleven ORs, while Oldenzaal accommodates four ORs, of which only two are currently suitable for surgeries. In the new situation, Enschede will accommodate eleven ORs and Oldenzaal four. The four ORs in Oldenzaal are part of an elective treatment center (Dutch: EBC). Oldenzaal focuses on elective outpatient and short stay inpatients, with a low level of uncertainty in surgery durations and a low risk of complications. The highly variable surgeries will be performed in Enschede. This means that in Enschede small, predictable surgeries can no longer be used to fill up gaps in the OR program. In addition, the total available number of OR-days in the new situation will be smaller than in the current situation. At the same time, the number of surgeries will increase due to population ageing (Centraal

Bureau voor de statistiek, 2009). Clever OR planning becomes more and more important in order to be able to cope with an increasing demand while being faced with reduced capacity.

The number of staffed beds in the wards is decreasing, due to cost reduction. This means that the bed utilization increases. Variability however causes fluctuations in bed demand. While on average the number of available beds should be sufficient, during peaks, the demand for beds might exceed the capacity. One of the key objectives of the BPR project is to reduce this variability. Intelligent OR planning can help reducing the variability on required resources.

The Safety management system is part of a national program, based on 10 themes (VMS Veiligheids programma, 2009). Although these themes do not directly relate to OR planning, some safety measures do influence OR planning. For example, one of the suggested interventions regarding the prevention of post operative wound infections (POWI) is to minimize the number of times a door opens. Another example is the prevention of "wrong patient" and "wrong location" errors. Last minute changes in an OR program increase the probability of these errors. Besides the introduction of a "time-out" at the beginning of surgical procedures, a robust OR schedule can prevent these errors from occurring.

3.3 Conclusion and demarcation of research scope

The general ORs of MST have a central position in this research. This research focuses on improving the resource capacity planning of these ORs. Van Houdenhoven et al. (2007) describe four hierarchical levels in resource capacity planning (Section 2.2). Decisions made on the tactical planning level have a large impact on operational planning. Optimizing the operational planning without considering the tactical level is therefore likely to result in a suboptimal solution. Therefore, we focus this research primarily on the tactical level, without neglecting the effect this has on operational resource capacity planning.

This research only uses surgery information from 2008 and limits resource information to that of surgical wards. In 2007, the registration codes for surgical procedures types have changed. This makes it impossible to link similar types of surgeries of 2007 and before to the types registered in 2008. This change in procedure codes also explains why no information is available about which instrument trays belong to which surgery types. The procedure books used for picking instrument trays, also list the old procedure notation.

The design of the business process concerning patient scheduling and the supporting information systems are important subjects to examine further. We expect that improving process design will lead to large benefits in efficiency. Nevertheless, this subject does not align with the logistic aspects of this research and therefore we exclude these core problems from this research.

3.3.1 This research

This research focuses on improving elective patient scheduling for the general ORs of MST. On a tactical level, we take into account the effects of proposed interventions on OR utilization and bed utilization in surgical wards. Additionally, this research includes the effect proposed interventions have on reducing the need for postponement in patient scheduling and improving robustness of the OR program. Since the realization of a new accommodation has major impact on resource capacity, we also include the strategic proposal to create an EBC in Oldenzaal.

3.3.2 Further research

In order to be able to optimize an OR planning, while considering availability of resources, such as equipment and instrument trays, data is required on the types and capacity of these resources per type of surgery. After collecting this data, further research on using resource data in optimizing the surgical schedule may lead to improvements in resource utilization.

We identified the number of late starts in the beginning of an OR-day as a source for inefficient use of OR capacity and human resources. We indentified the equal start of sessions combined with the fact that an anesthesiologist serves two ORs simultaneously as a cause for this problem. A possible intervention could to start one of the two ORs earlier. Further research is necessary to determine whether this intervention is in fact the best way to solve the problem.

We expect that redesigning the business process of the operational offline resource capacity planning and its supporting IT systems will lead to large efficiency improvements. Section 2.2 describes the current organization of the planning function and can be used as a starting point in redesigning the business process. A redesigned business process with functional IT support should facilitate the efficient execution of the core process, while increasing transparency between departments, and reducing the number of unnecessary administrative actions.

4. Research context

This chapter describes relevant literature on OR scheduling on a tactical level. The scope of relevant literature is not limited to the operating theatre, but also takes into account the operating theatre's integration with other departments. In Section 4.2, we elaborate on the similarities and differences between the situation of MST and those described in the literature. Section 4.3 concludes this chapter by stating which of the proposed interventions in the literature we expect to improve OR scheduling of MST.

4.1 Related literature

The objective of this research is to propose interventions that improve OR utilization, but also to take into account the effect that an OR program has on surgical wards. It is possible to optimize a schedule given a certain tactical block planning, but if tactical planning does not consider the effects on output variability, the proposed solution is unlikely to lead to a good solution concerning both OR utilization and variability in bed demand. Therefore we limit our search to literature concerning tactical OR scheduling (e.g. block scheduling, master surgical schedule) that includes resource utilization of resources other than the ORs. For a complete overview of literature on OR resource capacity planning, we refer to Cardoen et al. (2008).

The literature on tactical OR capacity planning where the operating theatre is considered as a part of a larger system is scarce. Most papers that address the tactical resource capacity planning problem consider the operating theatre as an isolated unit. For example, Blake et al. (2002) describe a mathematical model to derive an equitable distribution of surgery blocks among different specialties, according to predetermined production agreements. Blake et al. do not consider how such a block division affects additional or subsequent resources, such as ICU or hospital beds. Papers that do consider additional resources often simplify the mathematical model by assuming deterministic parameters for surgery durations or patient's length of stay (Adan & Vissers, 2002; Santibáñez et al., 2007; Tànfani & Testi, 2009; Testi et al., 2007; Vissers et al., 2005). Although this simplification dramatically reduces the complexity of the mathematical problems, it also decreases the way the model reflects reality. Especially in healthcare, processes can be highly variable and therefore deterministic models do not suffice. Nevertheless, only a limited number of authors do incorporate uncertainty in their mathematical models (Adan et al., 2009; Beliën & Demeulemeester, 2007; Van Oostrum et al., 2008b; Vanberkel et al., 2009).

4.1.1 Master Surgical Schedule

Van Oostrum et al. (2008b) present a master surgical scheduling approach, where they focus on the OR scheduling on a tactical level. The objective of the approach is to present a tactical schedule that maximizes OR utilization, while simultaneously leveling bed resource capacity utilization of succeeding departments such as surgical wards or ICUs. Traditional OR scheduling on this level focuses on the division of OR-days over the various specialties. Master Surgical Schedules (MSSs) do not only assign specialties to specific OR-days, but focus on assigning frequently occurring surgery types to specific OR-days. In order to cope with uncertainty in surgery durations, the authors use planned slack. Van Oostrum et al. differentiate between three types of surgical procedures:

- Elective procedures that occur often enough to be scheduled in an MSS;
- Elective procedures that do not occur often enough to be schedule in an MSS;
- Emergency procedures.

The first type of procedures can be directly added to the MSS. The second type of procedures are clustered in so called dummy procedures in order to take these into account while generating the MSS (Van Oostrum et al., 2008a). In order to generate the MSS, they propose an algorithm solving the problem in two phases. During the first phase the algorithm assigns procedures to so called Operating Room Day Schedules (ORDS). These ORDSs have the same capacity as OR-days and make it possible to maximize the utilization of these ORDSs, without actually assigning them to a specific OR-day. In the second phase the ORDSs are assigned to specific OR-days such that hospital bed capacity demand is leveled. The proposed solution approach is not limited to leveling bed resource capacity, but also enables considering other types of hospital resources, such as personnel or equipment. More information about the mathematical model can be found in Appendix K.

Beliën & Demeulemeester (2007) describe a similar approach. Instead of maximizing the operating room utilization and leveling bed requirements, Beliën & Demeulemeester solely focus on leveling bed occupancy. The authors describe and compare various models and algorithms for calculating cyclic master surgical schedules. Subsequently, Beliën et al. (2009) use these models to describe a decision support system, where the objective is not only to level bed occupancy, but also to minimize sharing of ORs between specialties, and maximize the weekly repetitiveness of the schedule. Vanberkel et al. (2009) also focus on the effect the block planning has on subsequent departments. The model presented in the paper determines distributions for ward occupancy, patient admissions/discharges and ongoing interventions. Adan et al. (2009) present another model to construct cyclic master surgical schedules, to which they refer to as admission plans. The research presented by Adan et al. is based on previous research (Adan & Vissers, 2002; Vissers et al., 2005). The objective of the research is to generate a master surgical schedule that minimizes the deviation of expected resource utilization from predetermined utilization levels (OR utilization and bed utilization).

Van Oostrum et al. (2008a) describe the managerial implications of using and implementing an MSS approach. In order to examine the success of a planning approach Van Oostrum et al. describe the differences between a decentralized planning approach and a centralized planning approach (see Table 9). The decentralized approach is similar to the approach currently used in OR planning in MST. The major disadvantage of this approach is the lack of coordination between departments and specialties. Even if all specialties come to an optimal schedule for the block assigned to them, this does not mean that the overall result is an optimal schedule. Dividing the OR plan in several parts, which are all independently planned, does not only make the combined patient flow hard to predict, but also decreases flexibility and thereby decreases robustness of the entire plan. However, the decentralized approach is a common approach in OR capacity planning. The most important reason is that it gives surgeons full autonomy. The medical expert (surgeon) can decide when to treat which patient, which might be a lifesaving decision if it is made based on medical grounds. However, the authority of the surgeon can also be a disadvantage. Their autonomy enables surgeons to ‘cheat’ by favoring certain patients. Another disadvantage, which we also identify in MST, is the high workload of the planners on the operational level, required to prevent resource conflicts.

The opposite of the decentralized approach is the centralized approach. Centrally organized OR planning enables the planner to keep track of the broader picture and increases flexibility, since all ORs are controlled by one central planning department. This flexibility enables the planner to attain higher resource utilization. A major disadvantage however, is the lack of flexibility to allow surgeons’ to make medical decisions on which patient to treat when.

Table 9 Pros and cons of decentralized planning approach, centralized planning approach (Van Oostrum et al., 2008a)

	Decentralized control	**Centralized control**
Advantages	• Full autonomy of surgeons • Limited data requirements on a tactical level • Managerial workload on tactical level	• Robustness • Resource utilization • Integration with other planning processes (although still substantial effort required) • Monitoring • Financial control
Disadvantages	• Coordination amongst surgeons • Coordination between surgeons and other departments • Predictability of patient flows • Robustness (against disruptions, against ‘cheating’) • Resource utilization • Managerial workload on the operational level • Financial control	• Little autonomy of surgeons (can result in ‘cheating’) • Substantial data requirements • Up-to-date data required • Managerial workload on the tactical level

The MSS approach incorporates the advantages of the centralized approach and adds a higher degree of surgeon’s autonomy. Additionally, the MSS approach requires little managerial control on the operational level and although the data requirements are substantial, the managerial workload on the tactical level is less than with the centralized approach, due to the repetitiveness of the program.

The implementation of the MSS approach has several managerial implications. Table 10 describes seven steps for implementing the MSS approach. The suitability of the MSS approach depends on the organizational culture and the organizational focus of a department. Van Oostrum et al. (2008a) distinguish specialty based focused units, delivery based focused units, procedure based focused units, and general purpose units. Delivery based focused units and procedure based focused units are both well suited for the MSS approach. For specialty based focused units and general purpose units, the suitability depends on: case mix variety, volume, number of (sub-)specialties involved, and the potential efficiency gains by introducing the MSS approach.

