Optimization of the thorax operating room capacity

'To achieve equilibrium between supply and demand by assessing methods for staffing and scheduling'

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Management summary

Problem definition

This research was initiated by the operational manager of the Operation Room department of the Thorax Center in Medisch Spectrum Twente, a large regional hospital in Enschede. In addition to a perceived low utilization rate of the operating rooms in regular time, the personnel experience a high work pressure, and a fluctuation of the workload during the day. Because MST is planning to realize a new building to accommodate the entire hospital, we investigate the capacity requirements for the specialty cardiothoracic surgery.

Research objective

The aim of this research is to improve the utilization rate of the OR department, minimize overtime, and to find a solution for the perceived high workload by assessing alternative methods for surgery scheduling.

Solution Approach

We start our research with an analysis of the practice of the OR department. We define performance indicators, and provide insight in the current performance of the Thorax OR department. We search the literature for methods for surgery scheduling, and compare the characteristics of the Thorax OR department to the models described in the literature.
Given the number of surgeries that have to be performed each year, we determine the minimum required capacity to perform the surgeries, and improve the efficiency of the OR department. Based on these calculations and the models described in the literature, we propose organizational interventions for the Thorax OR department.

We use a discrete event simulation model to test the performance of the proposed interventions. We design various scenarios to test the suitability and robustness of our proposed interventions. These scenarios cover various adjustments in the input parameters, a change in the number of emergency or elective patients, and a change in the overall session duration (increase or decrease).

We analyze the results of our simulation study, conclude our research, and give a recommendation to the management of the Thorax Center which interventions give the best results concerning the used performance indicators.

Results

Our analysis of the current performance shows that the utilization rate of the ORs is only 78%. In addition, sessions are often performed in overtime. With this utilization rate, hardly any overtime should occur. The major finding of the performance analysis is the deviation of workload during the day in relation with the number of personnel available during the day. In the morning hours, the workload is higher compared to the afternoon hours, whereas the number of personnel increases in the afternoon hours. Accordingly, the perception of unequally spread capacity usage during the day is justified.

The performed simulation study show that there are various interventions to improve the performance of the OR department. Based on the production requirements and a 33% accepted overtime probability, we have determined the minimal capacity requirements to be 508 minutes per day.

The performance of the proposed interventions is shown in terms of overtime, utilization and the required number of FTE. Based on the current input parameters, the interventions show better performance than the observed current system concerning the utilization rate and the required number of FTE. None of the interventions give better results in terms of the overtime indicators

A change of the session time has more influence on the key performance indicators for each intervention than an increase in the number of patients. Especially a decrease of the session time has positive impact on the key performance indicators.

An increase in the session duration leads to an increase in the utilization rate for each intervention. Disadvantage of an increase in the session duration is that the overtime frequency increases, and also the percentage of days that have more than one OR working in overtime is higher. Also, the number of cancellations grows according as the session duration increases.

Unlike we expected, the changeover times have large impact on the utilization rate and the overtime frequency of the OR department. Reducing the changeover time merely incorporates a change of the location where the work has to be performed and will therefore hardly contribute to a decrease of the workload.

Conclusions & recommendations

We conclude that shortening the regular working hours of the OR department from 7:45 am to 4:15 pm is the most robust when the input parameters change. Because the personnel of the OR department experiences and expects these changes in the input parameters, we recommend this intervention to the management of the OR department. In addition to advantages relating to the productivity indicators, this intervention also gives good financial results.

We recommend investigating which of the input parameters is different in 2009 than in 2008. If 2009 shows major differences, we may have to design and test additional interventions that contain combinations of the designed interventions.

We also recommend to investigate the possibility to share the OR capacity with other specialties. A more flexible hospital organization and cooperation between different surgical departments may improve the utilization rate of the OR department

Management samenvatting

Probleemstelling

Dit onderzoek is geïnitieerd door het teamhoofd van het thorax operatiekamercomplex (OK complex) van Medisch spectrum Twente, Enschede. Het teamhoofd ervaart een lage bezettingsgraad van de operatiekamers. Het personeel op de OK ervaart ook een hoge werkdruk, die erg fluctueert gedurende de dag. Omdat MST plannen heeft om een nieuw ziekenhuis te realiseren zal er onderzoek gedaan worden naar de benodigde capaciteit voor de thorax OKs voor het specialisme cardio-thoracale chirurgie.

Onderzoeksdoelstelling

Het doel van dit onderzoek is om de bezettingsgraad van het thorax OK-complex te verbeteren, tegelijk met het minimaliseren van het overwerk en om een oplossing te vinden voor de ongelijk verdeelde werkdruk gedurende de dag.

Methode

Ons onderzoek start met een analyse van het huidige proces in het OK complex. We definiëren prestatie indicatoren, en we maken de huidige prestatie van het OK complex inzichtelijk. We doen onderzoek in de literatuur naar methodes voor het plannen van operaties, en vergelijken de karakteristieken van het thorax OK complex met de modellen zoals die staan beschreven in de literatuur.

Gegeven de productie welke elk jaar behaald moet worden bepalen we de minimale capaciteitsbehoefte om deze operaties uit te voeren en de bezettingsgraad te verhogen. Op basis van deze berekeningen en de modellen zoals beschreven in de literatuur, doen we een aantal voorstellen voor mogelijke organisatorische interventies voor het thorax OK complex.

We gebruiken een simulatiemodel om de prestatie van deze interventies te testen. We beschrijven verschillende scenario's om de robuustheid van de interventies te testen. Deze scenario's omvatten aanpassingen in een aantal parameters; een verandering in het aantal spoed- of electieve patiënten, en een verandering in de operatieduur. We analyseren de uitkomsten van de simulatie, en doen een aanbeveling naar het management van het Thorax Centrum welke interventie het beste resultaat geeft op basis van de gestelde prestatie indicatoren.

Resultaten

Analyse van het huidige proces van het thorax OK-complex laat zien dat de bezettingsgraad slechts 78% is. Daarnaast worden operaties toch vaak na reguliere werktijd, in overwerk, uitgevoerd. Gegeven deze bezettingsgraad zou er nauwelijks overwerk voor mogen komen. De belangrijkste bevinding is dat de spreiding van de werkdruk en het aanwezige personeel gedurende de dag niet overeen komen. Tijdens de ochtenduren is de werkbelasting hoger dan in de middaguren, terwijl het aantal werknemers juist ’s middags hoger is. De perceptie van het personeel dat de werkdruk niet gelijkmatig over de dag is verdeeld is dus gerechtvaardigd.

De simulatie studie laat zien dat er verscheidene interventies zijn om de prestaties van het thorax OK complex te verbeteren. Gebaseerd op de productieafspraken, en een 33% kans op werk na de reguliere werktijd, is er een minimale capaciteitsbehoefte van 508 minuten per dag.

De prestatie van de voorgestelde interventies wordt weergegeven in termen van overwerk, bezettingsgraad en het benodigde aantal FTE. Gebaseerd op de huidige parameters resulteren de interventies in een betere prestatie dan het geoberserveerde huidige systeem in termen van bezettingsgraad en het aantal benodigde FTE. Geen van de interventies geeft betere resultaten betreffende de overwerk indicatoren.

Een verandering in de operatie duur heeft meer invloed op de prestatie van de interventies dan een toename van het aantal patiënten. Een afname van de operatieduur heeft positief effect op de prestatie indicatoren. Een toename van de operatieduur leidt tot een toename van de bezettingsgraad. Het nadeel van een toenemende operatieduur is dat de kans op overwerk en het aantal dagen dat meer dan 1 OK in overwerk is ook toeneemt. Ook zal het aantal afzeggingen toenemen naarmate de operatieduur toeneemt.

In tegenstelling tot wat we verwachtten, heeft de wisseltijd grote invloed op de prestaties van het OK complex. Het reduceren van de wisseltijd zal voornamelijk gericht zijn op het verplaatsen van de werkzaamheden naar een andere locatie, daarom zal het nauwelijks invloed hebben op de werkdruk.

Conclusie & aanbevelingen

Het verkorten van de reguliere openingstijden van 7:45 am tot 4:15 pm geeft de beste resultaten wanneer (een van) de parameters zal veranderen. Omdat het personeel van het OK-complex al een verandering in de parameters ervaart en verwacht, doen we deze aanbeveling naar het management van het Thorax Centrum Behalve de positieve resultaten op productiegebied levert deze interventie ook financieel voordeel op. Verder onderzoek kan gedaan worden naar mogelijke combinaties van de voorgestelde interventies. Dit zal wellicht alleen noodzakelijk zijn wanneer er uit data analyse over 2009 duidelijke verschillen naar voren komen in vergelijking met dit onderzoek.

Ook kan er onderzoek gedaan worden naar de mogelijkheid om de capaciteit van het OK complex te delen met meerdere specialismen. Een flexibele organisatie en samenwerking tussen verschillende snijdende specialismen zal mogelijk de bezetting van het OK complex verbeteren.

Preface

This report describes my research at the Thorax Center of MST, Enschede. It is the conclusion of my master Healthcare Technology Management (Industrial Engineering & Management) at the University of Twente.

Although my MSc graduation project was sometimes challenging, it has been a pleasant one. To attend open heart surgeries, and to come in close contact with the field of health care has been a major experience. The permanent interest from friends, colleagues, and family has continued my drive to complete this project.

First of all, I thank my supervisor Erwin Hans and from University of Twente. His critical views and constructive feedback helped me to structure the project, make short English formulations and keep an open mind. Structuring the project was rather difficult, because I intended to solve all problems of the OR department during my graduation, but of course this was not possible in the given time. I also thank my second supervisor Marco Schutten from University of Twente for his support. Furthermore, I thank Wilma te Kloeze from the Thorax OR department of MST. She was most helpful and I enjoyed our meetings. Thanks to the enthusiasm of Wilma, I can continue my work in MST! Special thanks for that!!

Finally, I thank the personnel of the OR department, and all others who have provided information and answers to my endless questions. Last but not least, a special thanks to my family and Klaas, for their support and keeping me focused and smiling☺.

I hope you will enjoy reading this report!

Enschede, 2010

Susan Veldhuis

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1 Introduction

1.1 Motivation of this research

This research focuses on the operating room (OR) department of the Thorax Center of ‘Medisch Spectrum Twente’ (MST), a large non-academic teaching hospital in Enschede. MST is currently planning the realization of a new building, which is to accommodate the two existing locations. The capacity of the three ORs of the Thorax Center is now dedicated to cardiothoracic surgery, but as a result of the building plans, the discussion has risen whether MST should merge the capacity of the Thorax Center with the OR capacity of other specialties. While the operational manager of the Thorax Center perceives a low utilization rate of the OR department, the staff perceives a high and fluctuating work pressure.

In this research, we demonstrate that the aforementioned problems are caused by an unequally spread capacity usage. We design and propose organizational interventions that contribute to solve this problem.

1.2 Research context

MST is one of the largest non-academic hospitals in The Netherlands, with 3.000 full time employees (FTE) and 1.070 beds. MST comprises of two inpatient accommodations: the main located in Enschede, the other located in Oldenzaal. In addition, MST has two outpatient clinics in Haaksbergen and Losser that contribute to the delivery of high quality of care.

MST attends to more than 435.000 outpatient visits and around 30.000 admissions each year. Besides the base care the hospital provides, MST is also a teaching hospital. Teaching hospitals have to comply with several criteria related to research and teaching programs (Topklinische en topreferentiezorg in STZ-ziekenhuizen, 2007). Appendix A lists these criteria. MST has admittance as a general hospital, a center for haemodialysis, a radio therapeutic center, a trauma center, and as a center for the treatment of AIDS (Medisch Spectrum Twente, 2008).

The Thorax Center has opened its doors in 2004 (Medisch Spectrum Twente, 2009). It is a department within the hospital dedicated to cardiac diseases. In addition to the performance of cardiothoracic surgeries, many other thoracic dysfunctions are treated at the Thorax Center as well.

1.3 Problem description

This research was initiated by the operational manager of the Operation Room department of the Thorax Center, who perceives a low utilization rate of the OR department of the Thorax Center. This low utilization rate of the OR department can cause high expenditures in terms of employee salary, material costs, and waiting lists. In today's setting of an ageing society, growing demand for healthcare capacity, structural shortage of skilled personnel (Boer & van Beuzekom, 2005), and increasing competition between healthcare institutions (Min VWS, 2009), efficiency is very important.

As mentioned before, MST is planning the realization of a new building that accommodates the entire hospital. The Thorax Center also moves to the new building, but the exact setting is not yet determined. The board of directors of MST is still discussing whether the Thorax Center should stay a department dedicated to cardiothoracic surgery, or merges its capacity with other specialties. The board discusses the number of ORs that are dedicated to cardiothoracic surgery, and the introduction of a hybrid OR - which allows the Thorax Center to execute different, more complex surgeries – also raises the plan of changing surgery scheduling to improve the utilization rate.

In addition to the perceived low utilization rate and the discussion about capacity distribution among specialties, the personnel experiences high work pressure. This relates to vacancies for the subspecialties surgery, anesthesiology, and clinical perfusionists, working at the Thorax Center. The personnel experiences high work pressure fluctuating during the day, especially high during the morning hours. A combination of these perceptions can be caused by an unequally spread capacity usage of the ORs during the day.

From the problem description, we derive the following problem statement:

The operating room department of the Thorax Center experiences an unbalance in supply and demand

1.4 Research objective

The aim of this research is to improve the utilization rate of the OR department, minimize overtime, and to find a solution for the perceived high workload by assessing alternative methods for surgery scheduling. We investigate the utilization rate of the OR department, the probability of overtime, the minimum capacity requirements, and the design of scenarios to test possible organizational interventions

To attain the objective, we find an answer to the following research questions:

1. *To what extent does an unbalance in supply and demand exist?*

We define and characterize the current practice in the OR department. Together with stakeholders of the OR department and a literature review, we define performance indicators. By gathering and analyzing data, we provide insight in the current performance of the OR department of the Thorax Center. From this process description, on which we elaborate in Chapter 2, the scope of the research is demarcated.

2. *Which methods for surgery scheduling can be used at the Thorax Center?*

A lot of research on surgery scheduling methods has been described in the literature. Chapter 3 describes the most important method for surgery scheduling that we found in the literature. We compare the characteristics of the Thorax Center to the model described in the literature and decide on the method that we include in the assessment of alternative scheduling methods. We conclude Chapter 3 by an overview of suitable organizational interventions for the Thorax Center.

3. *Which quantitative modeling approaches are suitable for the analysis of the proposed interventions?*

To test whether the interventions solve the problems at the OR department, we propose a method for testing. We carry out the steps of the proposed method and describe them in Chapter 4.

4. *How can we implement the chosen interventions in the organization?*

In Chapter 4 we describe the simulation study that we use to test the proposed interventions. In Chapter 5, we analyze the results of the simulation study that we performed. Subsequently, we conclude our research and give recommendations for implementation of the interventions that contribute to a solution of the central research problem in Chapter 5, 6, and 7.