Table 10 Steps for implementing the MSS approach (Van Oostrum et al., 2008a)

	Action	**Description**
1	*Define the scope*	Determine which resources to include in the MSS.
2	*Enable data gathering.*	Set strict guidelines for data gathering and develop tools that enable simple extraction of relevant information.
3	*Capacity planning*	Dimension and allocate resources that are to be incorporated in the MSS, thereby respecting target production agreements and agreements on utilization targets and resource availability. For shared resources, set clear allocation criteria in order to ensure transparency and encourage specialists to cooperate.
4	*Define a set of recurrent procedures*	Determine the set of recurrent surgery types. Use clustering techniques to generate homogeneous sets of surgery types based on both logistical and medical characteristics, such as diagnosis related group (DRG), (sub-)specialty, ward, expected surgery duration, and expected length of stay.
5	*Construct MSS*	Construct the MSS by leveling resource workload, optimize utilization, minimize overtime and minimize waiting time for semi-urgent and emergency patients (Van Oostrum et al., 2008b).
6	*Schedule patients*	Schedule emergency patients, semi-urgent patients and elective patients. Based on the urgency of the surgery, immediately assign emergency patients to the first available OR, or schedule the patients in the most suitable OR (depending on reserved slack, available resources). Schedule semi-urgent patients based on earliest due date. Elective surgeries can be assigned to the available slots by either the specialist or by an administrative department using predetermined guidelines. Guidelines for assigning elective patients include the patient's medically safe interval, a first come first serve (FCFS) strategy, and a prohibition of re-assigning patients during the time required to make preparations for the surgery
7	*Update MSS*	Update the MSS when changes in the case mix occur. In order to identify changes in the case mix, regular monitoring of access times is crucial.

In order for an MSS to be efficient, the surgery types involved need to be constructed with low variability. Surgery types that do not occur frequently enough are put together in so called dummy surgeries. A narrow definition of surgery types results in many dummy surgeries, thereby reducing the benefits of a MSS approach (Van Oostrum et al., 2009). Van Oostrum et al. (2009) propose a method to cluster surgery types. By clustering surgery types the volume of the dummy surgeries decreases. On the other hand, clustering surgeries may lead to loss of information. This means that there is a trade-off between the volume of dummy surgeries and the variability in resource demand.

4.2 Suitability of proposed interventions

Using a cyclic master surgical schedule approach, it is possible to take into account resource capacity utilization on the tactical level. Depending on whether the type of resources is included in the MSS, the approach prevents resource conflicts. Additionally, the MSS approach structures the organization of patient scheduling. This enables a higher level of control than currently exists in MST. The introduction of time slots simplifies patient scheduling on the operational offline level. Since time slots are reserved for specific surgery types, planners are able to assign elective patients to available slots several weeks before surgery, assuming time is reserved for semi-urgent patients.

The cyclic Master Surgical Scheduling approach, presented by Van Oostrum et al. (2008b), minimizes OR capacity and thereby maximizes utilization of available ORs. The second objective is the leveling of resource utilization, in for example ICU or surgical wards. These objectives coincide with the objective of this research. Although Van Oostrum et al. assume stochastic surgery durations, the authors use deterministic values for the duration of hospital bed requirements (LOS). During the computational experiments, Van Oostrum et al. use mean values for the average length of request for a hospital bed per surgery type. The computational experiments therefore cannot be generalized to a situation with large variation in demand for bed capacity per surgery type.

The length of stay of a patient after surgery does not only depend on the type of surgery, but also on other factors, such as the physical condition of the patient and the occurrence of complications. Beliën et al. (2007), Adan et al. (2009), and Vanberkel et al. (2009) acknowledge this uncertainty and model LOS by means of discrete (empirical) distributions. Aside from LOS, surgery durations also inhabit uncertainty. Although Adan et al. include this uncertainty in the LOS, they do not include uncertainty in surgery durations. Their model assumes deterministic surgery durations. Beliën et al., as well as Vanberkel et al., do not use surgery durations directly, but use a stochastic variable for the number of surgeries per block. Since they do not incorporate OR utilization in their model, Beliën et al. and Vanberkel et al. can suffice with stochastic variables for LOS and number of surgeries per block, which they both model using empirical distributions.

The main advantage of a cyclic approach compared to a non cyclic approach is that it prevents surgery types from being divided unevenly over the year. Additionally the managerial workload on the tactical level decreases, since the schedule repeats itself every cycle. This also enables surgeons and subsequent or supporting departments to work according to ‘fixed’ schedules. On the other hand, the cyclic concept of the approach also presents a disadvantage. In order to be able to successfully use the cyclic approach, the available resource capacity has to be identical for every planning cycle. MST chooses to use reduction periods to deal with decreased personnel levels during holiday seasons. During these reduction periods, one or more ORs remain closed. The cyclic MSS approach presented in the literature is incompatible with such variations in available resource capacity. In order to use the cyclic approach anyway, reduction periods have to be disregarded in the model, which will decrease the validity of the model. The way MST’s OR department is organized, however makes it possible to use different approaches for the different locations. During reduction periods, the capacity reductions can be limited to location Enschede, enabling a constant capacity level in Oldenzaal.

Another disadvantage of the cyclic MSS approach for location Enschede is that a cyclic MSS requires a certain repetitiveness of certain surgery types. MST has decided to dedicate the ORs in Oldenzaal to high volume, low variability surgeries, thereby excluding these surgeries from the OR schedule in Enschede. This increases suitability of the cyclic MSS approach for location Oldenzaal. The increase in case mix variation of location Enschede makes this location more suitable for the approach presented by Beliën & Demeulemeester (2007) or Vanberkel et al. (2009).

4.3 Conclusion

The master surgical scheduling approach presented by Van Oostrum et al. (2008b) addresses both the OR utilization objective as well as the bed capacity objective. The model assumes stochastic surgery durations and deterministic LOS. MST’s admission data 2008 shows variation in LOS among patients undergoing similar surgical procedures. Modeling MST’s situation therefore requires stochastic LOS. Additionally, the larger case mix variety in Enschede and the occurrence of reduction periods, make the implementation of the cyclic MSS approach difficult. For location Oldenzaal, however, the cyclic MSS approach is suitable. Especially when looking at the strategic decision to make Oldenzaal an Elective Treatment Center for high volume, and low variability surgeries.

5. Proposed interventions

Chapter 5 presents the proposed interventions for improving tactical capacity requirement planning. Chapter 4 showed the cyclic master surgical scheduling approach is suitable for the OR department in Oldenzaal. For Enschede, we propose the model of VanBerkel et al. (2009) for improving tactical planning. Section 5.1 describes how the proposed interventions can be applied to the specific situation in MST. After presenting MST specific interventions in Section 5.2, we subject these interventions to a qualitative examination in Section 5.3. We conclude by stating which interventions we investigate quantitatively.

5.1 Application of interventions from the literature to MST

5.1.1 Cyclic Master Surgical Scheduling approach

The master surgical scheduling approach is more suitable for Oldenzaal than for Enschede. Typically, surgeries performed in Oldenzaal are high volume, low variation surgeries. Additionally the length of stay of patients in the surgical ward is very predictable. In 2008, over 85% of all surgeries performed in Oldenzaal, were outpatient surgeries. These characteristics fit the restrictions of the master surgical scheduling approach.

We start with defining the case mix for surgeries that have to be performed in Oldenzaal. Before actually assigning master slots to these specific surgery types, we cluster surgery types that show comparable characteristics in terms of patient type, specialty, sub-specialty, distribution of surgery durations, surgical wards, and length of stay distribution. For each cluster of surgery types, we calculate the number of MSS slots per planning cycle based on the realized number of surgeries in 2008. In order to correct for minor demand fluctuations, we round down the number of surgeries per planning cycle to the nearest integer. Currently, the tactical block schedule has a planning cycle of 4 weeks. Therefore, we initially assume the same planning cycle. During the quantitative analysis, we compare the results for a planning cycle of 4 weeks, to the results when considering other planning cycles. Changing the planning cycle does require recalculating the number of MSS slots per planning cycle.

After we calculated the number of MSS slots per cluster of surgery types, we assign the master slots to specific OR-days. The model presented by Van Oostrum et al. (2008b) uses column generation to assign master slots to ORDSs. These ORDSs have the same capacity as the OR-days, where they can be assigned to. After maximizing the OR utilization by minimizing the amount of planned slack, given a predefined maximum probability of overtime, Van Oostrum et al. use integer linear programming to assign these ORDSs to actual OR-days in such a way that variability in required bed utilization is minimized. For reasons of convenience, we do not use column generation and integer linear programming, but generate an initial solution by assigning slots to specific days using list scheduling and subsequently improving the initial solution by interchanging ORDSs using local search. Although this methodology does not necessarily solve the problem to optimality, it does provide a fast and reasonable solution. Also, it does not require a solver to solve the mathematical problem. Subsequently, we use local search to level bed utilization.

The Master Surgical Schedule that results from the model is then used instead of the current tactical block schedule. During execution of the schedule, patients are scheduled in available slots that match their surgery type.

Since location Oldenzaal does not treat emergency patients, no OR capacity has to be reserved for emergency surgeries.

5.1.2 Relating tactical block planning to workload of surgical wards

Vanberkel et al. (2009) present an approach to determine ward occupancy distributions, and patient admission/discharge distributions. By calculating these distributions, the planner is able to evaluate the quality of a tactical block planning in terms of ward occupancy and nursing workload of subsequent surgical wards.

In preparation for the realization of an elective treatment center in Oldenzaal, the specialties that perform surgeries in Oldenzaal have determined which types of surgeries are suitable for such a centre. Medisch Spectrum Twente (2009a) has suggested that a certain percentage of the case mix that is suitable for Oldenzaal should in fact be scheduled in Oldenzaal. Scheduling this case mix in Oldenzaal has a large impact on the remaining case mix for location Enschede. Since the case mix of Enschede changes, the current tactical block schedule is no longer suitable. After determining the case mix for Enschede, we recalculate the required OR capacity per specialty. To generate an initial solution, we adjust the existing tactical block schedule such that the distributed OR capacity per specialty equals the recalculated required capacity. Based on this initial schedule, we calculate the 95% confidence interval for the number of required beds in every ward using the mathematical model of Vanberkel et al. (2009). By interchanging OR-days of different specialties and evaluating each solution with the model of Vanberkel, we level bed utilization in the wards..

5.2 Additional interventions

5.2.1 Planned slack

Currently, MST uses the quantile method to buffer for uncertainty in surgery durations. Section 2.4.3 and Appendix I.1 describe the disadvantages of this method for forecasting surgery durations, while reserving slack to cope with uncertainty. Instead of calculating these quantile values and using these during operational offline planning, planners can use expected surgery durations combined with an amount of planned slack.

By using planned slack (Hans et al., 2008), surgeries are added to an OR program using the expected duration of the combination of surgeries plus an amount of reserved (planned) slack. The size of the planned slack depends on the safety factor (β) used and the uncertainty in the surgery durations of the surgeries scheduled for the specific OR-day. Hans et al. define the amount of planned slack by:

$$\delta_{skt} = \beta \cdot \sqrt{\sum_{j \in N_{skt}} \sigma_j^2}$$

N_{skt} represents the set of all surgeries j of specialty s that are scheduled in OR k on day t.

By choosing parameter β, the planner can adjust the risk of violating the capacity restriction (c_{kt}). Figure 17 shows an example of filling an OR-day using planned slack.

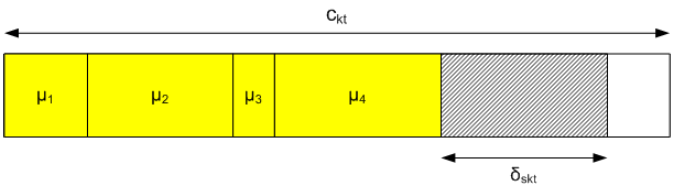

Figure 17 Example of using planned slack

The planned slack method can both be used in the operational as well as the tactical planning phase. In the tactical planning phase, a MSS slot for a certain surgery type (or cluster of surgery types) is only allowed on an OR-day if the expected surgery duration of all planned surgery types plus the amount of planned slack does not exceed the available OR time per OR-day.

In the operational phase, more information is available, since the planner now knows which specialist is going to perform the surgery and what activities are going to be performed. Based on this information the amount of planned slack can be calculated for every combination of surgeries in an OR block (or OR-day). The planner is generally not allowed to add a surgery to an OR program if the expected surgery duration of the combination of surgeries and the planned slack exceed the maximum capacity. By visualizing the amount of planned slack, the planner receives feedback on the uncertainty of the program.

5.3 Qualitative analysis of proposed interventions

During the qualitative analysis of the interventions, we elaborate on the expected strengths and weaknesses of the proposed interventions. We do not only take usability into account, but also consider expected implementation issues.

Cyclic Master Surgical Scheduling approach for location Oldenzaal

Chapter 4 already described general advantages and disadvantages of the cyclic MSS approach. In this section, we focus on the strengths and weaknesses that are particularly applicable to MST.

Strengths:

- The approach offers a tool that simultaneously improves OR efficiency and levels demand for subsequent surgical wards.
- The model is generic. This enables extending the model to other scarce resources, such as ICU beds, OR equipment, and instrument trays.
- The cyclic nature of the model prevents tactical planners from periodically creating a new block schedule. Once the data requirements are met, the algorithm calculates a new MSS. This reduces the managerial workload of the tactical planner.
- The concept of different slots for different types of surgeries enables surgeons to use the MSS similar to the way they used to schedule patients, using a traditional calendar. If a free slot exists, a patient that finishes the post operative screening can immediately receive a surgery date. This improves communication to the patient, but also decreases the workload of operational planners.

Weaknesses:

- The model assumes a cyclic schedule. During holiday periods, however, MST temporarily decreases capacity. These reduction periods prevent modeling OR planning using the cyclic MSS approach presented by Van Oostrum et al. (2008b). Also, the cyclicity of the model of Van Oostrum et al. prevents taking into account seasonal effects. Further research is required to adjust the model to be able to take into account reduction periods and fluctuations in demand.
- The model assumes discrete lengths of stay. This prevents the standard model from being used for tactical OR planning for the OR department in Enschede, since there is more uncertainty in length of stay for the surgery types performed in Enschede.
- In order for the tool to sufficiently model reality, the data requirements are extensive. Currently, MST uses various information systems. These systems are not always compatible with each other. Additionally, the report function of the hospital management system is very limited. This makes it difficult to gather the required data. During this research however, we have created different Excel based macro files that enable combining data from different data standards.
- The robustness of an OR schedule depends on the amount of slack that is reserved to cope with uncertainty. In order to cope with the occurrence of emergency or semi-urgent patients,

slack has to be reserved. When using slots to schedule surgery types it is necessary to know how much space to reserve for semi-urgent and how much space to reserve for emergency patients. Currently, these two types of patients are not separately registered, which prevents a planner to quantify the amount of slack required to cope with each type of patient.

- The slots in the master surgical schedule have to be linked to the demand. In order to identify and cope with fluctuations in demand, access times have to be monitored. Currently, planners can only retrieve the current number of patients on the waiting list. The system, however, does not have a report function, which makes it impossible to examine trends in demand. This can lead to a simultaneous decrease of OR utilization and an increase of access times.

Calculating ward occupancy distributions based on tactical block plan for location Enschede

Strengths:

- Application of the model in the Dutch Cancer Institute - Antoni van Leeuwenhoek hospital has proven that the model offers valuable insights to OR planners and motivates them to not only strive to optimal OR utilization, but also take into account the effect on subsequent departments (Vanberkel et al., 2009).

Weaknesses:

- The model presents probability distributions, based on a specific (tactical) OR plan. It does not generate a tactical block plan itself. However, based on these probability distributions, it is possible to calculate performance indicators for the variance in bed utilization in wards. After an initial solution has been generated, local search techniques can be applied to improve the schedule. After each solution proposed by the local search heuristic, the performance indicator has to be calculated. In order for the algorithm to be for this to lead to a practical heuristic, the algorithm to (re)calculate the performance indicator(s) should be sufficiently fast.
- The model only covers ward occupancy and workload, it does not consider OR utilization.

Planned slack

Strengths:

- The method takes into account the combination of surgeries and determines slack over the combination of surgeries instead of buffering for each surgery separately.
- By combining surgery types that have similar standard deviations, it enables the planner of the planning package to minimize the required amount of planned slack (portfolio effect).

Weaknesses:

- The current planning package uses the quantile method. It is unclear whether the vendor of the planning software is able and willing to incorporate planned slack into their model.
- The idea of providing the planner information about the uncertainty of an OR program using planned slack can give the planner valuable insights in the uncertainty of an OR program. On the other hand, the understanding of the method used to determine the amount of OR time required to finish the program becomes less obvious. Without instructing planners on the principle behind the planning method, distrust in the methodology might occur.

5.4 Conclusion

Master surgical scheduling

The master surgical scheduling approach is promising with respect to minimizing required OR capacity (thereby optimizing OR utilization) and leveling bed occupancy. Nevertheless the conditions that have to be met before being able to use the approach (Van Oostrum et al., 2008a) cannot be met for the OR department in Enschede. Oldenzaal on the other hand does meet these conditions. Adjusting the MSS approach to make it suitable for location Enschede goes beyond the scope of this research. We therefore test the MSS approach only for location Oldenzaal.

Tactical block planning

After having determined the case mix for location Oldenzaal and Enschede, we adjust the current tactical block plan for Enschede to generate an initial solution suitable for the case mix of Enschede. Next, we calculate the probability distributions for bed occupancy and workload using the model presented by VanBerkel et al. (2009). Based on this model we interchange surgical blocks until we find a new tactical block plan, where bed occupancy and workload of the surgical wards has sufficiently improved.

Planned slack

During the creation of the master surgical schedule and during the operational phase, we test filling the OR program using planned slack instead of the currently used quantile method.

6. Computational experiments

This chapter describes the evaluation of the proposed interventions based on quantitative criteria. Section 6.1 comments on the appropriate verification technique. After Section 6.2 describes the models itself and presents the assessment criteria, Sections 6.3 and 6.4 respectively describe the input distributions and technical design of the models. After we validate the model and present the experimental configurations in Section 6.5 and Section 6.6. In Section 6.7, we present the results of the quantitative evaluation and discuss the outcomes.

Since we consider different interventions for location Oldenzaal and location Enschede and use different techniques for evaluating these interventions, we discuss the experimental set-up for both locations separately. The case mixes of both locations make up the case mix of the entire hospital. Since we assume the case mix of the entire hospital remains stable, the input parameters for the case mix of location Oldenzaal and the input parameters for the case mix of location Enschede correlate. During the evaluation of the results, we combine the results of the experiments for both locations in order to comment on the effect on the entire hospital.

6.1 Verification technique

In order to determine the effect of the proposed interventions, we test our interventions on specific performance criteria. In order to do so, we have three options:

I. Real life experiments
II. Analytical models
III. Simulation study

Real life experiments have some major drawbacks in terms of costs, repeatability, and duration to complete the experiments. The requirement to examine the effect of multiple interventions, the time restriction, and the costs restrictions make real world experimentation infeasible for this research.

Analytical models are able to deliver results fast, can be executed repetitively and generally take less time to complete than real life experiments and simulation studies. Additionally, analytical models are generally easier to optimize than real life experiments and simulation studies. However, it is not always possible to create analytical models for real world situations. Especially in cases where random events interact, as is the case in the execution of surgical programs, analytical models become virtually impossible to solve or do not describe reality sufficiently.

Oldenzaal

In order to evaluate the effect of the proposed interventions on OR utilization (and overtime), we use a simulation model. The occurrence of various events that influence each other and the uncertainty in the occurrence and duration of events make the application of analytical models very complex. We therefore prefer using a simulation model. The state of the system (waiting lists, ORs, wards) changes instantaneously at separate points of time, due to the occurrence of events. Examples of events that might occur are: the opening of an OR, finishing a surgery, or the arrival of an emergency patient. We therefore use discrete event simulation. In Oldenzaal, all patients that visit the OR, stay in the same surgical ward. Since ward information and data on the length of stay of these patients is available, we are able to include ward occupation in the simulation model for location Oldenzaal.

Enschede

To evaluate the effect the proposed interventions have on the utilization of OR capacity, we use the same simulation model as we use for location Oldenzaal. In order to maintain a realistic view, we adjust the simulation model to the situation of location Enschede in 2008. In contrast to location Oldenzaal, we do not use the simulation model for evaluating ward occupancy. In Enschede, there are various surgical wards. These wards generally differ from each other by the primary specialty or specialties that are dedicated to it. Nevertheless, it happens that a patient has to be transferred to a different ward. These transfers contaminate the data for the link between surgical ward and surgery types. Therefore, we choose to evaluate ward occupation for location Enschede on a more aggregate level. This enables us to use the analytical model of Vanberkel et al. (2009).

The input parameters for the analytical model are the empirical distribution for the number of cases per specialty block, and the empirical distribution for the length of stay for patients of these specialties. To model the current situation, we determine the empirical distributions using the historical data of 2008. Obviously, there is no historical data for the number of cases per OR block for the future situation where there is an EBC in Oldenzaal. We therefore use the output from the simulation model as input for the number of cases per specialty block in the analytical model. Thereby, we are able to comment on the expected effects on bed occupancy caused by the realization of the EBC in Oldenzaal.

6.2 Conceptual model design

6.2.1 The project objectives

The aim of this study is to compare the effects of the proposed interventions on throughput, OR utilization, overtime probability, and variability in ward occupancy. The results of the simulation study and analytical model determine which interventions we propose for implementation.

6.2.2 Performance indicators

In comparing the different interventions, we use the following performance indicators for the utilization of OR capacity:

- Throughput (number of patients per OR-day)
- Net utilization of OR capacity
- Overtime probability per OR-day
- Average amount of overtime per OR-day that has overtime.

These performance indicators are similar for both locations. The performance indicator for the bed occupancy differs Oldenzaal and Enschede.

Oldenzaal

The simulation model generates patients that occupy beds in the surgical ward. The model uses the length of stay of each patient to determine how long a bed is occupied. Based on this information, we determine the average inpatient bed occupation and the coefficient of variation for the bed occupancy of elective inpatients.

Enschede

The analytical model determines a probability distribution for the bed occupancy. Instead of calculating the amount of occupied beds per day, the model calculates the probability distribution for the number of occupied beds per day. Based on these distributions, we calculate the average bed occupancy, the variation in bed occupancy and the 95% quantile values for bed occupancy. The 95% quantile value for the bed occupancy gives a more reliable measure for the number of beds that need to be staffed than the expected bed occupancy. Staffing beds based on the expected occupancy results in the ward being understaffed approximately half of the time. Since we are interested in the variation in bed occupancy, we use the coefficient of variability for the 95% quantile value of the number of required elective inpatient beds. Mathematically this can be represented by:

Let X_n be the number of occupied beds on day n=1,…,N, and $X_n \sim Empirically\ distributed$. Then the 95% quantile value for the number of occupied beds on day n is: $x_n :\ P(X_n \leq x_n) = 0.95$.