2 Context analysis

In this chapter, we analyze the current practice of the Thorax Center. We describe system characteristics and control in Section 2.1 and 2.2. We execute a performance analysis that we describe in Section 2.3. From this analysis, we derive an extended problem statement, and demarcate the research scope in Section 2.4. We analyze the current practice by observing the system, having interviews with employees, and analyzing the data from 2008 that we retrieve from the hospital data management system (OR Suite, 2010).

2.1 Process description

The Thorax Center is a department within the hospital. It is one of the 16 Thorax Centers in The Netherlands. It is located in the city of Enschede, near the German border. The service area of the Thorax Center is mostly regional, but also cardiologists from other regions refer to the Thorax Center. Moreover, a growing number of patients are referred from Germany.

Figure 2.1 displays the service area (referrals from cardiologists) in 2008.

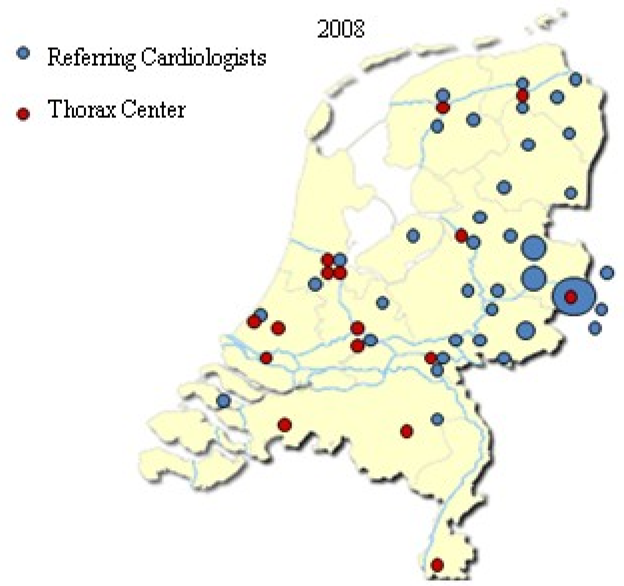


Figure 2.1: Service area of the Thorax Center.

The Thorax Center nearly covers all cardiothoracic treatments, mainly related to heart failure and heart dysfunction. Heart transplants are not executed. Beside surgeries, also coronary angiography (CAG), percutaneous coronary intervention (PCI), implementation of implantable cardioverter defibrillators (ICD), and research is executed (Medisch Spectrum Twente, 2009). The Thorax Center is divided in two parts: one part where surgeries are performed (the OR department), and the other part where all other interventions take place. This research focuses on the OR department.

The thorax OR department consist of four ORs of which three are used for surgery. Regular working hours of the OR are from 7.45 am to 4.45 pm, from Monday to Friday. During the weekends and special holidays (Christmas, Eastern, Queens Day, etc.), no elective surgeries are performed. During regular holidays, an adjusted surgery schedule is used: then only two ORs are scheduled each day. We refer to such periods as reduction periods.

2.1.1 Demand for open heart surgery

The perception of the management of the Thorax Center is that there is a decrease in the number of patients that need thoracic surgery. Figure 2.2 displays the number of patients on the waiting list for an open heart surgery in the Netherlands (thoracic surgery) from 2004 to 2009. Despite the ageing population, the number of patients on the national waiting list is decreasing. The main cause is the increasing capacity to perform thoracic surgeries.

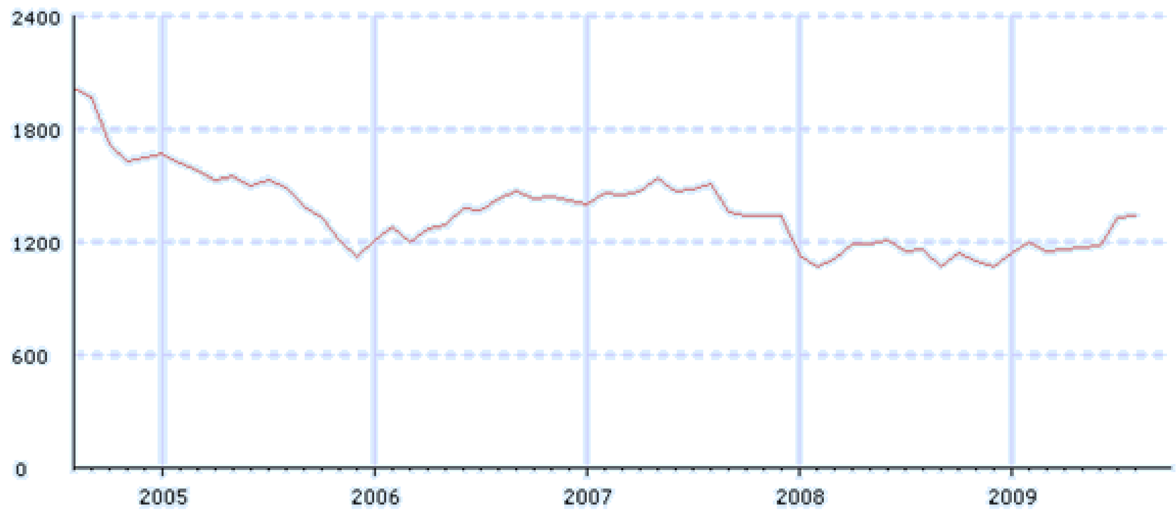


Figure 2.2: Number of patients on the waiting list in the Netherlands, waiting for open heart surgery. Source: ("Wachtlijstregistratie open hart operaties," 2009)

Figure 2.3 shows that the waiting list for MST follows the trend of the national waiting list. In 2008, compared with 2007, fewer patients on the waiting list are registered. The increase in number of patients on the waiting list in summer months can be explained by the reduced capacity because of the holidays.

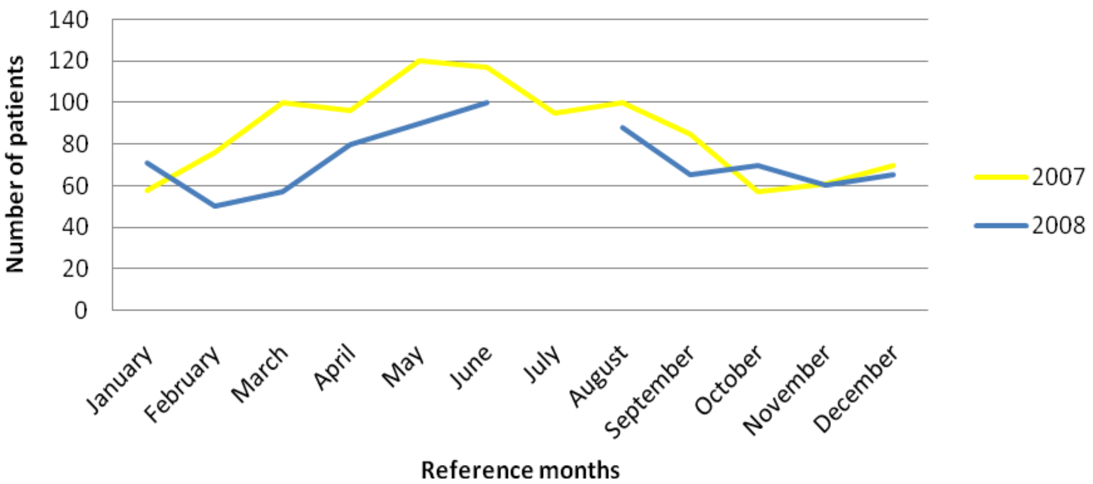


Figure 2.3: Number of patients per month on the waiting list for an open heart surgery. n=1831. Source: ("Wachtlijstregistratie open hart operaties," 2009)(Data for July 2008 is not available).

2.1.2 Surgeries

A total of 1324 surgeries were performed at the Thorax Center of MST in 2008. The majority of surgeries are bypass surgeries and cardiac valve surgeries, executed by cardiothoracic surgeons. Figure 2.4 gives an overview of the set of surgeries performed from 2005 to 2008. Appendix B gives a complete overview of the surgeries performed in 2008.

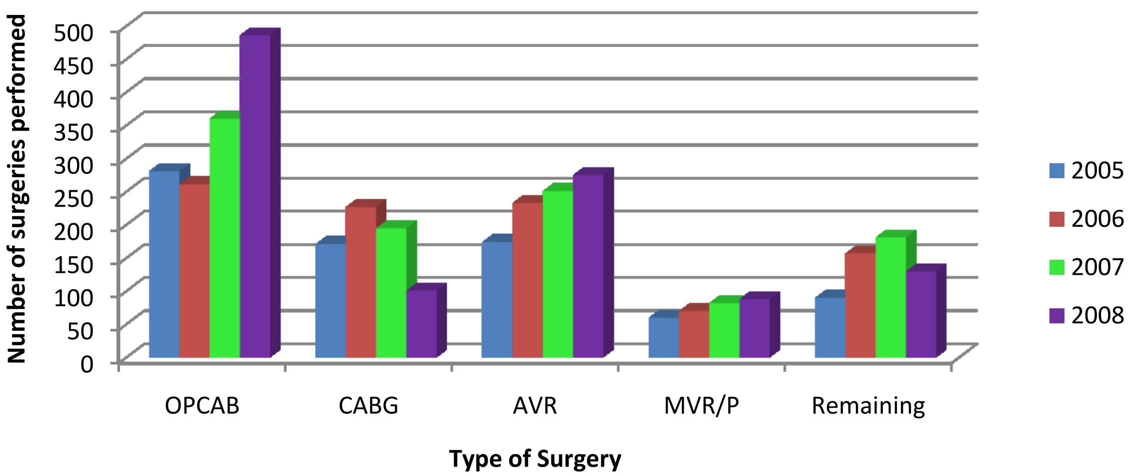


Figure 2.4: Set of surgeries performed at the Thorax Center in Enschede. T=2005 until 2008, n=3873. Source: Grandjean JG, MD. (OPCAB=off-pump bypass surgery, CABG=on-pump bypass surgery, AVR=aortic valve replacement, MVR/P=mitral valve replacement, remaining=lung, double and triple valve and more.

A striking difference in the trend is the increase in number of OPCABs, in contrary with a decrease in number of CABGs. The total number of bypass surgeries slightly grows (Figure 2.5). The change of method for bypass surgery can be explained by the preference of the surgeon. Not every surgeon is allowed to perform OPCAB and, also, every surgeon has its own preference for a type of surgery method. In the literature, no differences between OPCAB and CABG in terms of demographics and comorbidities have been distinguished. Also no differences have been reported in health-related quality of life (Chu et al., 2009; Puskas et al., 2004).

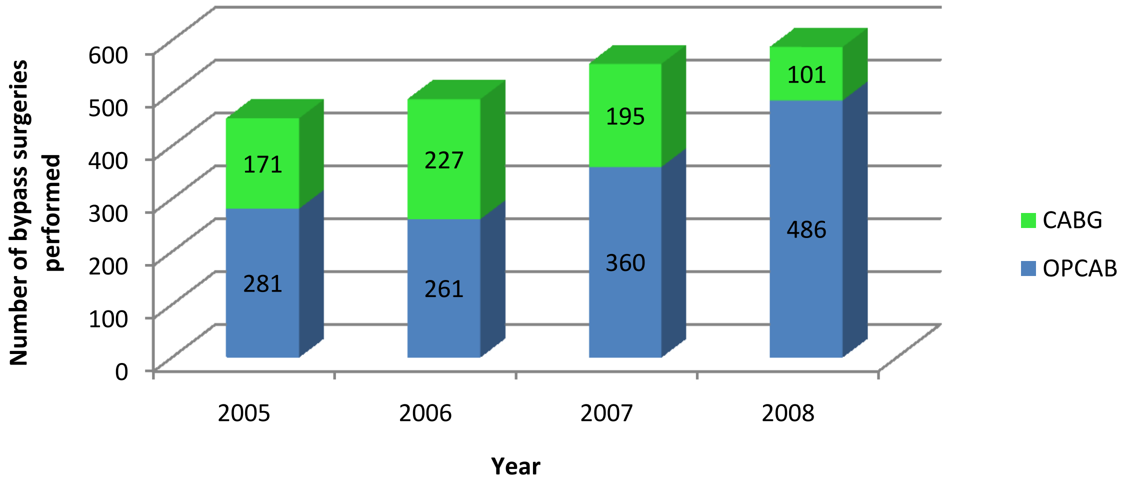


Figure 2.5: Number of bypass surgeries performed. n=2082. Source: Grandjean JG, MD.

2.2 Planning and Control

OR management addresses various managerial areas and various hierarchical levels of control. To outline the planning and control functions in OR management, we use the framework of Houdenhoven et al.(2007). This framework consists of four managerial areas and four hierarchical levels and describes the interaction between four levels of control within the Thorax OR department.

Figure 2.6 gives a graphical representation of this framework and its application to the OR department.

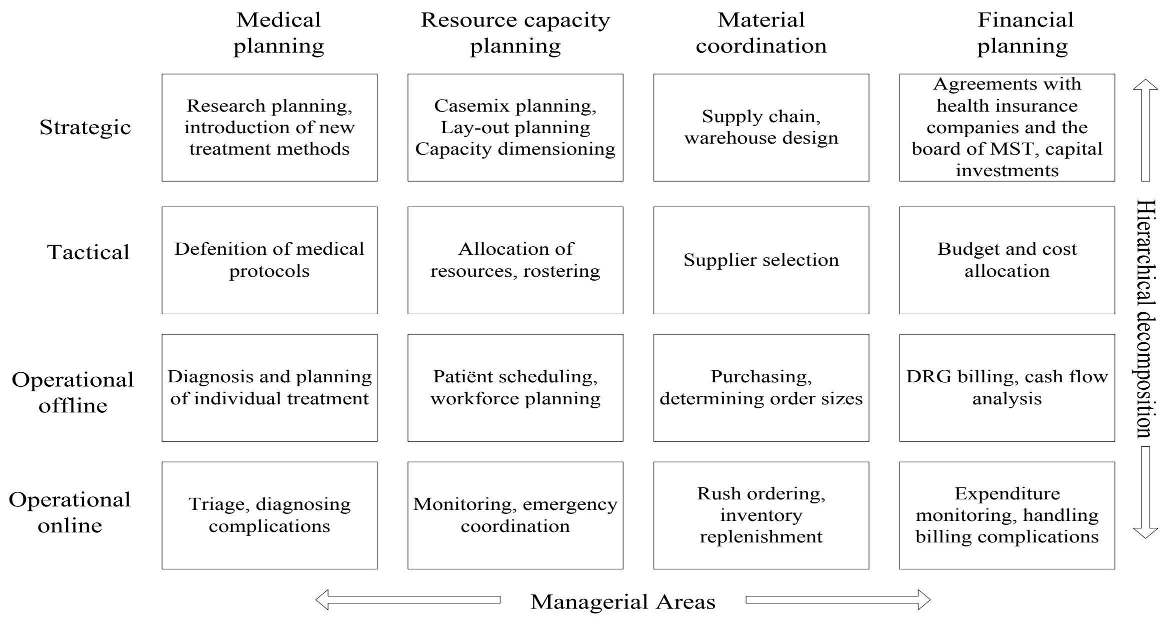


Figure 2.6: Framework for hospital planning and control.(Houdenhoven, 2007)

The organizational structure of the Thorax OR department is consistent with the framework proposed by Houdenhoven et al.(2007). To clarify the decisions made within the organization, we briefly describe the levels in the succeeding paragraphs. We display an organizational chart of the hospital in Appendix C.