The performance indicator for the variation of bed occupancy:

$$cv_x = \frac{S_x}{\bar{x}} \quad , where\ S_x = \sqrt{\frac{\sum_{n=1}^{N}(x_n - \bar{x})^2}{n-1}}, and\ \bar{x} = \frac{\sum_{n=1}^{N} x_n}{N}$$

6.2.3 Scope

Since the objective of this research is to present interventions that improve OR utilization and variability in bed occupancy of the surgical wards, we demarcate the scope of this simulation study to the general OR department and the subsequent wards. Although the availability of ICU bed capacity restricts the number of possibilities in scheduling elective patients in Enschede, the absence of data for the length of stay in the ICU prevents us from taking ICU availability into account. Additionally, the number of elective patients that require an ICU bed is limited to 2.9% of the entire elective case mix for location Enschede and 0% for location Oldenzaal. In case a conflict occurs, this affects a single patient only, whereas admission stops caused by crowded surgical wards cause entire programs to be cancelled. Other departments involved in the primary process, such as the inpatient clinic, the POS department, the OR holding area, and the recovery room, do not impose restrictions on the execution of the OR programs. Therefore, we do not include these departments in the simulation model.

Level of detail

- Patients are generated and placed on a waiting list, using the case mix characteristics of 2008.
- Based on the patient's due date, the patient is scheduled for an appropriate OR-day.
- Depending on the length of stay associated to the patient, each patient contributes to the bed occupancy of the surgical ward.
- The OR and ward are examined as if they were black boxes. The processes within the boxes are not relevant in terms of the predefined performance indicators and are therefore not included.
- Surgical ward beds are assumed to be occupied from the moment the patient is admitted until the patient is discharged.

Figure 18 shows how we include waiting list, wards, and ORs in the simulation model..

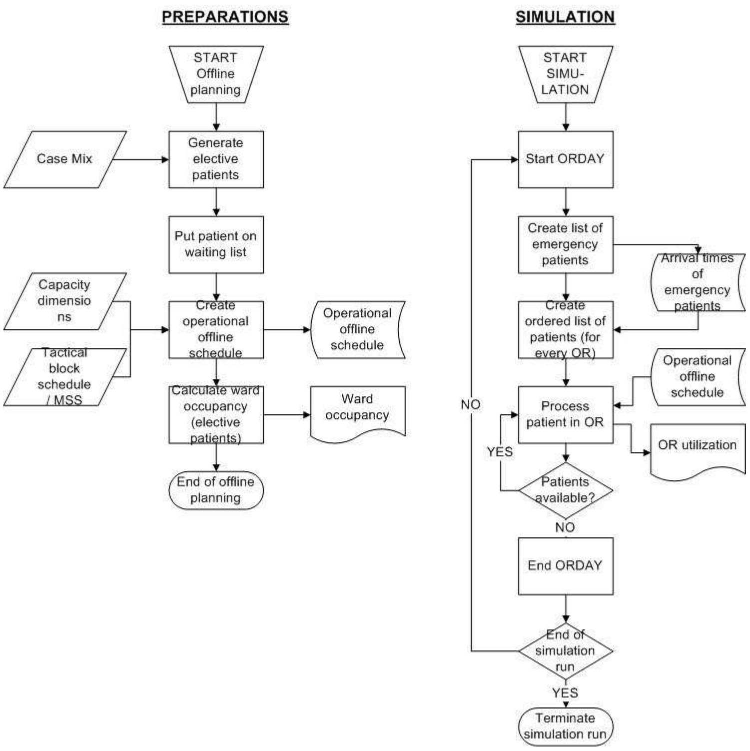

Figure 18 Flowchart of simulation model consisting of preparations (creation of operational offline schedule) actual execution of simulation runs.

Appendix O states the restrictions and assumptions for all model configurations in the simulation model.

6.3 Data gathering and data validation

We use the historical data of the general ORs in 2008 to determine the input distributions for surgery durations and changeover times in the simulation model. This data was already discussed during the quantitative analysis in Section 2.3 and Section 2.4. In order to validate the data, we presented our statistical analysis to OR management and various field experts (including specialists). For more information about the determination of probability distribution of input parameters, we refer to Appendix N.

Oldenzaal

In order to model surgery durations in the simulation model, we use a lognormal distribution. Since, we are not able to fit a distribution to the changeover times, we use the historical data to derive an empirical distribution. There is little uncertainty in the length of stay of patients in the surgical ward in Oldenzaal, therefore we assume the length of stay for Oldenzaal to be deterministic. Table 11 shows the input distributions for location Oldenzaal.

Table 11 Distribution used for input parameters for location Oldenzaal

	Distribution	Used in
Surgery Durations	Lognormal	Simulation model
Changeover times	Empirical	Simulation model
Length of stay	Deterministic	Simulation model

Enschede

The input parameters for the simulation model have the same distributions as the input distributions for location Oldenzaal. The input distribution for the length of stay differs from Oldenzaal. Since there is more variation in the length of stay of patients in the surgical wards in Enschede, we do not assume deterministic length of stay. Instead, we derive an empirical distribution based on the historical data. In order to be able to comment on the expected bed occupancy, using the analytical model, we use an empirical distribution for the number of patients per OR block. Table 12 summarizes the input distributions for Enschede.

Table 12 Dsitribution used for input parameters for location Enschede

	Enschede	Used in
Surgery Durations	Lognormal distribution	Simulation model
Changeover times	Empirical distribution	Simulation model
Length of stay	Empirical distribution	Analytical model
Cases per OR block	Empirical distribution	Analytical model

Appendix N gives more information on the determination of input parameters for the surgery durations and changeover times for both locations.

6.4 *Technical design of the simulation model*

Instead of having to create a simulation model from scratch, we are able to use the "The OR manager" software developed by the Centre of Healthcare Operations Improvement & Research (CHOIR) of the University of Twente. This Delphi based software program is a generic model for simulating resource capacity planning. Although the name "OR Manager" indicates the model is initially designed to model operating room planning, it is also used in simulating other resources, such as the radiology department.

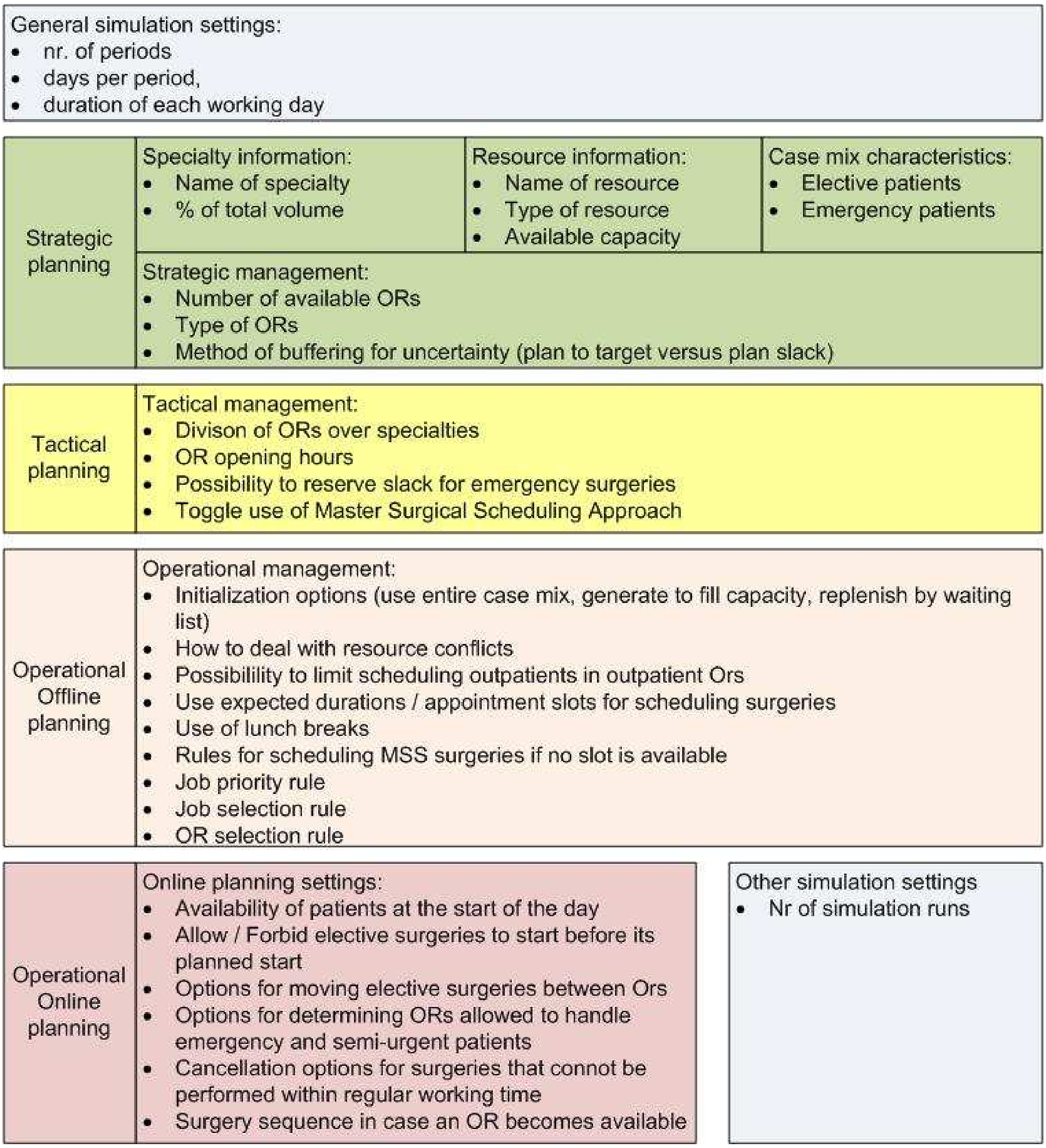

Figure 19 Hierarchical planning levels incorporated in simulation model

6.4.1 CHOIR's simulation model: "The OR manager"

"The OR manager" enables simulation of the execution of OR programs. In order to adjust the model to MST's specific situation, the program's user interface offers different settings for decision made on different hierarchical levels in resource capacity planning. Figure 19 shows how the model incorporates the different hierarchical levels of resource capacity planning and states the choices that can be made on each level.

6.4.2 Model limitations

Oldenzaal

The simulation model offers the possibility to use master surgical scheduling during tactical OR planning. However, the MSS routine in the simulation software differs from the integer linear programming technique and column generation heuristic proposed by Van Oostrum et al. (2008b). For each surgery type that uses MSS slots, the software distributes time slots over suitable OR-days using list scheduling. After an initial solution has been generated, local search techniques can be applied to interchange slots in order to minimize variation in bed capacity of surgical wards. During operational planning, the list scheduling algorithm fills the time slots with patients that require the appropriate type of surgery. After all slots are filled, the remaining capacity is filled by following predefined priority rules. The existing model does not allow the combination of a cyclic MSS and appointment slots. Instead, the model uses expected surgery durations and planned slack. Therefore in simulating cyclic master surgical slots, we use planned slack to cope with variability instead of the currently used quantile values. In order to evaluate the effect of introducing a cyclic MSS, we compare the performance of the cyclic MSS with planned slack to the performance of a cyclic block schedule with planned slack.

"The OR manager" does not offer the possibility to calculate the quantile values for the surgery durations of various surgery types itself. However, it does offer the possibility to define appointment slots. The quantile values determined from the historical data determine the length of the appointment slot for each type of surgery separately.

Enschede

Location Enschede has 11 ORs. One of these is used as a trauma OR and is ran by trauma surgeons. Although this OR is not defined as an emergency OR, the purpose of this OR is to perform both emergency and semi-urgent surgeries. Half of the available capacity is reserved for semi-urgent patients. The remaining capacity is reserved for emergency surgeries. Because planners do not consequently register semi-urgent surgeries as emergency or elective surgeries, the actual distribution cannot be derived from the historical data. The simulation model does not support two or more specialty blocks per OR-day. Therefore, we model the trauma OR as two separate ORs, one for (elective) semi-urgent surgeries and one for emergency surgeries. Both ORs get half the capacity of a regular OR (240 minutes instead of 480 minutes).

The graphical user interface of the simulation model allows only a limited number of different OR-days during tactical planning. This prevents us from using the tactical block schedule of 2008 as direct input for the tactical block schedule in the simulation model. Since the model does allow a cyclic schedule, we translate the block schedule of 2008 to a 4 weekly schedule that repeats itself 13 times. The annual OR capacity and the length of the OR blocks in the cyclic schedule are similar to those in the actual block schedule of 2008.

We programmed the analytical model using Microsoft Excel 2007 and Visual Basic For Applications. Calculating the probability distribution for the different specialties using the analytical model takes several minutes on a Packard Bell Easynote notebook with Intel Centrino 2DUO 2.1GHz processor and 4GB RAM. Since the analytical model calculates the steady state distributions for a cyclic roster, the entire distribution has to be recalculated after OR blocks are swapped. Every recalculation can take up to a minute, depending on the number of blocks, the maximum length of stay, and the maximum number of cases per OR block. Therefore, we did not extend the model with a local search algorithm. In order to be able to add a local search algorithm, we first have to optimize the model in terms of speed, or have to use faster programming languages. For the time being, we choose to swap OR blocks manually.

6.5 Verification & validation of the model

To verify and validate the simulation model, we test the model using the input data and block schedule of 2008, to which we refer to as the null configurations. We compare the performance indicators for the OR utilization and the probability and amount of overtime to those of the real-world observed data of 2008. To validate the simulation model, we evaluate the absolute differences between observed and simulated values. The null configurations represent the following settings:

- Oldenzaal: Block schedule Oldenzaal 2008, Quantile method (67%), Case Mix Oldenzaal 2008.
- Enschede: Block schedule Enschede 2008, Quantile method (70%), Case Mix Enschede 2008.

Oldenzaal

Table 13 shows the relative difference between the observed data of 2008 and the simulated data for Oldenzaal. We use the realized block schedule of 2008 as input for the simulation model. The available capacity can change during operational offline planning. In case an OR remains empty, this OR is closed, thereby reducing capacity. For the null configuration, no OR is closed during operational offline scheduling. This explains the relative difference of 0% with the historical data. The difference in number of OR-days can be explained by the fact that we model an OR-day that consists of two OR blocks as two separate OR-days. The number of elective surgeries per year in the simulation model is lower than the actual number of surgeries. Changing the simulation settings to allow more surgeries to be scheduled during operational offline planning causes the amount of overtime to increase drastically. The same holds for the overtime probability. Based on the historical input data, we are not able to adjust the simulation model such that the overtime probability increases and the total amount of overtime decreases. The number of patients per year and the total overtime per year both show a relative difference between observed and simulated values of 5% or less. We find this difference acceptably small. Therefore, we use the proposed simulation settings.

Table 13 Difference between observed values 2008 and simulation output Q(0.67)

	Simulation (averages)	Observed (data 2008)	Relative difference
Available capacity per year	4135 hrs	4135 hrs	0 %
Number of OR-days per year	526	524	+ 0 %
Number of elective surgeries per year	4201	4311	- 3 %
Net OR Utilization	80 %	80 %	- 0 %
Overtime probability	0.20	0.29	- 31 %
Total overtime per year	3235	3088	+ 5 %
Average elective surgery duration	48 min.	47 min.	+ 2 %
Standard deviation of elective surgery duration	34 min.	33 min.	- 3 %

Enschede

Table 14 shows the relative differences between results derived from simulating the null configuration and the observed data of 2008. We see that the deviation for most indicators is within 5%. The probability of overtime and the amount of overtime differentiate show larger deviations. While the probability of running into overtime for the simulated null configuration is significantly lower, the total amount of overtime per year is significantly higher. A possible explanation for the deviation is the difference between the way we incorporate emergency ORs and reality. In reality, the trauma OR is used for a mixture of elective (semi-urgent) and emergency surgeries. We model the emergency OR as a dedicated emergency OR with the capacity of half a day. All emergencies arriving outside this period cause disturbances on other programs, which are likely to result in overtime. In reality the trauma OR can deal with emergency surgeries from the beginning of the day unto the end, but also offers capacity for the elective patient, thereby increasing flexibility. Additionally, in reality, emergency surgeries that do not immediately require medical care can be postponed to the evening shift. Based on these possible explanations for the deviation in overtime (probability) and since altering the model either increases the deviation between the actual and simulated overtime probability, or the deviation between total simulated amount of overtime and the actual amount of overtime, we tolerate the observed deviations.

Table 14 Relative difference between performance indicators for null scenario Enschede (simulation) and historical data 2008

	Simulation (averages)	Observed (data 2008)	Relative difference
Available Capacity per year	20018 hrs.	20020 hrs	+ 0 %
Number of elective surgeries per year	10808	11123	- 3 %
Number of emergency surgeries per year	1286	1278	+ 1 %
Net OR Utilization	79.5 %	82.0 %	- 3 %
Total overtime per year	49479 min.	37280 min.	+ 33 %
Overtime probability	0.32	0.35	- 8 %
Average elective surgery duration	85 min.	84 min.	+ 1 %
Standard deviation of elective surgery duration	65 min.	62 min.	+ 5 %

6.6 Experimentation design

6.6.1 Number of replications

Due to the use of probability distributions in the simulation model, the performance indicators derived from the simulation differ for each simulation run. In order to get a reliable estimate of the expected value (μ) of each indicator, we repeat each experiment a number of times. Subsequently, we estimate the expected value for each indicator by taking the average of all identical experiments($\bar{X}$). By increasing the number of replications, the error made in estimating the expected values can be reduced. Consequently, after stating a desired confidence level for the mean, it is possible to determine the minimum required number of replications for each experiment. After making a trade-off between the desired confidence level and the required number of replications (Law, 2007, p. 501), we choose a confidence level of 95%, which coincides with a relative error of $\gamma = \frac{|\bar{X}-\mu|}{\mu} = 0.05$.

The required number of replications varies for each experimental setting. In order to calculate the actual required number of replications per experiment, we use the sequential procedure (Law, 2007, pp. 502-504). Table 15 shows the number of replications used in the simulation study for the null models of Oldenzaal and Enschede.

Table 15 Required number of replications for the null configurations

	Required number of replications
Oldenzaal	18
Enschede	8

6.6.2 Warm up period

A warm up period has to be considered in case the system requires time to reach its steady state behavior. For example, when simulating bed occupancy of a ward that does not close, the system needs a warm up period to reach a realistic and steady state.

Oldenzaal

The surgical ward ìn Oldenzaal closes during weekends. This means that the simulation is terminating. In case of such a terminating simulation, no warm up period needs to be considered.

Enschede

Although surgical wards in Enschede do not close, we do not use the simulation model for determining ward occupancy. The simulation model for Enschede only considers OR capacity. Since the OR capacity returns to its initial state every day, the simulation model is terminating. Therefore, we do not take into account a warm up period for the simulation model for location Enschede. The analytical model of Vanberkel et al. (2009), which we do use to calculate ward occupancy, assumes repetitiveness of the block schedule. Based on this repetitiveness it calculates the system's steady state. This means that no warm up period has to be considered for the analytical model either.

6.6.3 Interventions

In order to test each proposed intervention, several experimental factors can be changed. Which factors should be changed depends on the type of intervention. Again, we discuss the settings for each location separately.

Oldenzaal

The simulation model offers four options for making an operational offline OR plan:

1. Schedule surgeries based on expected durations until a predefined capacity target is reached;
2. Schedule surgeries based on quantile values that determine the length of predefined appointment slots;
3. Schedule surgeries based on expected duration and reserve slack to deal with disturbances;
4. Schedule surgeries based on a cyclic master surgical schedule (Van Oostrum et al., 2008b) and cope with uncertainty by reserving slack to deal with disturbances.

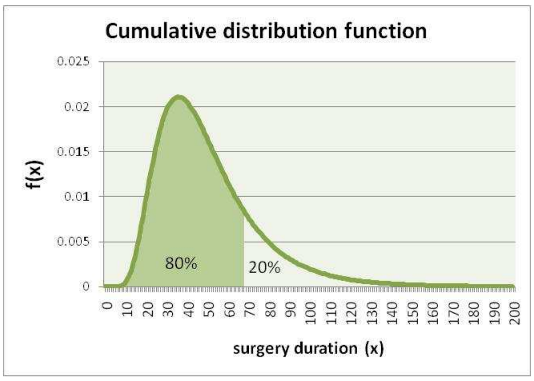

Figure 20 Example of 80% quantile value:
$x: P(X \leq x) = 0.8$

For location Oldenzaal we use all options except the first. For the second option, we define appointments slots per surgery type. Figure 20 illustrates how the quantile value determines the length of the appointment slot. In the example, a probability of 0.8 (80% quantile) coincides with an appointment slot of 68 minutes. To test the effect of changing the quantile values, we test different probabilities.

In order to test the effect of using planned slack, we use the third option. By changing the slack factor, we vary the overtime probability and net utilization. We compare the method of planning slack to the method of planning appointment slots based on quantile values.

To test the quantile method and the planned slack method, we use the tactical block schedule of 2008 in which OR blocks are assigned to specialties. For evaluating the cyclic master surgical schedule approach, we translate the existing block schedule to a cyclic schedule, such that the available capacity per specialty is similar for both approaches. Since the master surgical scheduling algorithm uses planned slack, we test the master surgical scheduling approach with the slack factor that most resembles the null configuration. We compare the performance measures for the master surgical scheduling approach to the performance of a cyclic block schedule with equal amount of planned slack.

Enschede

For location Oldenzaal, we consider a tactical block schedule with appointment slots only. The length of the appointment slots is similar to the realized situation in 2008. We use the analytical model of Vanberkel (2009) to evaluate how the tactical block schedule affects bed occupation of surgical wards. We modify the tactical block schedule by interchanging or moving OR blocks in order to decrease the expected variability in bed occupation. We evaluate the changes to the block schedule using the analytical model.

6.6.4 Scenarios

Scenario 1

We evaluate the proposed interventions for two scenarios. The first is the situation of 2008, with two ORs in Oldenzaal[3] and eleven ORs in Enschede. We consider the realization in Oldenzaal in 2008 to be the case mix for location Oldenzaal and the realization in Enschede to be the case mix for Enschede.

Scenario 2

The second scenario represents the future situation, where there is an EBC in Oldenzaal, which consists of 4 ORs, while the capacity in Enschede remains the same. For the case mix of location Oldenzaal, we consider the ambition presented by Medisch Spectrum Twente (2009a). We define the case mix for location Oldenzaal to be the case mix for the entire hospital minus the case mix for location Oldenzaal.

[3] During 2008, OR capacity in Oldenzaal decreased from four ORs in the beginning of the year, to two ORs at the end of the year.

6.7 *Configurations*

Based on the proposed interventions, the experimental factors, and the scenarios, we determine a number of configurations. We evaluate each configuration using either the simulation model (Oldenzaal) or a combination of the simulation model and the analytical model (Enschede).

Oldenzaal

Table 16 shows the configurations for testing the proposed interventions with scenario 1, the situation in 2008. Table 17 Configurations for simulation for location Oldenzaal (scenario 1): cyclic block schedule versus cyclic MSS.

	Identifier	Tactical planning	Method to deal with uncertainty	Experimental factor
10.	Old_cMSS_PS(0.5)	Cyclic block schedule	Planned Slack	$\beta = 0.5$
11.	Old_cMSS_PS(0.5)	Cyclic MSS	Planned Slack	$\beta = 0.5$

Table 18 shows the configurations for testing the proposed interventions with scenario 2, after the realization of the EBC.

Table 16 Configurations for simulation for location Oldenzaal (scenario 1), quantile method versus planned slack.