Strategic management level

The highest managerial level aims at the hospital's long term goals. At this level, the mission of the hospital is determined. The base of the mission of MST is patient-centeredness. Quality of care is the central point, but because of more and better informed patients, and conversely the introduction of Diagnosis Related Groups (DRGs), the aim of the hospital is to efficiently deliver high quality of care. The board of directors of MST has overall responsibility and is involved in the following decisions regarding to the capacity problem:

- Medical planning: the decision to educate medical students;
- Resource capacity planning: which surgical procedures to perform;
- Material coordination: building plans, how many ORs do we need?
- Financial decisions; the surgeons at the Thorax Center operate in a so-called partnership; they are an organization within the hospital. Agreements with the insurance companies are made with the manager of the partnership;
- Long-term planning and projects are initiated by the management, and they should also decide whether to outsource several projects.

Tactical management level

The tactical management level defines medium-term objectives, based on the decisions made at the strategic level. The business manager of the Thorax Center is concerned with these decisions. Concerning the capacity allocation of the OR, the Thorax Center only executes cardio-thoracic surgeries. Also, the business manager decides about the amount of FTE available for every discipline at the OR department.

Operational offline management level

Together with the administration and planning department, the unit manager level creates detailed plans and schedules for resources and materials. This is typically done for a time horizon of 1 to 2 weeks. The 'offline' plans and schedules are created before actually executing them. At this level, personnel is assigned that is needed to perform surgeries. Surgery scheduling is currently executed only 1 week in advance, mainly because of the absence of a waiting list. During the entire week, changes in the planning occur, even one day in advance.

Operational online management level

This level deals with monitoring and reacting to unexpected and unanticipated events. During the execution of plans and schedules that are created on the operational offline level, disturbances such as emergency surgeries can occur. At this level, emergency patients that interrupt the surgery schedule and other disturbances have to be handled.

This research mainly focuses on the tactical and operational offline management level. On the tactical level, the business manager is concerned about the amount of FTE hiring for executing surgery. At this level also capacity allocation and surgery scheduling methods are assessed and decided on. The unit manager on operational level must adequately schedule personnel at each shift, and plan the surgeries concerning the methods derived at tactical level.

2.2.1 Planning process

In this section, we describe the process of scheduling surgeries. This process starts at the moment a specialist decides a patient needs surgery, and stops at the moment the surgery finishes.

When a patient has visited the outpatient clinic cardiology and anamnesis is established, there are three possibilities: conservative treatment, treatment via PCI or ICD, or surgery. Of these, surgery is the most extensive treatment. When the specialists decide that a patient needs surgery, the administration and planning department puts this patient on a surgery list. Because the OR capacity is dedicated to thoracic surgery, only one specialty is represented here. The administration and planning department makes a provisional surgery schedule concerning the following guidelines:

1. All the (semi-) urgent, unscheduled patients on the waiting list are planned;
2. Usually 5 sessions are planned each day; 2 in OR1, 2 in OR2, and 1 long surgery in OR3.
3. Sessions are put in the hospital data management system, where they obtain a planned time. If the planned session time of the surgeries on the list fit within the surgical time available, and the surgeon is available for surgery, the session is scheduled.[1]
4. Sessions that do not fit in the available time are put back on the waiting list.

The provisional surgery schedule is usually ready one week in advance. After making this provisional surgery schedule, the administration and planning department sends it to the unit manager of the OR department and the surgeons. They perform further feasibility checks considering materials, personnel, and time.

If the surgery schedule complies with all constraints, it is approved. Adjustments can now only be made due to unexpected circumstances such as emergency patients, or surgeries that are cancelled. The schedule for the next day is generally approved around 4.00 pm the day before execution.

The patient receives information about the surgery from the administration and planning department. This information includes information about the day of surgery, the type of surgery, risks of surgery, and the routing before and after surgery. The patient does not get information about the time the surgery will be performed.

The day before surgery, the patient is admitted to the hospital on dedicated wards. After the surgery, the patient has to recover at the Intensive Care Unit (ICU). The capacity of the ICU is dedicated to cardiothoracic surgery patients and holds 12 beds. If the general ICU is fully occupied, emergency patients are admitted to the thoracic ICU. The capacity of the ICU is not taken into account in this research.

[1] If the personnel of the planning office does not agree with the planned time (because it is not accurate, they manually change the planned session time.

2.3 Performance measurement

A lot of research has been performed to determine the efficiency of the OR department. In The Netherlands, a benchmarking project related to OR efficiency has been performed on academic hospitals (van Hoorn & Wendt, 2008). The authors conclude that uniform time registration parameters are not available, and therefore the performance cannot be compared with other hospitals. They developed a uniform time-registration system, to prevent any ambiguity. Figure 2.7 displays this registration system, which contains different time moments relating to OR sessions. From this time-registration system, performance indicators are derived. Appendix D gives an overview of these indicators.

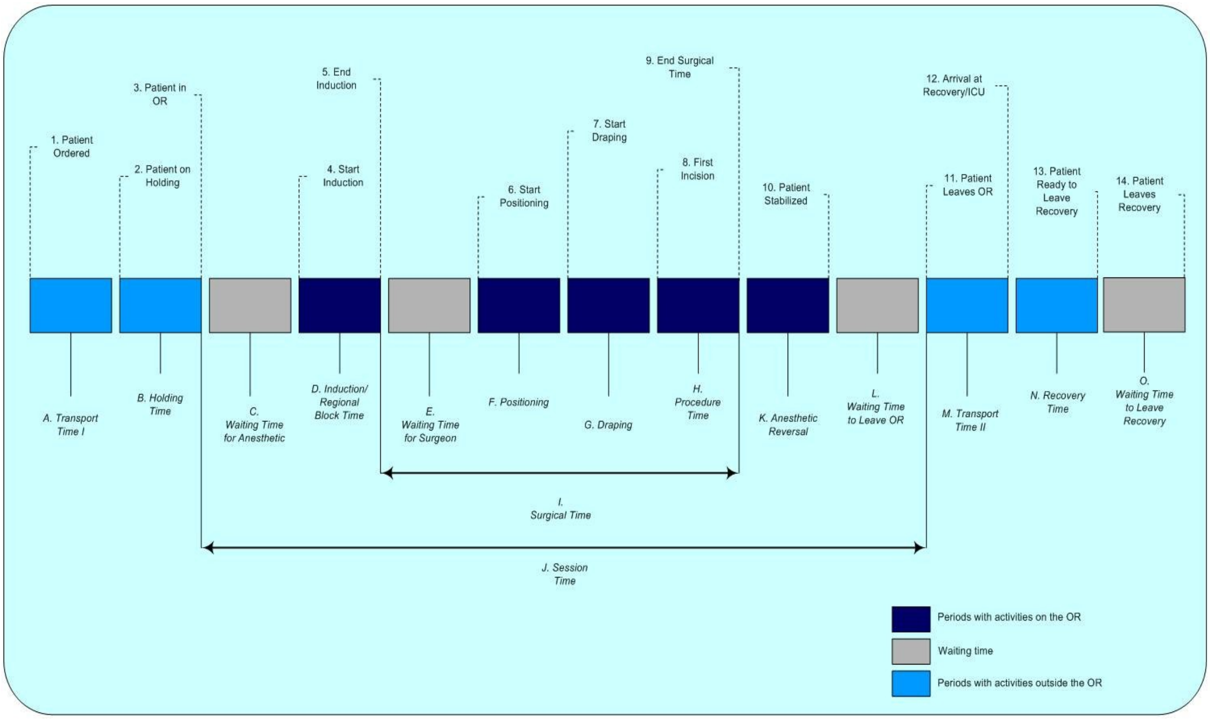


Figure 2.7: Uniform time registration system (van Hoorn & Wendt, 2008)

At the Thorax Center, not all indicated time moments are registered. Table 2.1 gives an overview of the time moments that are registered during the session.

Time registration moments
3. Patient in OR
4. Start induction
5. End induction
8. First incision (start OR)
9. End surgical time
11. Patient leaves OR

Table 2.1: Time moments registered during the session

As we may want to compare the performance of the OR department in future research, we use the performance indicators proposed by Van Hoorn & Wendt (2008). We describe the key performance indicators in Section 2.3.1.

2.3.1 Key performance indicators

In Appendix D, the performance indicators as defined by Hoorn & Wendt (2008) are described. To describe the performance of the thorax OR department, we introduce key performance indicators. We also use these indicators for the analysis of the results in Chapter 4 and 5. We use the following key performance indicators:

1. Utilization rate

We describe the utilization rate of the OR department in equation [20] in Appendix D. The net utilization of the OR department is defined as: (the sum of the duration of sessions that start within regular working time or half an hour before) divided by (the difference between start and end of regular working hours * number of OR days). We count the duration of the sessions that falls within the regular working hours. Time moments of the registration system involved are *3. Patient in OR* and *11. Patient leaves OR*. We elaborate on the utilization rate in Section 2.3.2 and Section 2.3.3.

2. Overtime frequency

We define overtime as the session time executed outside the regular schedule; the difference between the finishing time of the last session of the day outside regular working hours, and the end of regular working hours. The overtime frequency is based on equation [24] in Appendix D. It is defined as: (the number of OR days on which overtime occurs) divided by (the number of OR days that count for utilization). We elaborate on the overtime frequency in Section 2.3.4.

3. Number of days that have more than one OR in overtime

In addition to the overtime frequency, we also count the number of days that more than one OR works in overtime. Because the current practice allows one OR working in overtime, the management of the OR department is interested in the second or third OR that works in overtime. We elaborate overtime in Section 2.3.4.

4. Workload

We investigate the personnel shifts and the number of FTE available during the day. We discuss the workload in Section 2.3.5

2.3.2 Session time

One of the main indicators to measure the use of capacity is the utilization rate. Before measuring the utilization rate, we elaborate on the planned session time and realized session time. Session time is the time between *3. Patient in OR* and *11. Patient leaves OR.*

Figure 2.8 shows an overview of the session times that are realized and planned in 2008. In Section 2.2.1 we already mentioned that the session time is estimated based on historical times. These estimations depend on the accuracy of the hospital data management system and the planning office. The data management system estimates the session time based on the activity code of the session, and assigns more weight to recently performed surgeries.

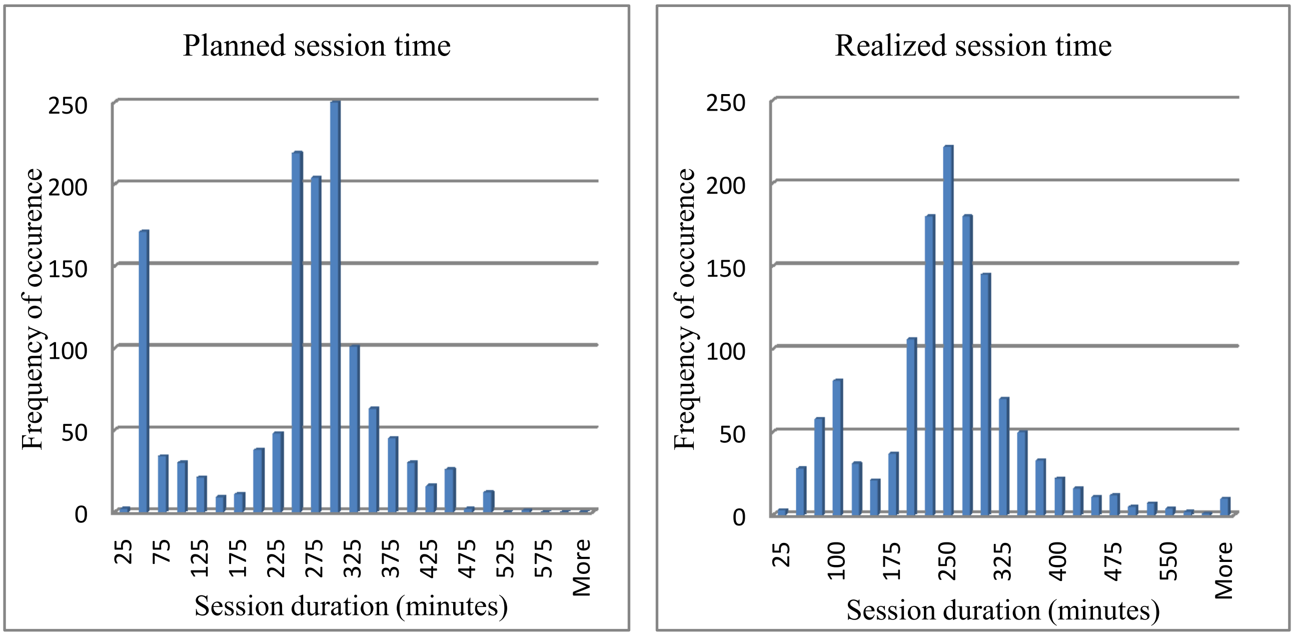


Figure 2.8: Planned and realized session time. T=2008, n=1324. Source: hospital data management system

Figure 2.8 illustrates a deviation between the planned and realized session times. A striking difference is the peak at planned session time of 50 minutes. The planning department registers sessions in the hospital data management system as elective or emergency sessions. We only label sessions as emergency sessions if they have a specific activity code or if they arrive outside regular working hours, because during regular working hours, time is reserved for these sessions and they do not interrupt the schedule. From the sessions with a planned time of 50 minutes, 72% is registered as an emergency session.

Of the 1324 sessions, only 183 are realized within -5% to +5% of their planned time. Figure 2.9 shows the average deviation from the planned time, for sessions within regular working hours. We measure the average deviation as the realized duration minus the expected duration, divided by the expected duration (Equation [35] in appendix D).