	Identifier	Tactical planning	Method to deal with uncertainty	Experimental factor
0.	Old_Block_Q(50)	Block schedule	Quantile method	$P(X \leq x) = 0.50$
1.	Old_Block_Q(60)			$P(X \leq x) = 0.60$
2.	*Old_Block_Q(67) (Null conf.)*			$P(X \leq x) = 0.67$
3.	Old_Block_Q(70)			$P(X \leq x) = 0.70$
4.	Old_Block_Q(80)			$P(X \leq x) = 0.80$
5.	Old_Block_PS(0.2)		Planned Slack	$\beta = 0.2$
6.	Old_Block_PS(0.5)			$\beta = 0.5$
7.	Old_Block_PS(1.0)			$\beta = 1.0$
8.	Old_Block_PS(1.5)			$\beta = 1.5$
9.	Old_Block_PS(2)			$\beta = 2$

Table 17 Configurations for simulation for location Oldenzaal (scenario 1): cyclic block schedule versus cyclic MSS.

	Identifier	Tactical planning	Method to deal with uncertainty	Experimental factor
10.	Old_cMSS_PS(0.5)	Cyclic block schedule	Planned Slack	$\beta = 0.5$
11.	Old_cMSS_PS(0.5)	Cyclic MSS	Planned Slack	$\beta = 0.5$

Table 18 Configurations for simulation for location Oldenzaal (scenario 2).

	Identifier	Tactical planning	Method to deal with uncertainty	Experimental factor
12.	Old_cBlock_PS(0.5)_N	Cyclic block Schedule	Planned Slack	$\beta = 0.5$
13.	Old_cBlock_PS(0.5)_N	Cyclic MSS	Planned Slack	$\beta = 0.5$

Enschede

For location Enschede, we do not consider using cyclic master surgical scheduling. Table 19 shows which configurations we use to evaluate both scenarios. For both configurations, we use the quantile method.

Table 19 Configurations for simulation of interventions for location Enschede, including null configuration

	Identifier	Tactical planning	Method to deal with uncertainty	Experimental factor	Scenario
14.	*Ens_Block_AS(.70) (Null conf.)*	Block schedule	*Quantile method*	$P(X \leq x) = 0.70$	Scenario 1: 2008
15.	Ens_Block_AS(.70)_N	Block schedule	Quantile method	$P(X \leq x) = 0.70$	Scenario 2: EBC

Additionally, we use the analytical model to determine the bed occupation of surgical wards and propose changes to the block plan that reduce the variability of the bed. For scenario 2, with an EBC in Oldenzaal, we determine the probability distribution for the number of inpatients per OR block from the simulation model.

6.8 Results of the quantitative analysis

This section presents the results of the quantitative analysis. We evaluate the proposed interventions using the performance indicators described in Section 6.2. We distinguish between the proposed interventions for location Oldenzaal and the interventions for location Enschede. For scenario 2, the scenario with the EBC in Oldenzaal, we evaluate the performance of each location separately, and evaluate the performance of the hospital as a whole. First, we discuss the results of the simulation studies. Then, we present the results for the bed occupancy in Enschede using the analytical model.

6.8.1 Oldenzaal scenario 1: current situation

For location Oldenzaal, we evaluate three types of interventions: use of quantiles, use of planned slack, and the introduction of a cyclic MSS (Van Oostrum et al., 2008b). The first two interventions are not exclusively applicable to Oldenzaal, the cyclic MSS is.

Table 20 shows the performance measures for the different configurations for location Oldenzaal. The various configurations correspond to the configurations presented in Section 6.7.

Table 20 95% Confidence intervals of the simulation results for OR utilization of the configurations for location Oldenzaal: Quantile method, Planned slack method, and cyclic MSS.

	Configuration	Nr. of replica-tions	Through-put (avg. patients per OR-day)	Nr. Of OR-days	Average net OR utilization [95% conf. interval]	Overtime (OT) probability [95% conf. interval]	Avg. OT per OR-day with OT (min.) [95% conf. interval]
0.	Old_Block_Q(50)	*6*	*8.9*	*487*	*0.838 [0.835, 0.841]*	*0.550 [0.526, 0.574]*	*43.2 [40.4, 46.1]*
1.	Old_Block_Q(60)	*6*	*8.5*	*505*	*0.816 [0.814, 0.818]*	*0.328 [0.316, 0.340]*	*34.8 [31.5, 38.0]*
2.	*Old_Block_Q(67) (Null configuration)*	*18*	*8.2*	*518*	*0.794 [0.792, 0.795]*	*0.201 [0.194, 0.209]*	*31.0 [29.1, 32.9]*
3.	Old_Block_Q(70)	*26*	*8.0*	*523*	*0.786 [0.784, 0.787]*	*0.152 [0.139, 0.165]*	*26.9 [22.7, 31.0]*
4.	Old_Block_Q(80)	*90*	*7.3*	*526*	*0.734 [0.734, 0.735]*	*0.050 [0.039, 0.061]*	*28.0 [17.8,38.2]*
5.	Old_Block_PS(0.2)	*8*	*8.5*	*510*	*0.819 [0.816, 0.822]*	*0.362 [0.343, 0.381]*	*35.1 [33.2,37.0]*
6.	Old_Block_PS(0.5)	*10*	*8.3*	*521*	*0.809 [0.806, 0.811]*	*0.268 [0.247, 0.289]*	*30.5 [29.1, 31.9]*
7.	Old_Block_PS(1.0)	*16*	*8.1*	*525*	*0.783 [0.781, 0.784]*	*0.166 [0.146, 0.185]*	*28.6 [25.6,31.5]*
8.	Old_Block_PS(1.5)	*38*	*7.7*	*526*	*0.754 [0.753, 0.755]*	*0.093 [0.081, 0.105]*	*24.7 [20.4, 28.9]*
9.	Old_Block_PS(2)	*72*	*7.4*	*526*	*0.726 [0.725, 0.727]*	*0.053 [0.046, 0.059]*	*20.3 [16.6,24.9]*

Quantile method versus planned slack

Table 20 shows the output of the simulation model for location Oldenzaal. The table shows that by decreasing the quantile value it is possible to attain a higher level of OR utilization. However, decreasing the quantile value also leads to a higher probability of overtime and a higher amount of overtime. Increasing OR utilization by changing the quantile value therefore comes down to a trade-off between OR utilization and (risk of) overtime. Furthermore, the results show little difference between planning with planned slack and planning using the quantile method.Figure 21 and Figure 22 show that both methods can be used to get the same level of performance.

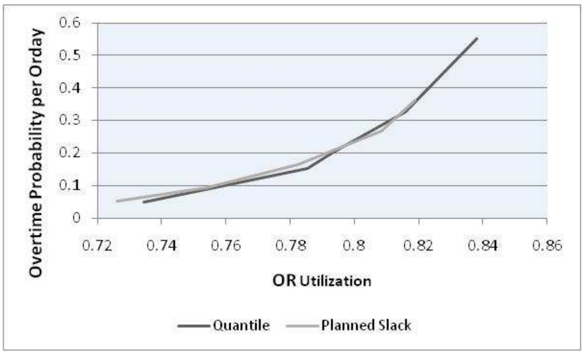

Figure 21 Quantile method versus planned slack: Relationship between overtime probability and OR utilization.

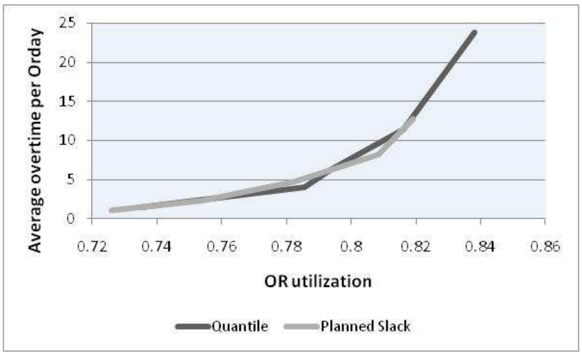

Figure 22 Quantile method versus planned slack: Relationship between average overtime per day and OR utilization. ***(average overtime per day = probability of overtime * average overtime per OR-day in overtime).***

Since all configurations presented in Table 20, result from the same block schedule and neither configuration takes bed occupancy levels into account, there is little difference between the configurations using the Quantile method and configuration using the "Planned slack, in terms of average inpatient bed occupancy and the coefficients of variability for the inpatient bed occupation. Appendix Q presents a complete list of the simulation results for the inpatient bed occupancy.

Cyclic master surgical schedule versus cyclic block schedule

Since the simulation model does not allow a combination of cyclic master surgical scheduling and the quantile method, we have to use a planned slack configuration to comment on the effect of master surgical scheduling. We choose the 'planned slack"-configuration Old_Block_PS(0.5), since the confidence intervals for this configuration are closest to the null configuration. We translate the block schedule from the historical data of 2008 to a cyclic block schedule. In order to evaluate the performance of the cyclic MSS with planned slack (Old_cMSS_PS(0.5)), we compare the results of the MSS to the results of a cyclic block schedule with planned slack (Old_cMSS_PS(0.5)).

Table 21 95% confidence intervals for the performance measures of simulated configurations for OR utilization: Cyclic MSS versus cyclic Block schedule (scenario 1).

	Configuration	Nr. of repli-cations	Throughput (avg. nr. of patients per OR-day)	Nr. Of OR-days	Average net OR utilization [95% conf. interval]	Overtime (OT) probability [95% conf. interval]	Avg. OT per OR-day with OT (min.) [95% conf. interval]
10.	Old_cBlock_PS(0.5)	*17*	*7.2*	*533*	*0.800 [0.799, 0.801]*	*0.266 [0.256, 0.275]*	*31.2 [28.2, 34.1]*
11.	Old_cMSS_PS(0.5)	*18*	*7.1*	*533*	*0.803 [0.801, 0.805]*	*0.268 [0.257, 0.278]*	*28.1 [25.2, 30.9]*
	Confidence interval[4] of the difference (α = 0.05): (Old_cBlock_PS(0.50) – Old_cMSS_PS(0.5)				*[-0.005, -0.001]*	*[-0.020, 0.006]*	*[-0.075, 3.762]*

[4] *Confidence interval of difference between configurations using Welch procedure*

Table 21 shows the results of the simulation for the OR utilization performance indicators. The difference between the average net utilization for the cyclic MSS (Old_cMSS_PS(0.5)) and the cyclic Block schedule ($\alpha = 0.05$) is statistically significant. Although the difference is small, the cyclic MSS performs better than the cyclic block schedule. The differences between the indicators for the overtime probability and the average overtime per OR-day that has overtime are too small to find a significant difference between both configurations.

Table 22 Performance measures of simulated configurations for inpatient bed utilization: cyclic block schedule versus cyclic MSS *(average bed occupancy and standard deviation include days with zero occupancy, such as weekends).*

	Configuration	Average Inpatient Bed occupation	Standard deviation of inpatient Bed occupation	Maximum bed occupancy	Coefficient of variability
10.	Old_cBlock_PS(0.5)	*1.76*	*1.88*	*9*	*1.07*
11.	Old_cMSS_PS(0.5)	*1.77*	*2.05*	*11*	*1.16*

Table 22 shows the performance measures for the inpatient bed occupancy. The cyclic master surgical scheduling algorithm implemented in the simulation model, does not reduce average inpatient bed occupation or level inpatient bed occupancy. It even results in a higher coefficient of variation. The algorithm used in the simulation model uses list scheduling to assign slots to suitable OR-days. Although the list scheduling rules offer the planner a method to give priority to certain objectives (such as shortest due date first, or longest surgery duration first), the algorithm does not optimize OR utilization or level bed capacity. In order to improve OR utilization, we schedule longest expected surgery duration first. Additionally, we choose “best fit” to select the OR in which the surgery is planned. This causes similar surgery types to be scheduled on the same OR-days. Although blocks of similar types of surgery make the bed occupancy better predictable, the coefficient of variation for the inpatient bed occupancy deteriorates. Nevertheless, even without efficiency gains, the master surgical scheduling approach provides benefits to both personnel and patients. The possibility of scheduling patients in predetermined slots facilitates an efficient planning process. Additionally, the methodology provides a framework for the direct scheduling of patients. A condition that has to be met before a master surgical schedule can be successfully implemented is that it takes (specialty specific) restrictions into account, such as a prescribed sequence of surgeries. Uniformly clustered surgery types help respecting these restrictions.

6.8.2 Oldenzaal scenario 2: realization of EBC in Oldenzaal

The second scenario, we evaluate is the realization of an EBC in Oldenzaal. The increased capacity in Oldenzaal results in a shift in the case mix. Since the objective is to fill the OR programs in Oldenzaal as efficiently as possible, a part of the elective case mix shifts from Enschede to Oldenzaal.

Oldenzaal

Table 23 95% confidence intervals for the simulation output for the cyclic block scheduling approach and the cyclic master surgical scheduling approach for Oldenzaal: *(Scenario 2008 (10/11) versus Scenario EBC (12/13)*

	Configuration	# runs	# elective patients	Average Throughput (patients per OR-day)	# OR-days	Average net OR utilization	Overtime (OT) probability	Avg. OT per OR-day with OT (min.)
10.	Old_cBlock_PS(0.5)	*17*	*3829*	*7.2*	*533*	*[0.799, 0.801]*	*[0.256, 0.275]*	*[28.2, 34.1]*
11.	Old_cMSS_PS(0.5)	*18*	*3798*	*7.1*	*533*	*[0.801, 0.805]*	*[0.257, 0.278]*	*[25.2, 30.9]*
12.	Old_cBlock_PS(0.5)_N	*13*	*6440*	*7.2*	*897*	*[0.819, 0.822]*	*[0.249, 0.259]*	*[30.5, 35.7]*
13.	Old_cMSS_PS(0.5)_N	17	7043	7.5	936	*[0.820, 0.823]*	*[0.253, 0.283]*	*[30.2, 36.7]*

Table 23 shows that the shift in case mix significantly increases OR utilization for location Oldenzaal. Both for the ‘standard’ block scheduling approach (Old_cBlock_PS(0.5)_N) and the cyclic MSS approach (Old_cMSS_PS(0.5)_N), the confidence intervals for the OR utilization are higher than for the scenario’s based on historical data from 2008 (Old_cBlock_PS(0.5) and Old_cMSS_PS(0.5)). Table 24 shows that the master surgical scheduling approach has a lower coefficient of variation for the bed capacity of the surgical ward. This can be explained by the fact that the OR capacity increases in the EBC. The increase in OR capacity leads to more OR blocks that can be interchanged in order to level bed utilization of the wards.

Table 24 Performance measures of simulated configurations for inpatient bed utilization for location Oldenzaal, scenario 2: EBC ***(measures include days with zero occupancy, such as weekends).***

	Configuration	Average Inpatient Bed occupation	Standard deviation of inpatient Bed occupation	Maximum bed occupancy	Coefficient of variability
10.	Old_cBlock_PS(0.5)_N	*4.42*	*5.58*	*17*	*1.26*
11.	Old_cMSS_PS(0.5)_N	*5.97*	*4.94*	*20*	*0.83*

Enschede

The shift in case mix has a positive effect on OR utilization in Oldenzaal. Table 25, however, present the drawbacks of this decision. The average net OR utilization for Ens_Block_AS(.70)_N is significantly lower than the OR utilization for Ens_Block_AS(.70). Since the more predictable surgeries are performed in Oldenzaal, Enschede looses efficiency. The differences between overtime probability and average overtime per OR-day with overtime do not significantly differ.

Table 25 95% Confidence intervals for the simulation output for location Enschede (scenario 1: situation 2008, scenario 2: EBC Oldenzaal)

	Configuration	# runs	# elective (emergency) patients	Average Throughput (patients per OR-day)	# OR-days	Average net OR utilization	Overtime (OT) probability	Avg. OT per OR-day with OT (min.)
14.	Ens_Block_AS(.70)	*9*	*10714 (1286)*	*4.4*	*2739*	*[0.793, 0.796]*	*[0.314, 0.331]*	*[52.6, 58.6]*
15.	Ens_Block_AS(.70)_N	9	7980 (1278)	4.4	1902	*[0.769, 0.773]*	*[0.293, 0.316]*	*[55.7, 61.5]*

MST

By combining the performance measures for location Oldenzaal and Enschede, we determine the logistical performance for the entire hospital. For scenario 1, we combine Old_cMSS_PS(0.5) and Ens_Block_AS(.70). For scenario 2 we combine Old_cMSS_PS(0.5)_N and Ens_Block_AS(.70)_N.

Table 26 95% Confidence intervals for the performance measures of simulated configurations for OR utilization: Cyclic MSS versus cyclic Block schedule (scenario 1).

Scenario		# elective (emergency) patients	Throughput (avg. nr. of patients per OR-day)	Nr. Of OR-days	Average net OR utilization	Overtime (OT) probability	Avg. OT per OR-day with OT (min.)
1.	Historical data 2008 (df=18)	*14512 (1286)*	*4.4*	*3272*	*[0.782, 0.81]*	*[0.235, 0.393]*	*[37.4, 66.4]*
2.	EBC Oldenzaal (df=18)	*15023 (1278)*	*5.3*	*2838*	*[0.768, 0.804]*	*[0.215, 0.377]*	*[36.1, 83.6]*

Table 26 shows that there is no statistical evidence of a difference between the logistical performance of scenario 1 and scenario 2. The benefit for location Oldenzaal is cancelled out by the efficiency loss for location Enschede.

6.8.3 Changing tactical block schedule Enschede

For evaluating the effect the tactical block schedule has on the bed occupancy in the wards, we use the analytical model presented by VanBerkel et al.(2009). In order to comment on the difference in bed occupancy between scenario 1 (current) and scenario 2 (realization of EBC), we compare the bed occupancy distributions for both scenarios. The corresponding block plan that is used for the session distribution in Enschede can be found in Appendix P. Figure 23 shows how the bed occupation fluctuates throughout the week. We see that weekends cause down peaks in the bed occupancy, which ultimately leads to up-peaks during the week. The performance indicator we use is the coefficient of variability of the 95% quantile value for the number of occupied beds in a ward. The results for the current case mix in Enschede can be found in Figure 23 and Table 27.

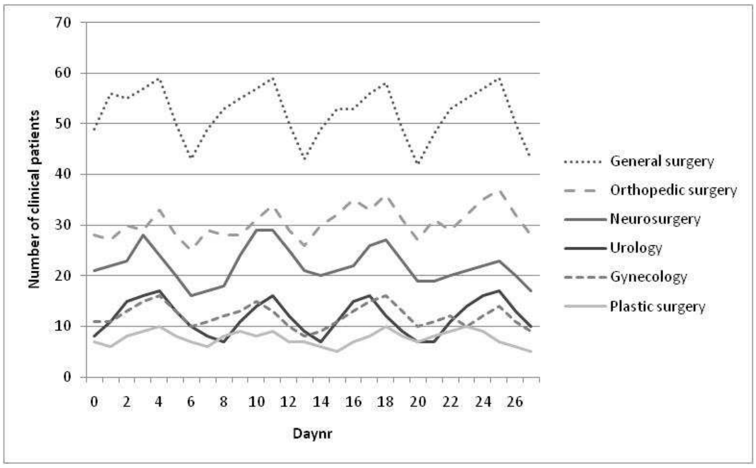

Figure 23 95% Quantile value for the number of clinical surgical patients per day in the surgical wards (current case mix) Number of clinical patients in ward $x = \{\min x : P(X \leq x) \geq 0.95\}$.

Table 27 Coefficient of variation for the 95% quantile value for the number of patients in the surgical wards.

	$CV_{current\ case\ mix}$	$CV_{new\ case\ mix}$	$CV_{new\ case\ mix\ +\ swaps}$
General surgery	0.11	0.06	0.06
Gynecology	0.16	0.27	0.22
Orthopedic surgery	0.10	0.09	0.09
Neuro surgery	0.16	0.13	0.13
Plastic surgery	0.19	0.15	0.15
ENT surgery	0.68	0.57	0.57
Urology	0.28	0.26	0.27
Jaw surgery	0.40	0.51	0.51

Besides the coefficient of variation for the bed occupancy for the current scenario, Table 27 also the results for the scenario 2, the new case mix. The table shows that the changes in the case mix have a positive influence on the coefficient of variability for the ward occupation. Table 27 and Figure 24 show lower fluctuations for most specialties. This can be explained by the overcapacity, due to a shifting part of the case mix to Oldenzaal. Not all ORs have to be fully scheduled all days of the week. This enables us to move blocks forward in the week, which has a positive effect on the variation. During weekends, surgical wards face an outflow of patients. This means that in the beginning of the week, the surgical wards are least occupied. In terms of leveled bed occupancy, it is preferred to increase the inflow of patients in the beginning of the week, to compensate for the outflow during the weekend. Therefore, for the bed occupancy level of the surgical wards, it is preferred to have more OR capacity available in the beginning of the week. The feasibility of such a solution however depends on the capacity restrictions of supporting departments, such as the recovery room, or the central sterilization department. Peak demand for resources in the beginning of the week might cause conflicts or lead to an increase in stock levels to buffer for uncertainty.

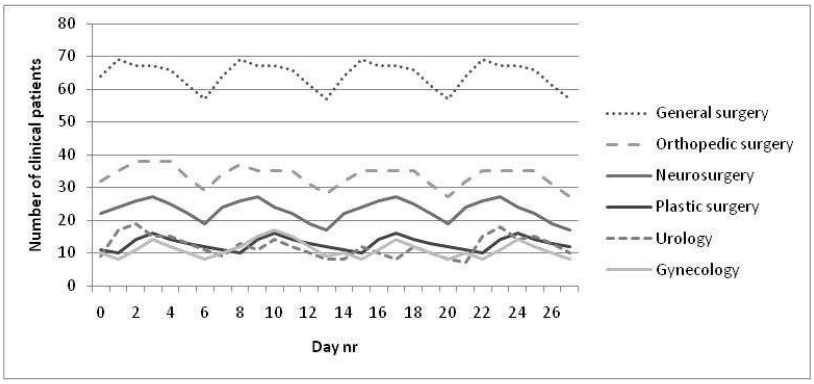

Figure 24 95% Quantile value for the number of clinical surgical patients per day in the surgical wards (new case mix) Number of clinical patients in ward $x = \{\min x : P(X \leq x) \geq 0.95\}$.

Although the number of patients that receive surgery in Enschede decreases as a result of moving smaller better predictable surgeries to Oldenzaal, Figure 24 shows that the actual ward occupation with respect to clinical patients does not decrease, and sometimes even increases. This is the result of moving outpatients to Oldenzaal, which results in a higher number of inpatients in Enschede.

6.9 Conclusion

The difference between scheduling surgeries using expected durations plus an amount of planned slack and scheduling appointment slots using quantile values is negligible. However, both methods provide planners with possibilities to choose input parameter that influence the risk and amount of overtime, and the utilization of OR capacity.

Although with minimal difference, the cyclic master surgical schedule outperforms the cyclic block schedule solutions in terms of OR utilization. The difference in overtime (probability) between the cyclic MSS and cyclic block schedule do not differ significantly. The cyclic MSS has a positive effect on the bed occupancy level of the surgical wards for the second scenario with an EBC in Oldenzaal. Nevertheless, the MSS approach can result in a negative effect on the bed occupancy when the available OR capacity is limited. If this limited capacity prevents the tactical planner from combining surgery blocks that level each other's bed occupancy out, a cyclic master surgical scheduling approach can even result in a higher variation in bed occupancy than a regular cyclic block schedule.