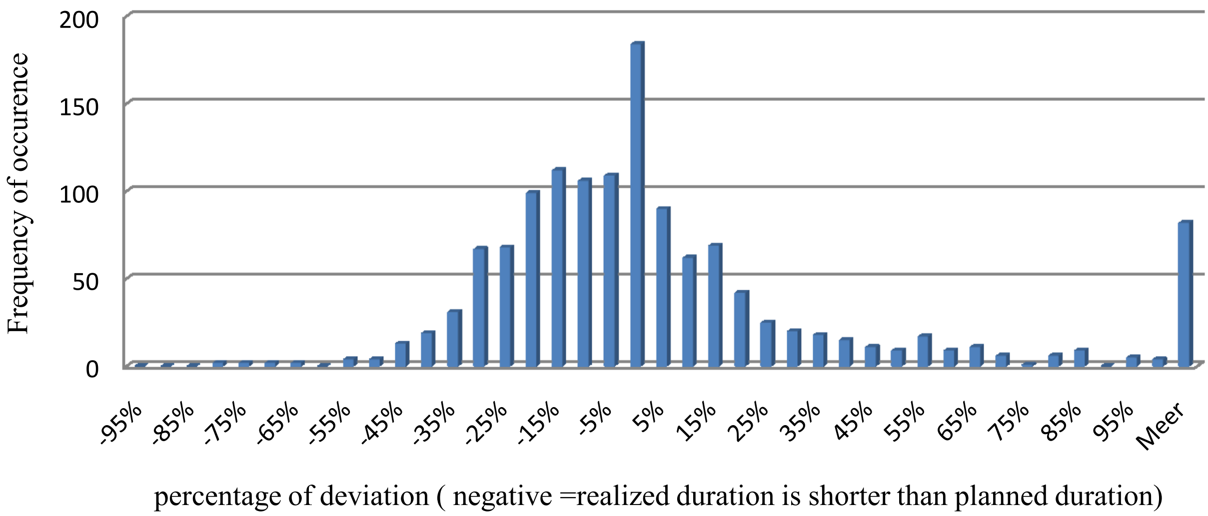


Figure 2.9: Average deviation from planning of the session time. T=2008, n=1324. Source: hospital data management system.

The duration of the planned session is in 55% of the sessions longer than the realized session time. Clearly, if the estimation of the session time would occur more accurately, this can benefit the utilization rate of the OR department. If we do not take into account the inaccurately estimated emergency sessions, we find in 59% of the sessions that they have shorter realized durations than their planned durations.

2.3.3 Utilization rate

The utilization rate is an important measure for the use of capacity. A low utilization rate leads to unnecessary idle time. A high utilization rate may lead to high staff workload and overtime. However, if the completion time of a session is outside the regular working hours of the OR department, the completion time of the session is set to the end of OR day for the calculation of the utilization. This means that the part of the session that is performed outside the regular opening hours is not taken into account as session time for the net utilization rate.

Changeover times between sessions are also not taken into account as session time. The maximum value for the utilization rate therefore depends on the number of changes that occur between sessions. Each time a changeover occurs, the OR is not available for surgeries, and so the utilization rate decreases. Overtime occurs when surgeries finish after regular working hours. Reasons that overtime occur may be that surgeries take longer than expected or emergency surgeries arrive. Because the session time of the performed surgeries limits the number of changeovers during an OR day, this does not influence the utilization rate substantially. If at some point of the day it is expected that a next surgery may lead to overtime, it may be decided to cancel the surgery. This decision to cancel a surgery is left to the surgeon and medical personnel.

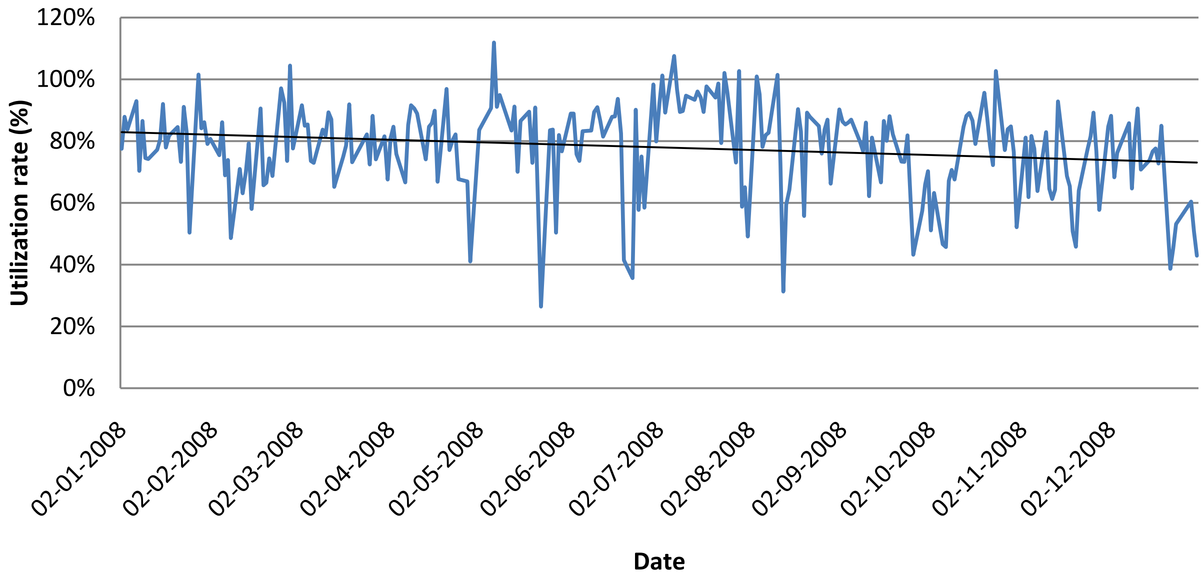


Figure 2.10: Net utilization of the OR department. T=2008. Source: hospital data management system. The black line shows the trend in the utilization rate.

Figure 2.10 displays the net utilization rate for the OR department in 2008. The average net utilization rate is 78%. Appendix E includes the utilization rates for the separate ORs. Figure 2.10 shows a fluctuating utilization rate during the year. This fluctuation in the utilization rate can possibly cause the perceived high workload. Also the utilization rate per day of the week differs. On Monday, the average net utilization is 83%, and this is decreasing, whereas on Friday the utilization rate is only 73%. This can be caused by planned meetings on Friday afternoon.

Because there is a perceived high workload, we investigate the utilization rate during the day.

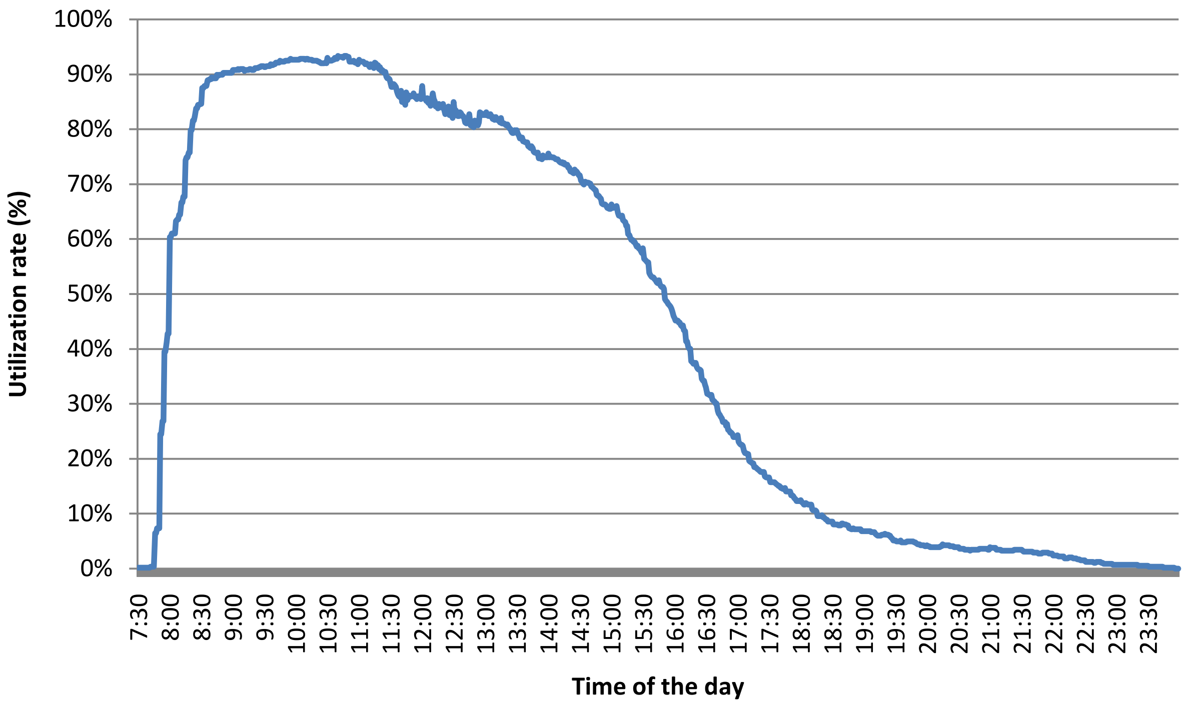


Figure 2.11: Net utilization during the day. T=2008. n=585. Source: hospital data management system.

Figure 2.11 displays the utilization rate during the day. This utilization rate is measured over the regular weeks. Morning hours have high utilization; in the afternoons, the utilization rate quickly decreases. In Section 2.2.1 we already mentioned that five sessions are planned each day. In one OR, only one long surgery is planned. This planning method is based on the long operating times of one surgeon. This surgeon has retired in 2007, and is replaced by a surgeon with perceived shorter operating time. Therefore, the current planning method has to be revised.

2.3.4 Overtime and empty OR duration

Ideally, all sessions are performed within the regular working hours of the OR department. Table 2.2 presents the average duration and frequency of overtime per OR. The unit manager permits an overtime frequency of 33%.

Overtime	**OR1**	**OR2**	**OR3**
Average duration (minutes)	76,5	69,0	93,3
Overtime frequency (%)	28,40	32,14	21,55
n	248	252	212

Table 2.2: Descriptive statistics for the realized overtime. T=2008, n=712. Source: Hospital data management system.

2.3.4.1 Days that have more than one OR working in overtime

We count the number of regular working days that more than one OR works in overtime. In 2008, 49 days have more than two ORs working in overtime (19,5%).

2.3.4.2 Empty OR durations

In addition to sessions which ends outside the regular working hours, there are also days on which the last session finishes earlier than the end of regular working hours. We call this empty OR duration. Figure 2.12 illustrates the time between the end of the last session and the end of the regular working hours. A positive number means the session ends in overtime, a negative number represents empty OR duration.

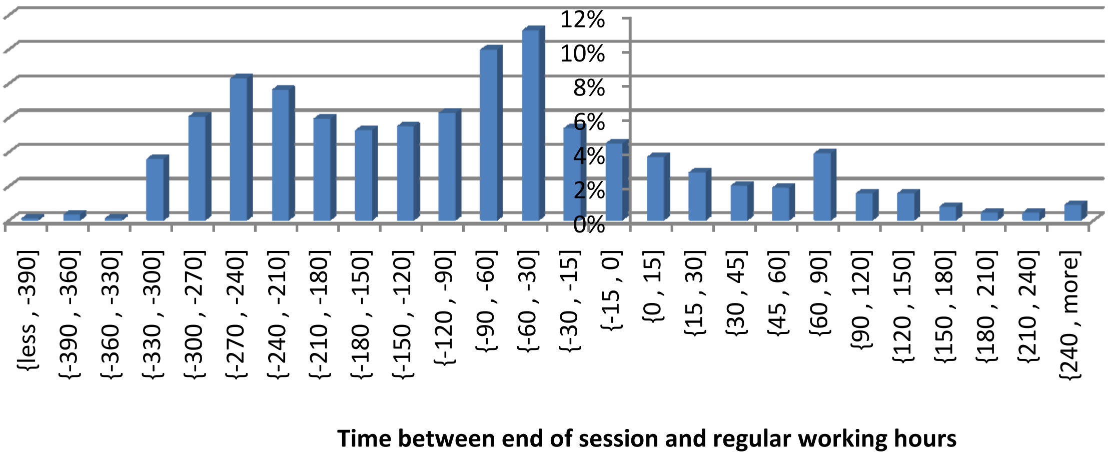


Figure 2.12: Time between the end of the last session of the day and the end of regular working hours. T=2008, n=1072. Source: hospital data management system. A positive number means the session ends in overtime, a negative number represents empty OR duration.

We conclude that the low utilization rate is mainly caused by empty OR durations. Given the session time of session time of surgeries performed at the Thorax Center, it is possible to fill up the long empty OR durations, empty OR durations, but it is difficult to fill up the small empty OR durations. Due to the session time as session time as displayed in

Figure 2.8, we investigate the percentage of empty OR durations. Table 2.3 present these frequencies.

Minutes of empty OR duration	percentage
[1-60]	52%
{60-90]	20%
{90-120]	8%
{120-more]	21%

Table 2.3: Frequency for different durations of empty OR durations. T=2008, n=893. Source: Hospital data management system

2.3.5 Workload

Before assessing the perceived high workload, we first give a formal definition of workload.

"The amount of work that has to be completed over a given period" (Van Dale, 2010).

Nevertheless, incidental factors can contribute substantial sources of variability to the workload as proposed above. For the OR department it is difficult to quantify the workload. Therefore, we assume that only the work performed at the OR is included. OR personnel have specific competences and authorizations. Therefore, each task has a limited number of people able and authorized to perform this task. This limits the possibilities of deploying personnel. For ORs, regulations exist for the minimum personnel requirements. Table 2.4 presents the number of personnel per discipline that must be available for an OR day. Appendix H gives an extensive overview for the required number of FTE.

Discipline	OR day	One day (3 ORs)
Surgeon	1	3
Assistant Surgeon/OACV	1	3
Nurse (circulating/scrub)	2	6
Anesthetist	0,5	2
Assistant-anesthetist	1	3
Perfusionists	1	3

Table 2.4: Minimum personnel requirements for an OR day and a single day.

Figure 2.11 displays the utilization rate during the day. To elaborate on the perceived high workload, we assess on the shifts of work, relating to the utilization rate. Because the unit manager cannot influence on the number of surgeons, assistant-surgeons, and anesthetists available, we assume that they are not the bottleneck in the current workload. Figure 2.13 displays the net utilization rate for the OR department, realized in 2008, together with the available percentage of personnel per discipline, related to 3 ORs.