The realization of an elective treatment center in Oldenzaal, does not directly lead to higher efficiency gains for the entire organization. The number of inpatients in the surgical wards in Enschede will increase because of the changes in the case mix. Increasing capacity in Oldenzaal makes it possible for the tactical planners in Enschede to create a block schedule that decreases variability of bed occupancy of surgical wards by increasing capacity in the first days of the week. Changing the tactical plan in such a way does however create variability in resource demand of supporting departments, which cannot be ignored.

7. Implementation issues

Chapter 8 describes the issues corresponding to the implementation of the proposed solution.

7.1 Master Surgical Schedule

The cyclic Master Surgical Scheduling approach (Van Oostrum et al., 2008b) provides powerful means to create a tactical plan in which the utilization of scarce resources is taken into account. The probability of resource conflicts that lead to admission stops can thereby be reduced. However, a number of threats can be identified that can potentially prevent the approach from being implemented successfully (Table 28):

Table 28 Possible threats for implementing the MSS approach

Threat	Description
• Reduction of access times	Several specialties are faced with reducing access times. Although this is a positive development for the patient, it complicates the prediction of the minimum demand for specific surgery types.
• Surgeon specific waiting lists	Currently each surgeon has its own waiting list. Specialists are not keen on forming one combined waiting list with their colleagues. The more specific surgery types have to be categorized, the larger the part of the case mix that cannot be scheduled using predefined slots.
• Occurrence of reduction periods	Reduction periods lead to variation in the availability of resource capacity. This prevents cyclic schedules from being executed properly. Additionally, seasonal effects on demand for specific surgery types complicate defining the minimum demand per period. These effects can be decreased by clustering surgery types.
• Possibility to make last moment adjustments	Currently, specialists are able to make last moment adjustments to their own agendas since patient scheduling is postponed until 1 to 2 weeks before surgery. In case of a cyclic master surgical schedule, where the types of surgeries are defined, it gets harder for specialists to trade OR blocks with collegues that have (slightly) different specialties. Especially when direct scheduling is offered and patients are assigned to time slots several weeks in advance, it is important that surgeons' schedules do not change after they have been determined.

An important opportunity however, that also appeals to many specialists is the possibility of scheduling patients the moment they have finished their preoperative screening. This feature can persuade surgeons to cooperate in defining appropriate clusters of similar surgery types, determining an indifferent case mix, and preventing surgeons to make last moment adjustments to either their own agendas or the (sequence) of the OR program. In order to implement this approach, specialists have to be involved and informed in both the creation of the master schedule, as well as the execution.

Involving specialists in the change process shares part of the responsibility of a successful implementation and subsequently decreases the probability of ‘mutiny’. Since specialists are both involved in delivering the case mix as well as executing the program, they have the power to make or break the methodology.

In order to facilitate direct scheduling of patients, the admission office or a counter of the admission office has to be located near the POS in Enschede as well as the POS in Oldenzaal. Additionally, in order to guarantee direct patient scheduling for multiple specialties, adding patients to a specialty’s program can no longer be performed by personnel that exclusively schedules one specific specialty. To be able to prevent impractical sequences, experienced employees have to be involved in creating or evaluating the master schedule and setting up clear guidelines for scheduling patients for their specific specialty.

7.2 Planned slack versus quantile method

In order to be able to use expected surgery durations and planned slack instead of appointments slots calculated by a specified quantile value, changes have to be made to the current OR planning system (ORSuite). The supplier of ORSuite has a large list of software improvements that need to be integrated in the system. Many of these improvements have a higher priority than the development of the option to create OR programs using planned slack. Additionally, the current forecasting method using a specified quantile value has recently been improved as a result of the data analysis conducted during this research. Before drastically changing the code behind the planning system by implementing the new methodology, both the supplier as well as the OR planning system administrators want to evaluate the effects of the new quantile settings and improved methodology first.

In order to fully benefit from scheduling surgeries that fit together nicely using planned slack, operational planners have to be familiarized with the concept of variation. Tutoring operational planners can help planners to evaluate the risk of overtime and combining the right type of surgeries in order to improve OR utilization. This enables planners to not only examine programs on the expected duration, but also on the probability of running into overtime. However, in order to be able to make the uncertainty of an OR program visible to the operational planner, extensive (graphical) changes to the OR planning software have to be made.

7.3 Shifting OR blocks

Changing the tactical plan by shifting blocks in order to improve the variability in ward utilization seems a relatively easy and low budget opportunity to improve efficiency. Shifting OR blocks has little impact on the way the business process is organized. Nevertheless, shifting OR blocks can only be done in close collaboration with the specialties involved. Many specialties are not only involved with performing surgeries in MST, but also operate in other hospitals, or are bound by specific times for outpatient clinic duties. Because of these inter-departmental and inter-organizational relations, changing the tactical plan can lead to infeasible solutions. Therefore, before actually swapping and shifting OR blocks the hard and soft restrictions every specialty has with respect to a distributing OR blocks have to be evaluated.

7.4 Conclusion

The implementation of the cyclic MSS approach will raise a large amount of implementation issues. Nevertheless, the possibility to reduce the number of resource conflicts and, even more importantly, the possibility to facilitate direct scheduling of patients can have large benefits to both efficiency as well as patient satisfaction. In overcoming implementation issues, close contact to both specialists as well as experienced planners is vital. The need to inform specialists is also present when implementing changes in the tactical OR plan as a result from shifting OR blocks. The implementation of scheduling using planned slack instead of appointment slots depends on the willingness of the software supplier to make adjustments to their planning package. Since the forecasting algorithm within the software package has recently been improved, the supplier gives little priority to implementing such an invasive change in the way surgery durations are forecasted (and visualized).

8. Conclusions and recommendations

This chapter states the conclusions and recommendations. We start by repeating the objective of the research as we presented in Chapter 1. After answering the research question, we provide recommendations for further research.

8.1 Conclusions

The objective of this research was to present and evaluate interventions that improve OR utilization, reduce variability of bed occupancy in surgical wards and decrease the number of changes to the OR program before the program is actually executed. In order to reach this objective, we evaluated these interventions: adjust quantile values to increase OR utilization, plan slack to cope with uncertainty, use a cyclic MSS (Van Oostrum et al., 2008b) for the elective treatment center in Oldenzaal, and evaluate the expected ward occupancy that results from (changes to) the tactical block schedule in Enschede using an analytical model.

By using a lower quantile value to forecast surgery durations, OR utilization can be increased. This however increases the probability and amount of overtime. Whether to increase the net OR utilization or to decrease the amount and risk of overtime is a decision that has to be made by the OR management. Prevented that the quantile method is applied correctly and both methods are used with the appropriate parameters, the quantile method as well as the method of planning slack can influence OR utilization and overtime probability similarly. Since the simulation study did not show significant benefits for using planned slack, and the quantile method is currently incorporated in the OR planning software, we propose not to change the method of forecasting surgery durations. We do suggest adjusting the quantile value to attain the preferred level of OR utilization and overtime probability.

The cyclic master surgical scheduling approach offers the possibility to take into account resource demand during the formulation or adjustment of the tactical plan. After defining uniform groups of surgery types and assigning these surgery types to slots in the OR program, an operational planner can add a surgery to an empty and suitable slot the moment an appropriate patient arrives. This enables the planner to give the patient the date of surgery directly after they have visited POS. This makes the scheduling process more efficient, while at the same time patient satisfaction improves. Since it is possible to evaluate a program before patients actually arrive, the reliability of the OR program increases, thereby decreasing the number of changes to the OR program before execution. The cyclicity of the cyclic MSS approach prevents it from being used in environments where there are fluctuations in the availability of resources and fluctuations in demand. The focus on low complexity, low variation, and high volume surgeries in the elective treatment center in Oldenzaal makes the cyclic MSS more suitable for OR planning of location Oldenzaal.

For location Enschede, the current cyclic MSS is not suitable. Instead, we propose an analytical model that enables the tactical planner to determine the effect a certain tactical block schedule has on the ward occupation. The realization of the elective treatment center in Oldenzaal changes the case mix for both locations. This offers the possibility to allocate OR capacity in Enschede such that the variability in bed occupancy of surgical wards significantly decreases.

The suggested interventions offer tools to increase OR utilization, evaluate and level bed utilization of surgical wards, and decrease the risk of disturbances during operational planning, which lead to changes in the OR program.

8.2 Further research

An important step in actually generating a cyclic master surgical schedule that enables direct scheduling is an accurate definition of uniform groups of surgery types. Further research is required on the medical and logistical characteristics that determine if surgeries can be scheduled in the same slot.

The analytical model used for evaluating ward occupancy based on a tactical block schedule (Vanberkel et al., 2009) does not have the ability to improve the block schedule. The Excel based model currently used, takes too much computational effort to include local search heuristics. Further research is required on optimizing the model, such as calculating incremental changes instead of recalculating the entire probability distribution or by programming the model in faster programming languages.

The current algorithm behind the cyclic MSS in the simulation model does not optimize the MSS on resource availability. In order to integrate such an algorithm into the simulation model, further research is required.

The cyclic MSS approach presented by Van Oostrum (2008b) assumes that OR capacity remains constant throughout the year and assumes demand for surgery types is distributed uniformly over the year. During holiday periods, however, MST temporarily decreases capacity. Additionally, MST performs specific types of surgeries that show seasonal effects in the surgery demand. These reduction periods and seasonal effects prevent using the cyclic MSS approach in Enschede. A possible starting point for improving the cyclic MSS approach to deal with reduction periods is to first scale up the annual number of required slots, and then divide the number of required slots over the number of periods. Next, by reducing the number of slots in the reduction periods, the number of slots can be matched to the actual demand. However, the problem with this approach is that it assumes that during reduction periods, capacity is being reduced evenly during the planning cycles. In reality, OR capacity is reduced by discarding entire OR sessions, thereby compromising the cyclicity of the schedule.

Further research is required to adjust the model to be able to take into account reduction periods and (seasonal) fluctuations in demand.

Another possibility for making the cyclic MSS suitable for both locations is to avoid the use of reduction periods. If reduction periods are discarded, capacity can be divided uniformly over the year. This not only enables the use of a cyclic MSS, but also decreases variability in demand for (supporting) resources, such as bed utilization in wards. To be able to abandon the principle of reduction periods a number of conditions have to be met: demand during holiday periods should be sufficient to actually fill the OR programs, and there have to be sufficient human resources to keep up capacity during holiday periods. To investigate whether discarding reduction periods is a realistic option, and how this should be organized, further research is required.

We expect that redesigning the business process of the planning function and its supporting IT systems will lead to large efficiency improvements. This research describes the current organization of the planning function. It can be used as a starting point in redesigning the process in order to create a process that is closer to its key functionality, increases transparency between departments, select IT that supports the business process, and reduce the number of unnecessary administrative actions.

List of abbreviations

512	OR assistant on duty (carrying pager 512)
BPR	Business Process Redesign
CHOIR	Centre for Healthcare Operations Improvement and Research
CV	Coefficient of variation
DBC	Diagnosis-treatment-combination (in Dutch: “Diagnose Behandel Combinatie”)
EBC	Elective Treatment Center (in Dutch: “Electief Behandel Centrum”)
ENT	Ear-Nose-Throat
ER	Emergency room
GP	General practitioner
ICU	Intensive Care unit
JUS	Annual Working hours method (in Dutch: Jaar Uren Systematiek)
KPI	Key performance indicator
LOS	Length of stay
LTHP	Long term accommodation plan (Dutch: lange-termijn huisvestingsplan)
MSS	Master Surgical Schedule
MST	Medisch Spectrum Twente
OR	Operating room
PACU	Post anesthetic care unit
POS	Preoperative screening (department)
RVE	Result responsible unit (in Dutch: “Resultaat Verantwoordelijke Eenheid”)
UMC	University Medical Center
WLRS	Waiting list registration system

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