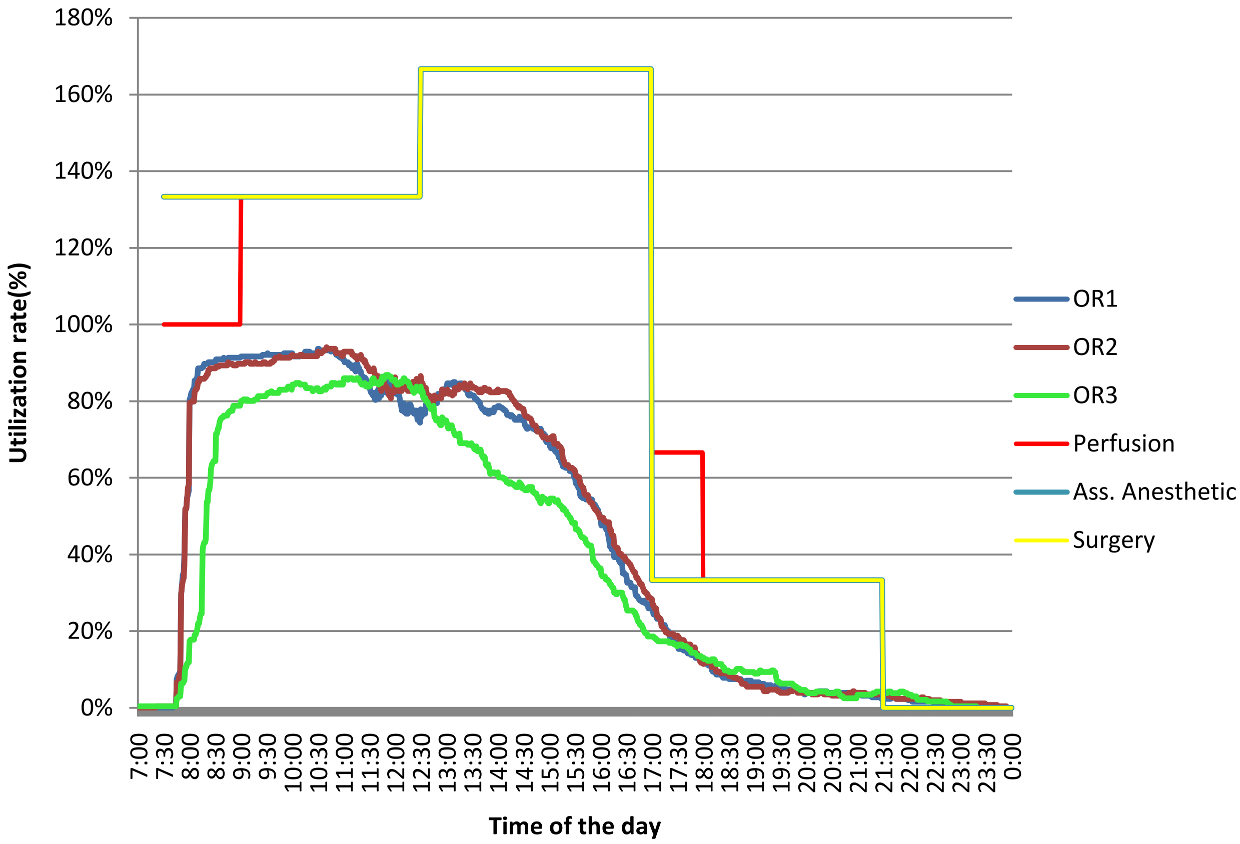


Figure 2.13: The minimum personnel requirement related to the utilization rate of the separate ORs. Source: hospital data management system/personnel.

Without taking into account the complementary tasks of the disciplines, the number of personnel available during the day complies with the minimum personnel requirement that day. The distributions do not correspond; the peak in utilization is during morning hours, whereas the peak in availability of personnel is during the afternoon. The changeover during the lunch break is performed before the personnel from the second shift is available.

2.4 Conclusions and demarcation of the research scope

We found many points of attention and improvement during our performance analysis. We elaborate in Section 2.4.1 on the most important findings. In Section 2.4.2 we demarcate the scope of the research.

2.4.1 Conclusions

2.4.1.1 Planned vs. realized session time

One of the major findings concerning the planning of the OR sessions is the high deviation in session time. Currently, sessions are planned concerning historical times, but this system does not seem to be accurate. Of all sessions, 164 sessions have a planned session time that equals 50 minutes, whereas the average duration of these sessions is 149,8 (σ=119,6) minutes. If we can improve the accuracy of estimating the session duration, this could benefit the utilization rate of the OR department.

2.4.1.2 Utilization vs. workload

The utilization rate of the OR department is 78 % (σ=15). In addition, sessions are often performed in overtime. With this rate of utilization, hardly any overtime should occur. Because of the planned 2 session each day, and the ability to start sessions taken into account the lunch break, we should investigate whether the surgery schedule can be adjusted to prevent working in overtime and improve the utilization rate. This should contribute to the workload during the day.

The major finding of the performance analysis is the deviation of workload during the day and the number of personnel available during the day. Accordingly, the perception of unequally spread capacity usage during the day is justified.

2.4.2 Research scope

We focus this research on assessing methods for the tactical level of planning. We assess different methods of surgery planning, which is referred to as ‘the process of reconciling supply and demand’ (i.e., dealing with capacity decisions; Cardoen et al., 2008). Furthermore, we analyze several organizational interventions, which comprise various capacity allocations to test the influence of the amount of available capacity on the settled performance indicators. We choose a top-down approach for the problem statement because we have to optimize the tactical level decisions before assessing details on operational level.

In the next chapter, we assess relevant methods for surgery planning that we find in the literature. We assess organizational interventions possible for the Thorax Center, and come up with implementation methods based on a performed simulation study. We describe this study in Chapter 4, we analyze the results in Chapter 5, and we describe relevant implementation methods and recommendations for implementation in Chapter 6.

3 Solution approach

We demarcate our research scope to investigate methods to improve the utilization rate of the OR department, taking into account the preferred maximum overtime probability. A lot of research has already been performed on tactical methods for planning. Section 3.1 gives an overview of the most relevant methods. Section 3.2 translates our findings in the literature to interventions that hypothetically contribute to a solution for our problem. Section 3.3 proposes interventions for testing, and this chapter ends with a description of our test approach in Section 3.4.

3.1 Tactical planning methods in the literature

This section gives an overview of the various OR planning and scheduling problems in the literature. We focus entirely on the tactical OR capacity planning and scheduling problem. Tactical decisions comprise the usage of resources on a medium term, usually with a planning horizon of several weeks. It is verified whether the planned elective surgeries cause resource conflicts for the OR, for subsequent departments, or for required instruments with limited availability (Blake & Donald, 2002; Dexter et al., 2005). The decisions are based on estimates of future OR workload and therefore require accurate estimates of the future demand per specialty (Dexter et al., 2005).

Two main approaches exist for the division of OR time. When a closed block planning approach is used, each specialty will receive a number of OR blocks (usually OR-days). The open block planning approach operates first-come-first-serve (FCFS).

Subsequent to the division of OR time, elective patients have to be scheduled for surgery. There are two steps in the scheduling of elective patients. First, the patient must be scheduled for surgery on a given date, and second, the patient must be assigned to a specific OR and starting time (Ozkarahan, 2000). Beliën and Demeulemeester (2009) provide an extensive review of recent research on operating room planning and scheduling. We refer to the following articles in specific, because their objectives are similar to our intended objectives. Guinet and Chaabane (2003) describe the problem as a general assignment problem that aims at reducing patient stay duration and overtime costs. Ozkarahan (2000) introduces a goal programming model for the assignment of surgical operations among multiple ORs, to prevent over or underutilization. Testi et al. (2007) propose a three-phase approach that has proven to be effective in improving the OR productivity by increasing the number of surgeries performed as well as reducing overtime costs and postponed operations. Fei et al. (2009) propose a column-generation-based heuristic to maximize the utilization and minimize overtime costs.

Merely all these planning approaches use the implementation of a Master Surgery Schedule (MSS). Master surgical scheduling is a cyclic, closed block planning approach, which assigns a fixed amount of time at a given day and time to a particular surgeon or service (Testi et al., 2007; Blake & Donald 2002; Beliën et al., 2009). The goal of an MSS approach is to optimize utilization, level the workload, and construct a robust schedule (van Oostrum et al., 2009), which complies with our research focus. The use of an MSS allows the unit manager to coordinate the personnel and resources involved in an early stage, and therefore able to respond to unforeseen events, such as the arrival of emergency patients.

3.2 Interventions

In this section, we propose interventions that may contribute to an improvement in the utilization rate of the OR department. We distinguish 4 main types of interventions: a modification of the regular working hours, an adjustment in the estimation procedure of the session times, an adjustment in changeover time, and an adjustment in the offline scheduling algorithm. In Section 3.2.1 to 3.2.5 we propose various interventions per intervention type, and discuss why we test these interventions.

3.2.1 Modification of the regular working hours

The extension of OR shifts may improve OR efficiency, especially during prolonged operations (Peltokorpi et al., 2008). Extending the OR shifts improves the possibility of scheduling 3 sessions each day. Aside from the extension of OR shifts, it may be beneficial to shorten the OR shifts such that the efficiency improves without changing the surgery schedule. Therefore, we investigate the length of an OR shift. To prevent overtime, the planning department must plan slack time, which is based on the variability of the surgery durations. The amount of slack is related to the probability of overtime (Hans et al., 2008).

Despite the potential advantages in lengthening the OR shift, doing so may have several disadvantages. Extension of the OR shifts may result in an increase in sickness notice, and patient related disadvantages (Dzoljic et al. 2003). In addition, the capacity of subsequent departments is not sufficient to cope with more sessions each day. Therefore, we have to investigate the amount of capacity necessary to fulfill the production requirements.

To calculate accurate parameters for the degree of modification, we first calculate the minimum capacity requirement. Appendix F gives a complete overview of the calculation, Table 3.1 summarizes our findings.

Overtime probability (%)	Capacity requirement (minutes)
38	493,7
34	501,1
33	503,3
31	508,5
27	515,9

Table 3.1: Minimum calculated capacity requirement, given a certain probability of overtime. T=2008, n=1324. Source: hospital data management system. (See Appendix F for the calculations.)

Table 3.1 indicates the minimum capacity requirement per OR day. These calculations include all emergency surgeries performed in 2008; nevertheless, these sessions cannot be scheduled, and do not always occur in regular working hours. If we do not include the emergency surgeries in our capacity determination, for a 33% overtime probability we need an OR shift of 485,1 minutes.

We distinguish various interventions relating to the modification of the regular working hours, and all interventions can be implemented without major investments. Regarding personnel preferences, we also investigate the possibility to open a flexible OR. This OR has different opening hours compared with the other ORs. Personnel suggested opening hours from 9.00 am until 3.00 pm, such that children's school time is taken into account. We propose the following interventions, which we base on the minimum capacity requirement:

i. Shorten regular working hours, from 7:45 am to 3:45 pm;
ii. Shorten regular working hours, from 7:45 am to 4:15 pm;
iii. Decrease of number of OR days per week, 14 OR days, from 7:45 am to 4:45 pm;
iv. Decrease of number of OR days per week, 13 OR days, 7:45 am to 4:45 pm;
v. Flexible OR, 2 ORs from 7:45 am to 4:45 pm, 1 OR from 9:00 am to 3:00 pm.

3.2.2 Improve the accuracy of session time estimation

In comparison with other specialties, cardiothoracic surgeries are relatively long and have high variability (Dexter et al., 2008; Lehtonen et al., 2007). There are two components to the inaccuracy of the session durations with the same predicted duration: bias and imprecision. An example of bias is when all sessions take on average 20 minutes less than their predicted duration; an example of imprecision is the duration variability. This variability of the actual durations of sessions can result in long patient and surgeon waiting times on the day of surgery (Dexter et al., 2005).

The more accurately the session time for a planned surgery can be estimated, the more precisely the OR hours can be scheduled while still avoiding overtime. (Peltokorpi et al. 2008; Strum et al., 2003; van Houdenhoven et al., 2006). However, estimation of the session time is not easy because it depends on the patient pathology, which is partially known, and on surgeons' expertise (Wright et al., 1996). The current data management system of MST estimates session time based on historical times, where recent performed sessions have a higher weight factor in this estimation. This system is not accurate, as we showed in Figure 2.9.

If we can design an accurate method that is able to accurately estimate session times, this would result in better surgery schedules, and an increased utilization rate of the OR department.

vi. Improve the accuracy of the estimation of the session times.

3.2.3 Reduce the changeover time in the OR

The utilization rate of the OR department is based on session time. However, sessions cannot immediately follow, because of the changeover time (cleaning time and startup time). Non-operative time decrease the maximum utilization rate of the OR department.

If we can decrease the changeover time, the utilization rate possibly increases. There are several possibilities to decrease the changeover time. The changeover time consists of several parts. After the session, the OR has to be cleaned, and startup time is necessary to make the OR ready for the next session. When the OR is ready for the next surgery, time in the OR is used for inducing the next patient. By moving non-operative actions, such as inducing the patient, outside the OR, extra time is available in the OR.

vii. Decrease changeover time.

3.2.4 Modification of the offline scheduling

As we mentioned in Section 2.2.1, patients are randomly selected from the waiting list. However, it might be interesting to investigate the impact of a modification of this selection algorithm. We investigate the influence on the interventions by selecting patients from the waiting list based on their due dates; patients which have the earliest due date are selected first.

viii. Select patients based on descending due dates

3.2.5 Master Surgery Schedule

In Section 3.1 we elaborate on the MSS. If we use a four week recurrent schedule, only 50% of all surgeries can be performed every week. Furthermore, the management of the Thorax Center wants to give patients the possibility to choose their preferred day of surgery. If we use an MSS, we cannot guarantee this flexibility of the surgery schedule.

3.3 Proposed interventions

We summarize the interventions discussed in Section 3.2 in Table 3.2.

i.	Shorten regular working hours, from 7:45 am to 3:45 pm
ii.	Shorten regular working hours, from 7:45 am to 4:15 pm
iii.	Decrease of number of OR days per week (14 OR days, from 7:45 am to 4:45 pm)
iv.	Decrease of number of OR days per week (13 OR days, from 7:45 am to 4:45 pm)
v.	Flexible OR, from 9:00 am to 3:00 pm
vi.	Improve the accuracy of the estimation of the session times.
vii.	Decrease changeover time
viii.	Select patients based on descending due dates

Table 3.2: Overview of proposed interventions

Intervention (vi) acts as a constraint for the realization of the interventions, we should keep this in mind when we enter the implementation phase. As we already mentioned in Section 2.3.3, the changeover time does not affect the utilization rate of the OR department substantially, therefore we focus on the interventions which comprise changes in the regular working hours of the OR. We test interventions (i) to (v). We also test the influence of a change in the offline scheduling algorithm, which is incorporated in intervention (viii).

Each intervention contains an OR division that indicates the number (and opening hours) of ORs open during a day. Because we simulate a single year, we can accurately specify this OR division. Appendix F gives a detailed description of the OR division for each intervention.

Intervention / Parameter	i	ii	iii	iv	v
Number of OR days per week	15	15	14	13	15
Total capacity per week (minutes)	7200	7650	7560	7020	7200
Number of patients per year	1200	1200	1200	1200	1200

Table 3.3: OR division per intervention.

Table 3.3 summarizes the parameters for each intervention. The number of OR days per week is mentioned, the total capacity for each interventions is calculated and, the number of patients is set.

3.4 Test approach

In the previous sections, we mention several interventions that should contribute to an improved utilization rate. To test whether the proposed interventions lead to an improvement, we should investigate methods for testing.

Discrete event simulation is a useful technique to describe the flow of patients during a hospital stay (Davies, 1994). It is a tool that can accommodate different parameters affecting the OR capacity allocation (Ramwadhdoebe et al., 2009). Many studies that investigate OR capacity allocation using simulation as a method for testing. For example, at the University of Twente many graduation projects focus on operating room scheduling (www.choir.utwente.nl). Merely all these graduation students have contributed to the same simulation software for testing their interventions. This software program, called the Operating Room Manager (Hans & Nieberg, 2007), gives insight in a modeled hospital's OR department at various levels of control. In subsequent steps, the actual planning and scheduling process is organized, starting with strategic choices on capacities for an upcoming year, and ending with daily, online planning of actual elective and emergency surgeries in each OR. Because in this software many options that we want to use are already modeled, we use this software program to perform the simulation study.

We perform a simulation study following the steps formulated by Law (2007). Box 1 gives an overview of the approach. In Chapters 4 and 5, we will discuss each step in more detail.

Test Approach

1. Conceptual design: formulate the problem and plan the study
2. Technical design and data gathering
3. Validation and verification of the model
4. Experimental design and simulation
5. Analyze output data

Box 1: Test approach to compose a simulation study to test the proposed interventions (Law 2007).

4 Methodology

This chapter gives a detailed description of the steps defined in Box 1. Section 4.1 presents the conceptual design, with the objectives of the study, the model scope, and the system configurations that are modeled. Section 4.2 elaborates on the technical design of the model; we specify the model parameters and present the model assumptions. Section 4.3 describes the current performance, and the steps for model validation. Finally, Section 4.4 gives a detailed description of the scenarios that we use to test the robustness of the proposed interventions.

4.1 Conceptual design

First, we design a conceptual model before we actually build the simulation model. The model design is a description of how the system of interest should be modeled (Law, 2007). It impacts all aspects of the study, and describes the objectives, inputs, outputs, content, and simplifications of the model.

4.1.1 Objectives

We formulate the following objectives of the simulation model:

- The model describes the process for the thorax operating rooms.
- The model is user-friendly, enabling users to easily run various scenarios and set decision variables within these interventions.
- The model measures output in terms of resource utilization, overtime frequency, and the number of days that have more than one OR in overtime. Furthermore, the model measures various output parameters that can be of interest for determining other indicators for the productivity.

4.1.2 Contents of the simulation study

We require our model to be a close representation of the OR department and its process steps. Therefore, the model closely follows the aspects described in Section 2.2. Figure 4.1 gives a simplified representation of these aspects.

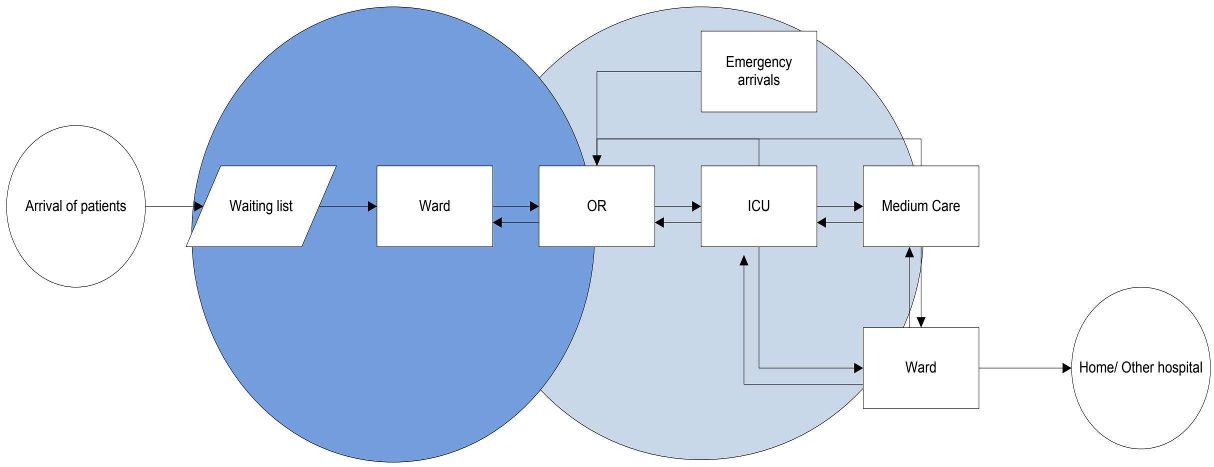


Figure 4.1: Simplified representation of the actual system

In our model, we focus on 2 steps. First, we consider the offline scheduling: assigning patients on the waiting list to a specific date, OR, and start time. Second, we consider the online scheduling; define rules for assigning patients to an OR when an OR becomes empty (i.e., at the start of the day or when the previous surgery in the OR is completed).

4.1.2.1 Offline scheduling

When patients are placed on the waiting list for surgery, they are assigned characteristics, such as the type of surgery that is required, arrival date, and due date. Next, the elective patients remain on the waiting list until they are scheduled for surgery.

The offline scheduling problem concerns assigning the patients on the waiting list to an OR. Assignment of surgery has to satisfy various resource constraints: regular working hours, the ICU capacity and patients' hospitalization. The regular working hours are from 7:45 am to 4.45 pm. Patients are hospitalized one day before surgery.

The first step in the offline scheduling algorithm is to select a patient for surgery. We randomly select a patient from the waiting list. The next step is to select an OR for surgery. A patient that is selected from the waiting list is assigned a planned time. A patient is assigned to an OR concerning the best fit selection rule; a patients is assigned to the OR for which the capacity gets filled the most by adding this surgery's planned time. The surgery schedule is complete if no patients can be selected from the waiting list and added to an OR without violating the capacity constraint, or a total of 6 surgeries are assigned (due to the capacity constraint of the ICU department). Since we want to optimize the utilization rate of the OR department without changing the current planning process, we do not use local search methods to optimize the schedule.

4.1.2.2 Online scheduling

During the execution of the offline surgery schedule, disturbances such as emergency surgeries can occur. Online scheduling considers which session should be executed in an OR when the OR becomes available.

We use the following priority rule for selecting a surgery:

1. Emergency surgery.
2. Surgery with the longest expected duration.
3. Surgery that has been planned in that OR
4. Surgery with earliest planned start.
5. Surgery that fits the best in the OR
6. Surgery with the longest waiting time.

By executing this algorithm, we determine the arrival of emergency sessions as the highest priority. The session that was actually planned on the time an emergency session arrive is replaced in the schedule and handled by the algorithm as stated above. As Figure 4.1 displays, the online scheduling algorithm also deals with patients that return from the ICU or the medium care department. We deal with these patients as emergency patients.

During online scheduling, we also consider the occurrence of cancelling a surgery. A surgery can be cancelled due to several circumstances:

- The ICU capacity is not sufficient to deal with another patient.
- A certain percentage of the planned session time is outside regular working hours.
- An emergency session arrives and no empty OR is available.

If a session is cancelled, it will be executed the next day.

4.1.3 Ranking & Selection

To evaluate a given solution, we use the key performance indicators as in Section 2.3.1. Table 4.1 lists the key performance indicators, and also the objective we want to obtain.

Key performance indicator	Objective
Utilization rate	Maximize
Overtime probability	Minimize
Number of days with more than one OR in overtime	Minimize
Workload	Level the workload, minimize the number of FTEs

Table 4.1: Key performance indicators with the intended objectives for our simulation study

To score the proposed interventions, we perform statistical analysis of the output from the different interventions, to find differences between the interventions. We have to score each intervention on the stated indicators. The main stakeholder (the unit manager) has indicated that all criteria are equally important. Our analysis will result in recommendations to the management of the OR department.

4.2 Technical design and data gathering

We use the Operating Room Manager (Hans & Nieberg, 2007) to perform the simulation. This software program gives insight in a modeled hospital's OR department at various levels of control. In subsequent steps, the actual planning and scheduling process is organized, starting with strategic choices on capacities for an upcoming year, and ending with daily, online planning of actual elective and emergency surgeries in each OR.

4.2.1 Data gathering

From our conceptual design, we conclude that we need the following input data for the simulation model:

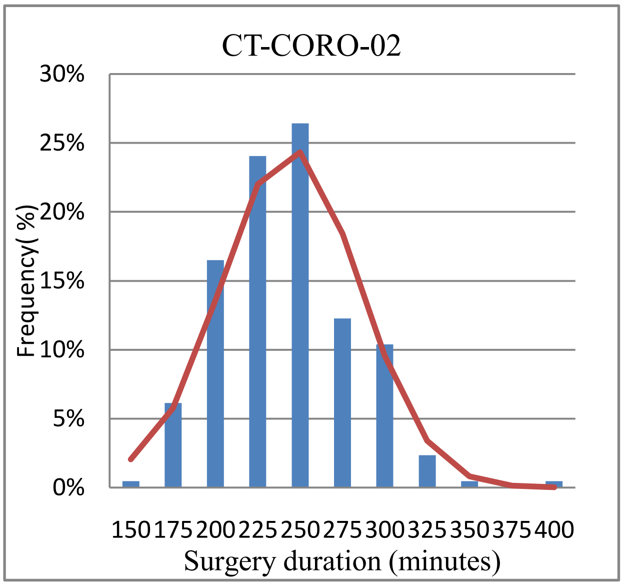
- Distribution of surgery durations.
- Changeover times.
- Slack time.
- Emergency arrivals.

We perform statistical analysis to determine the distribution of the session durations, which we describe in Section 4.2.1.1. Subsequently, we elaborate the changeover time and the slack time in Section 4.2.1.2 and 4.2.1.3 respectively. Finally, Section 4.2.1.4 elaborates on the emergency arrivals.

4.2.1.1 Session duration

The sessions performed from January 2008 to December 2008 form the basis of our simulation model. We include all sessions performed, and determine a standard set of surgeries to include in our simulation model. Appendix G clarifies this set of surgeries. Various studies, see for instance Strum et al. (2003), describe that surgery durations can best be described by a lognormal distribution.

By random sampling we determine for several surgeries via the χ^2-test a similarity with the lognormal distribution. We also determine the similarity with the normal distribution. The χ^2-test for determining the similarity with the normal distribution resulted in a 99% resemblance. Figure 4.2a presents a histogram for the realized session times for the surgery with activity code CT-CORO-02, together with the expected values for the normal distribution. Figure 4.2b present a histogram for the realized session times for all realized elective sessions, together with the expected values for the normal distribution. The χ^2-test in both cases shows a 99% fit with the normal distribution.



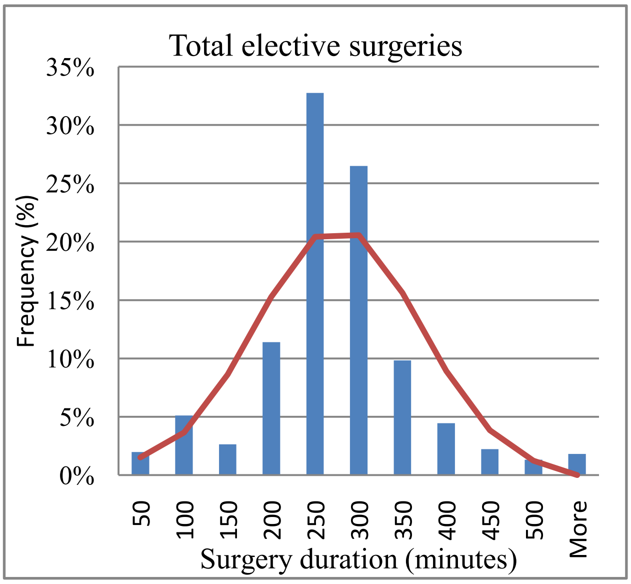


Figure 4.2a: Histogram for surgery with activity code CT-CORO-02. b. Histogram for the total surgery durations. The bars represent the frequency of realized session times; the line indicates the expected values of the normal distribution. T=2008. Source: Hospital data management system.

4.2.1.2 Changeover time

As mentioned in Section 2.3.3, the duration of the changeover time influences the productivity of the OR. Therefore, we include this parameter in our simulation model. Currently, it is not necessary to ensure an as short as possible changeover time because of the excess of capacity. Due to this, the changeover times we subtract from the data of 2008 are not representative for the minimal required changeover time. Together with the unit manager of the OR department, we determine the amount of changeover time that is necessary to perform each surgery. We assume a set-up time of 15 minutes, and a cleaning-time of 15 minutes.

4.2.1.3 Slack time

Hans et al. (2008) use the concept of norm utilization and extend on it by introducing planned slack. Because the sum of the surgery durations is normally distributed (See Figure 4.2b), we can use a general formula to calculate the amount of planned slack that ensures a certain overtime probability. This formula is:

$$\delta = \beta \cdot \sqrt{\sum_{i \in S} \sigma_i^2} \qquad [1]$$

In the formula, σ_i is the standard deviation of surgery i, μ_i is the average duration of surgery i, and S is the set of surgeries scheduled in the concerned OR. By summing the square of the standard deviations (the variation of S) and taking the square root of this sum, we get the standard deviation of the sum of these surgery durations. By multiplying this standard deviation with β, the slack factor, we are able to determine the amount of planned slack δ necessary to achieve a desired overtime probability. For example, $\beta = 0{,}43$ gives a 33,36% probability of overtime (66,64% probability that the surgeries are completed within regular working hours).

4.2.1.4 Emergency arrivals

Emergency sessions at the thorax OR department do not randomly arrive during the day. Almost all emergency patients are patients that have been operated earlier that day and for whom complications have occurred. They have to be operated as soon as possible. From the data of 2008, we see that these patients mainly arrive after the first session of the day until evening hours.

4.2.2 Assumptions

For the offline scheduling algorithm, we make the following assumptions:

- All patients on the waiting list have to be scheduled within four weeks of waiting.
- Per day, on average one OR may work in overtime; therefore we accept an overtime probability of $\frac{1}{3}$.
- Each OR is able to process any type of surgery, and a surgery has the same processing time in every OR.
- We focus on the OR, and do not take into account the length-of-stay for subsequent departments.
- The case-mix of the department is constant over the year and without seasonal trends.
- A maximum number of 6 elective surgeries can be assigned on a single day because of the limited ICU capacity.
- All elective surgeries are performed during regular working hours.
- Patients are randomly selected for surgery.
- All resources necessary (anesthetic, perfusion, and surgical equipment) are available in each OR over the opening hours.
- A sufficient number of surgeons are available on each OR day to perform surgeries.
- We consider planned slack after regular time as planned overtime.

Online scheduling assumptions:

- Patients who are scheduled for day t are hospitalized day $t-1$, such that they are ready at the start of day t.
- Because of the hospitalization, during online scheduling patients do not cancel their surgery.
- Elective sessions may start before their planned times.
- Elective sessions may move to another suitable OR, following the stated algorithm.
- All ORs can handle emergency sessions.
- A session is not performed if more than 30% of the planned session time is outside regular working hours.

- If a session is cancelled, it is scheduled the next day.
- We focus on arrivals during regular working hours, i.e. we do not take into account evening sessions and weekends.
- Setup- and cleaning times are deterministic; we assume a duration of 15 minutes each.
- Surgery durations are normally distributed.

4.3 Model validation

We validate our model to ensure a reliable representation of the current system. In Section 4.3.1 we specify three important simulation factors to achieve accuracy of experimentation. In Section 4.3.2 we then validate our model by comparing several outcomes of the current system with the outcomes of the simulation model.

4.3.1 Accuracy of experimentation

Before we are able to comment on the validity of our model, we determine the accuracy of the outcomes, which is based on three important simulation factors, namely the number of runs, the length of the warm-up period, and the length of a simulation run (Law, 2007)

4.3.1.1 Number of runs

Our simulation model works with statistical distributions and therefore uncertainty plays a role. Nonetheless, we want to make sure that the results of our simulations are reliable. To get results with sufficient precision, we have to perform enough runs. Using the sequential procedure (Law, 2007), we obtain an estimate of μ with a relative error of γ, and a confidence interval of $100(1-\alpha)$. We use the total overtime duration to determine the minimum number of runs. The confidence-interval half-length equals:

$$\delta(n,\alpha) = t_{n-1,1-\alpha/2}\sqrt{\frac{S^2(n)}{n}} \qquad [2]$$

n= number of runs

S^2= variance estimate

t = critical point for the normal distribution(For α=0,05; t=1,96)

The sequential procedure is as follows:

1. make n_0 replications of the simulation
2. Compute $\bar{X}(n)$ and $\delta(n,\alpha)$

3. If $\delta(n,\alpha)/\bar{X}(n) \leq \gamma'$, use $\bar{X}(n)$ as the point estimate for μ and stop.
4. If not, make $n+1$ runs and go to step 2.

Figure 4.3 gives a graphical representation of the outcome of this algorithm.

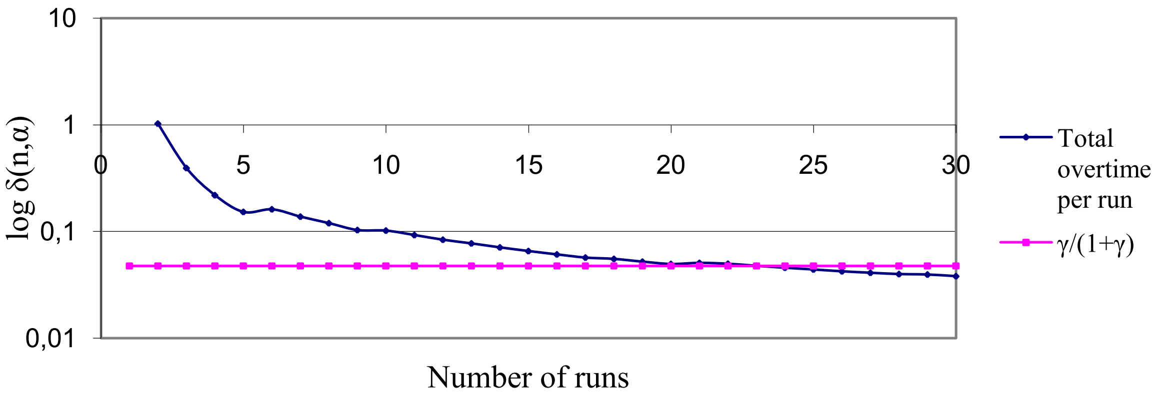


Figure 4.3: Graphical representation of the determination of the number of runs. We use a relative error γ of 0,05 and a confidence interval of 95%.

The required number of runs in order to achieve the same level of confidence for the other performance indicators is 24. We set the number of runs at 30, which represent 30 years without reduction weeks.

4.3.1.2 Run length & warm-up period

Simulations may be either terminating or non-terminating, depending on whether there is an obvious way for determining the run length (Law, 2007). In this case, we have a terminating simulation, because we have an event that specifies the length of each run. We focus our simulation model on the normal weeks. Because we want to determine the capacity requirement given the data of 2008, we choose a run length equal to the number of regular weeks, which is 39 weeks or 585 OR days.

A warm-up period is a period after which the simulation model is an actual representation of the system. In our case the ORs are empty at the start of every day. Cancelled patients follow the same rules as other patients for the next day. Therefore, we do not have a warm-up period.

4.3.2 Current performance and model validation

The regular opening hours of the ORs are from 7:45 am to 4:45 pm. During these hours, sessions are performed. However, personnel shifts are from 7:30 am to 5:00 pm. The startup time of the first session, and the cleaning time of the last session of the day are not included in the regular working hours of the OR. Therefore, we use a startup time of 15 minutes, and a cleaning time of zero, to correspond the model with the current system. We use the input parameters as Table 4.2 displays.

Input parameter	Current System	simulation
Number of OR days	585	585
Total capacity (minutes)	330525	330525
Number of emergencies	39	38
Number of electives	970	970

Table 4.2: input parameters

Table 4.3 presents the outcomes of the simulation, compared with the outcomes of the current system.

Indicator	Current System	Simulation	Relative difference
Total overtime duration (minutes)	11751	8247	29,8%
Overtime frequency	26,7%	24,4%	8,3%
Number of overtime days	156	143	8,3%
Utilization rate	72%	73%	-2,2%
Elective surgery duration in regular	233720	238994	-2,3%
Emergency duration in regular time	3628	3617	0,3%
Total elective surgery duration	244375	245849	-0,6%
>1 OR in overtime	38	44	-15,8%

Table 4.3: Simulation outcomes, compared with the current system

A number of issues catch our attention. The first difference is in the overtime duration. In our simulation model, we have a deterministic setup and cleaning time of 15 minutes per surgery. In the current system, our changeover time varies, as Figure 4.4 displays. Concerning the excess of capacity, there is no need to start up surgeries immediately after the previous surgery. However, this “late start” of the session may possibly cause the amount and frequency of overtime.

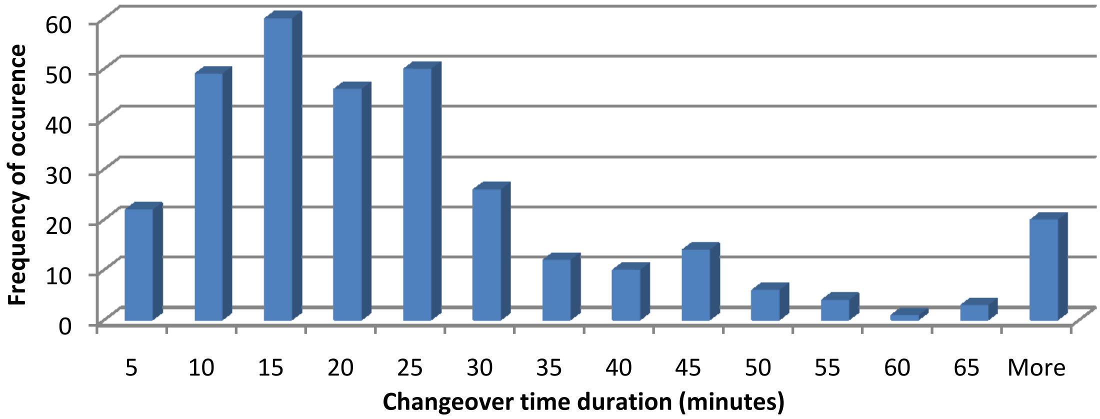


Figure 4.4: Realized changeover times in 2008. n= 311, source: Hospital data management system.

The second remarkable difference is the number of days that more than one OR works in overtime. Contrary to the total overtime duration and the overtime frequency, the number of days that more than one OR works in overtime is higher in our simulation model than in the current system. The difference is 6 days, which is only 1 percent of the total number of OR days. We assume this difference is negligible.

Although the model does not agree with the current system on all calculated indicators, but due to the addition of the changeover times, the model is a satisfactory representation of reality.

4.4 Experimental design

The next step in the design of our simulation study is the experimental design. The robustness and performance of the proposed interventions in Section 3.3 will be tested in several scenarios. In cooperation with the unit manager of the OR department, we specify 2 types of scenarios, which we elaborate in Section 4.4.1, and 4.4.2 respectively.

4.4.1 Increase in the number of sessions

Since 1997 the number of open heart surgeries performed in the Netherlands is relative stable, partly caused by the shift to PCIs (see Section 2.1). The last 3 years the number of surgeries has slightly increased, because of the opening of new Thorax Centers. The perception of the staff is that the number of patients stabilizes the upcoming years. However, to test the influence of the number of patients on the robustness of our capacity allocation, we use the national trend for the number of clinical patients. The prognosis for the rate of growth for clinical patients is 3,3% each year (Van de Vijsel, 2009). We also investigate on an increase of emergency patients, because this can have large impact on the amount of overtime and the overtime frequency.

A. Increase in the number of emergency sessions
B. Increase in the number of elective patients

In Table 4.4 we specify the scenarios.

4.4.2 Modification of the session duration

In Chapter 2 we already mentioned that the operating time per surgeon differs. In the middle of 2009, 2 surgeons are employed, and the perception is that the surgery time of the surgeons has significantly decreased. Also, the surgeons at the Thorax Center become more skillful in performing heart surgeries. Possibly this also will lead to a decrease of the session duration. Therefore, we design scenarios in which session durations are decreased by -2% to -12%. Contrarily, the types of surgery can become more complicated, which will lead to an increase of the session duration. Therefore, we also design scenarios with a +2% to +7% increase of the session duration.

C. Average decrease of the session duration
D. Average increase of the session duration

Table 4.4 summarizes the proposed scenarios.

Scenario	1	2	3	4	5	6
A (number of emergencies)	40	42	44	46	48	50
B (number of electives)	1000	1030	1060	1090	1120	1150
C (decrease of session time)	-2%	-4%	-6%	-8%	-10%	-12%
D (increase of session time)	+2%	+3%	+4%	+5%	+6%	+7%

Table 4.4: Overview of the scenarios

In this chapter we have described our simulation model and proven its validity. In the next chapter we will present the results concerning the possible interventions.

5 Results

In this chapter, we present the computational results of the simulation study. First, we present the results when using the current input parameters in Section 5.1. Second, we investigate the influence of the different scenarios and interventions on the key performance indicators. Section 5.2 elaborates the utilization rate, Section 5.3 elaborate on the overtime frequency, Section 5.4 on the days that have more than one OR working in overtime, and Section 5.5 give an overview of the required number of FTE per intervention. Subsequently, we measure the impact of a modification of the offline scheduling in combination with the other proposed interventions and present the results in Section 5.6 . Finally, Section 5.7 presents the overall results.

5.1 Current parameters

We measure the impact of our proposed interventions relative to the performance in the current system. Hereby, we use the key performance indicators described in Section 2.3.1. Table 5.1 gives an overview of the proposed interventions.

i.	Shorten regular working hours, from 7:45 am to 3:45 pm
ii.	Shorten regular working hours, from 7:45 am to 4:15 pm
iii.	Decrease of number of OR days per week (14 OR days, from 7:45 am to 4:45 pm)
iv.	Decrease of number of OR days per week (13 OR days, from 7:45 am to 4:45 pm)
v.	Flexible OR, from 9:00 am to 3:00 pm
vi.	Select patients based on descending due dates
cs.	Current system (15 OR days, from 7:45 am to 4:45 pm)

Table 5.1: Overview of the proposed interventions

We present the results in an overview per key performance indicator for interventions (i) to (v) to allow easy comparison. The interventions (see Table 5.1) are placed in rows; the columns indicate the specifics of the key performance indicators measured. Table 5.2 presents the outcomes of the simulation study.

Key Performance Indicator / Intervention	Utilization rate (%)	Overtime frequency (%)	Days with more than one OR working in overtime (%)
(cs)	74,2	29,9	9,9
(i)	78,9	44,7	17,5
(ii)	77,1	38,1	14,4
(iii)	80,9	33,2	12,3
(iv)	83,2	52,7	26,0
(v)	81,4	47,1	20,4

Table 5.2: Simulation outcomes for the proposed interventions. The results are obtained using the current input parameters (run length = 39 weeks, accuracy=95%)

Based on the results (Table 5.2), we conclude that none of the interventions contribute to an improvement on all key performance indicators. A logical explanation for this is that the higher the utilization rate, the higher the expected overtime frequency. We want to maximize the utilization rate, and minimize the overtime frequency (See Section 4.1.3).

The capacity used in each intervention has major influence on all key performance indicators. Each intervention has less amount of regular capacity available compared to the current system, which result in an increased utilization rate for all interventions. In Table 3.3 we present the capacity per week for each intervention. Intervention (iv) has the least available regular capacity, which results in the highest utilization rate. However, this also results in the worst performance for both overtime indicators. We cannot conclude that the performance is strictly related to the available capacity, because intervention (i) and (v) have equal available amount of capacity, but they do not perform equally. Likely the distribution of capacity spread over the week and the length of an OR shift causes this unbalanced performance.

Because the Thorax OR department is a very specialized department, with merely long and high variable session durations, planning of sessions will hardly improve all key performance indicators simultaneously. This is also not possible, because we have conflicting objective indicators.

To be able to give a proper recommendation to the management of the OR department, we start our analysis of the results with a ranking of all interventions. We score the interventions using the following method. We calculate the relative difference of the interventions in comparison with the outcomes for the current system.

The relative difference is measured as follows:

$$\frac{(\text{Realized}-\text{Expected})}{\text{Expected}} * 100\% \qquad [3]$$

In this case, the realized parameter is the value of the key performance indicator for the intervention, the expected parameter relates to the value for the current system.

Subsequently, we scale the relative differences from “0” to “1”, in which the intervention with the worst relative difference obtains a “0”, and the best performing intervention obtains a “1”. We repeat this until all interventions are scored for all key performance indicators. The overall score is based on the three scores, and is determined following the algorithm as we elaborated above. Table 5.3 presents the results.

Key Performance Indicator / Intervention	**Utilization rate**	**Overtime frequency**	**Days with more than one OR working in overtime**	**Overall score**
(i)	0,70	0,41	0,62	0,67
(ii)	1	0,75	0,85	1
(iii)	0,38	1	1	0,92
(iv)	0	0	0	0
(v)	0,30	0,29	0,41	0,38

Table 5.3: Overall results for the interventions when using the current input parameters. The numbers indicate the rank for the relative difference in comparison to the current system. The higher the value, the better the relative difference (Max=1). The last column presents the overall results.

From the scores as Table 5.3 presents, we see that intervention (iv) and (v) give the worst overall results. Based on the current input parameters, intervention (ii) contributes the most to a relative improvement of the objective in comparison with the current system (see Section 4.1.3). The management of the OR department expects different parameters settings in the future, because of the nomination of new surgeons and more experienced personnel.

To test the performance of the interventions under various circumstances, we perform multiple simulations based on the experiments designed in Section 4.4. In addition to the experiments described in Section 4.4, we also investigate the influence of the changeover time, which we label as scenario E.

5.2 Utilization rate

The first part of the objective as mentioned in Section 4.1.3 is to maximize the utilization rate. We determine per intervention the relative average difference for each scenario; in comparison with the outcomes of the interventions when we use the current input parameters (see Table 5.2). The intervention that contributes the most to an improvement of the utilization rate obtains a "1"; the intervention that leads to the least improvement of the utilization rate obtains a "0". Table 5.4 gives an overview of results for the utilization rate per intervention.

Scenario type / Intervention	CP	A	B	C	D	E	Total
(i)	78,9	1	0,65	0,76	0,31	0,62	0,75
(ii)	77,1	0,88	1	0,48	0,87	0,51	0,81
(iii)	80,9	0	0,82	0	0,49	0	0
(iv)	83,2	0,80	0,31	0,51	0	0,40	0,26
(v)	81,4	0,60	0	1	1	1	1

Table 5.4: Overall results for the utilization rate of the proposed interventions. CP are the results when we use the current input parameters.

When we increase the number of emergency and elective patients, shortening the regular working hours (intervention (i) and (ii) respectively) gives the best results. When we vary the session duration and the changeover time duration, intervention (v) contributes the most to an improvement of the stated objective for the utilization rate. Intervention (ii) gives the best overall result. We use this score in section 0 to present the overall results.

5.3 Overtime Frequency

The second part of the objective function is to minimize the overtime frequency. We present the results for the overtime frequency in Table 5.5.

Scenario type / Intervention	CP	A	B	C	D	E	Total
(i)	44,7	0	0,43	0	0,02	0	0
(ii)	38,1	0,14	1	0,54	0,59	0,68	0,73
(iii)	33,2	0,98	0,16	1	0	0,22	0,75
(iv)	52,7	1	0,88	0,55	0,16	1	1
(v)	47,1	0,90	0	0,68	1	0,40	0,76

Table 5.5: Relative influence of the different parameters settings on the overtime frequency of the proposed interventions. CP is the results when we use the current input parameters.

When we increase the number of emergency patients, the intervention related to a shortening of the regular working hours (intervention (i) and (ii)) give far the worst results. This is probably caused by the fact that emergency patients merely arrive at the end of the day. Intervention (iv) contributes the most (i.e. on average for all input parameters) to an improvement of the overtime frequency.

5.4 Number of days that have more than one OR working in overtime

The third part of the objective is to minimize the number of days that have more than one OR working in overtime. Table 5.6 presents the results.

Scenario type / Intervention	CP	A	B	C	D	E	Total
(i)	17,5	0	0,47	0	0,01	0	0
(ii)	14,4	0,15	0	0,67	0,44	0,78	0,50
(iii)	12,3	0,66	0,0	1	0	0,26	0,43
(iv)	26,0	1	1	0,66	1	1	1
(v)	20,4	0,72	0,99	0,85	0,80	0,51	0,78

Table 5.6: Relative influence of the different parameters settings on the number of days that have more than one OR working in overtime of the proposed interventions. CP is the results when we use the current input parameters.

We remark that a decrease of the number of OR days per week to 13 days (intervention (iv)) gives far better results than shortening the regular working hours (intervention (ii) and (iii)). However, the outcomes for intervention (iii) when we use the current input parameters are higher for intervention (iii) than for the other interventions. Therefore, it is most likely that this intervention has the best relative difference.

5.5 Number of FTE

Decreasing the capacity of the OR department does not only positively influence the personnel satisfaction by equally spreading the workload during the day, it may also have financial benefits.

Changing the regular working hours does affect the personnel shifts. In this section, we try to give an overview of the necessary number of FTE, per intervention. We also show the financial results of the interventions. We focus on the number of FTE for anesthetic and surgical (nurses).

We calculate the financial benefits per FTE as follows:

$$s(v * 12x) \quad [3]$$

x = average gross monthly salary.

s = social costs = 30%

v = holiday pay = 8%

Key performance indicator / Intervention	Anesthetic (# FTE)	Surgical (# FTE)	Total financial benefit (€/yr)	Total
(cs)	10,6	17,7	-	
(i)	9,0	16,3	€154.284	1
(ii)	9,6	15,9	€146.439	0,93
(iii)	10,3	17,1	€47.069	0
(iv)	10,0	16,5	€94.139	0,44
(v)	10,1	16,7	€78.449	0,29

Table 5.7: Annual financial benefit for each intervention caused by a decrease in the number of FTE needed. The benefit is related to the current system

Table 5.7 presents per intervention the required number of FTE, and the financial benefits relating to the current system. The last column of Table 5.7 presents the score for the relative difference in annual financial benefit for each intervention.

5.6 Impact of the modification of the offline scheduling

As we described in Section 4.1.2.1, the current offline scheduling algorithm randomly selects patients from the waiting list for surgery. Due to this, scheduling of surgeries may not be optimal. To investigate the impact of this scheduling algorithm on the key performance indicators, we test intervention (vi) in combination with the other proposed interventions. Table 5.8 present the results.

Key performance indicator / Intervention	Utilization rate	Overtime frequency	Days with more than one OR in overtime
(cs)	75,0	29,3	8,7
(i)	82,5	40,4	14,5
(ii)	77,6	39,1	13,7
(iii)	80,4	33,0	12,5
(iv)	83,4	53,7	26,0
(v)	85,3	49,4	20,9

Table 5.8: Influence of a modification of the offline scheduling algorithm in combination with the proposed interventions

If we compare these results with the results we obtained with the current offline scheduling algorithm (See Table 5.2), we see some differences. To classify these differences, we use the method described in Section 5.1.

Key performance indicator / Intervention	Utilization rate	Overtime frequency	Days with more than one OR in overtime
(i)	0,95	1	1
(ii)	0,23	0,15	0,40
(iii)	0	0,36	0,06
(iv)	0,15	0,20	0,13
(v)	1	0	0

Table 5.9: Overall results for the interventions when using the modified offline scheduling algorithm. The numbers indicate the rank for the relative difference in comparison to the current system. The higher the value, the better the relative difference (Max=1).

Table 5.9 present the results. These results are included in the overall results per performance indicator. Remarkable is that intervention (i) gives the best results, whereas for the other scenarios this intervention does not score very well. As we mentioned in Section 3.2, for an 33% overtime probability we need an OR shift of 485 minutes. Probably this desired probability can only be obtained with an optimal surgery schedule, instead of a random selection.

5.7 Overall results

In the previous sections we elaborated the results of the proposed interventions by simulation various scenarios. In this section we give an overview of the results by elaborating the results of the separate objective parts. As we already mentioned, the unit manager has indicated that all criteria are equally important. The results we obtained in the previous sections are based on possible new circumstances that we may expect. To give a complete overview, we should include the performance obtained with the current input parameters. Table 5.10 presents the overall results for the proposed interventions.

Key performance indicator / Intervention	**Utilization rate**	**Overtime frequency**	**>1day overtime**	**Financial benefit**	**Current input**	**Overall results**
(i)	0,75	0	0	1	0,67	0,17
(ii)	0,81	0,73	0,50	0,93	1	1
(iii)	0	0,75	0,43	0	0,92	0
(iv)	0,26	1	1	0,44	0	0,32
(v)	1	0,76	0,78	0,29	0,38	0,59

Table 5.10 : Overall results for the proposed interventions.

As Table 5.10 shows, intervention (ii) gives the best overall results (i.e. improves the objective the most). Also, for the current input parameters, this intervention performs the best. In the next chapter, we elaborate on the implementation of the interventions.

6 Implementation

In Chapter 5 we showed the results of our simulation study. The management of the OR department experiences a change of the input parameters, and implementation of one of the proposed interventions should lead to an improvement of the stated objective.

In this chapter we describe issues that we should pay attention to when we enter the implementation phase. First, we should indentify all stakeholders. Therefore, we perform a stakeholder analysis. We start with this stakeholder analysis in Section 6.1, where we describe the characteristics of each stakeholder and we describe possible issues the stakeholders might have with the interventions in Section 6.2. In Section 6.2.1 we also describe the process of implementation that is used for the problem that we dealt with in this research.

6.1 Stakeholder analysis

Stakeholders need to be strategically managed and taken into account in strategic, tactical, and operational decision taking: insufficient involvement of stakeholders and infrequent communication have been pointed out as one of the leading causes of project failure (Mitchell et al., 1997). We identify the following stakeholders:

1. Patients
2. Medical specialists
3. OR personnel
4. Management of the OR department
5. Board of the hospital

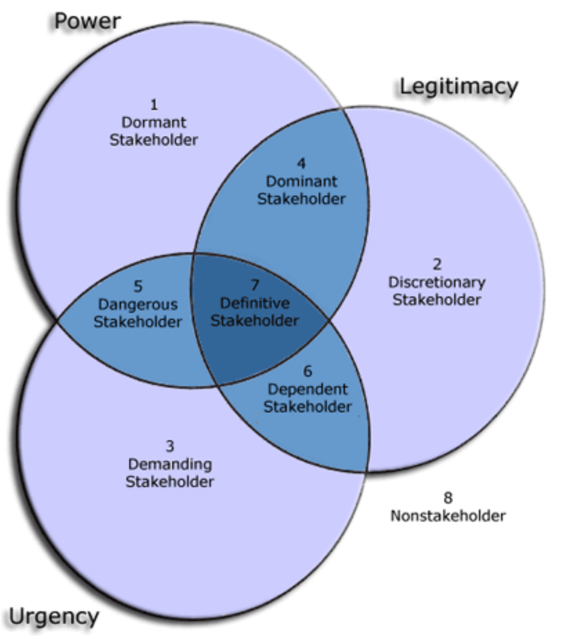


Figure 6.1: Overview of the stakeholder theory by Mitchell (1997)

We use the stakeholder theory of Mitchell et al., (1997), which defines stakeholder groups, and by which we are able to characterize the stakeholders in terms of urgency, power, and legitimacy. Table 6.1 gives an overview of the different types of stakeholders, depending on the combination of the three characteristics.

Stakeholder	**Power**	**Urgency**	**Legitimacy**	**Classification**
Patients	+	-	+-	Dormant/Dominant
Medical specialists	+	-	+	Dominant
OR personnel	-	++	++	Dependent
OR management	++	+	+	Definitive
Board of directors	+	+	+	Definitive

Table 6.1: Stakeholder characterization for the Thorax OR department

As Table 6.1 shows, both the management of the OR department and the board of directors of MST are definitive stakeholders. The management of the OR department is leading in the implementation phase, because they can accept or reject the proposed intervention.

We classify the medical specialists as dominant stakeholders, they have more power than the OR personnel, and more ability to influence the management. They have no urgency to implement an intervention that reduces the OR capacity, because the production requirement they set is achieved. In contrary to the medical specialists, the OR personnel has less power to influence the management of the OR department. The urgency for this stakeholder is present, because they possible change working shifts which has impact on their daily life.

Finally, we classify the patients as dormant or dominant stakeholders. Patients are better informed, and may choose their preference hospital to undergo surgery. If the Thorax Center Enschede has long waiting lists or bad service, patients choose another Thorax Center.

Based on this stakeholder analysis, we should carefully take into account all stakeholders preferences. However, the management of the OR department, together with the board of directors of MST is leading.

6.2 Implementation of the proposed interventions

In addition to the advantages and disadvantages related to the productivity of the OR department as we described in Chapter 5, there are also other consequences when implementing one of the proposed interventions.

The first problem arises with the elective patients that will encounter a higher number of disturbances in the elective program, resulting in postponement or cancellation of elective surgeries. Specialists and OR personnel encounter this problem. The second issue comprises decreasing the number of OR days per week. Surgeons may encounter problems when they are not able to operate in three ORs. As a consequence of the different opening hours of the ORs, communication between OR personnel, for instance to swap shifts, may suffer.

Third, scheduling of surgeries using planned slack requires a modification of the scheduling heuristics at the planning office. The planning office already uses a system that comprise historical operating times when scheduling surgeries and it should be a small step to incorporate planned slack with these historical times.

The board of the hospital, especially the works council of MST, should approve the change of the working shift of the personnel. Because this is a strategic decision, it should be taken carefully. Furthermore, all stakeholders should be informed about the plans to implement the interventions.

6.2.1 Current process of implementation

During the last phase of the execution of this research, the management decided that the implementation phase should already start. The management composes a project team to elaborate the proposed interventions. This project team consist of several employees of the Thorax OR department; one surgery assistant, one perfusionist, one anesthetic assistant, one surgeon, the unit manager of the OR department, and me. The goal of this project team is to deliver a sound recommendation to the management of which intervention should be implemented.

As project team, we choose to elaborate the three best interventions based on this research. We enumerate several advantages and disadvantages of the interventions, that are not only related to the productivity of the OR department; mainly social and financial aspects play a role here.

The next step is to inform the personnel of the OR department of our findings. We encounter major resistance in this group. Changing the regular working hours of the OR is correlated with a change of personnel shifts. Therefore, this influences also the personal life of personnel, which is a highly sensitive subject. To be able to include personnel preferences in the recommendation to the management, we set up a questionnaire where people can point out their preference.

The next step within the implementation is to analyze the questionnaires and include this in our recommendation. Subsequently, the management has to make the decision which intervention to implement.

In this chapter, we have performed a stakeholder analysis to indentify the stakeholders and described the issues that the stakeholders may deal with when implementing one of the proposed interventions. Because we already entered the implementation phase, we have described the steps we have taken so far. At this stage, the management has to decide which intervention to implement. The next step will possibly be to carry out a pilot with the chosen intervention. We will conclude this research in the next chapter, and give recommendations for further research.

7 Conclusions and recommendations

7.1 Conclusions

We refer back to the aim of the study which we defined in Chapter 1:

The aim of this research is to improve the utilization rate of the OR department, minimize overtime, and to find a solution for the perceived high workload by assessing alternative methods for surgery scheduling. We investigate the utilization rate of the OR department, the probability of overtime, the minimum capacity requirements, and the design of scenarios to test possible organizational interventions

An extensive performance analysis of the Thorax OR department of MST show three major points of interest that may cause the perceived low utilization rate and an unequally spread workload during the day. The first point is the high deviation in session time. Second, the analysis show that the utilization rate of the OR department is 78% (σ=15). In addition, sessions are often performed in overtime. The major finding of the performance analysis is the deviation of workload during the day and the number of personnel available during the day. Accordingly, the perception of unequally spread capacity usage during the day is justified.

The performed simulation study show that there are various interventions to improve the performance of the OR department. Based on the production requirements and a 33% accepted overtime probability, we have determined the minimal capacity requirements to be 508 minutes per day.

Because the Thorax OR department deals with long sessions with high variability, a change in the input parameters might influence the productivity. To test the robustness of the proposed interventions, we use scenarios that represent the various circumstances; a change of the number of elective or emergency patients, a change of the session duration, and a change of the offline scheduling algorithm.

If we look at the utilization rate, intervention (v) contributes the most to an improvement of the utilization rate. This intervention is the most robust for all changes in the input parameters, except for an increase in the number of patients. Shortening the regular working hours (intervention (ii) and (iii)) has better results when we increase the number of patients. Drawback of a major increase in the elective number of patients is that the number of cancellations also increases, which affect the patient satisfaction.

Intervention (iv) contributes the most to an improvement of the overtime indicators.

A change of the session time has more influence on the key performance indicators for each intervention than an increase in the number of patients. Especially a decrease of the session time has positive impact on the key performance indicators. For intervention (v), this gives the best results (i.e., the utilization rate is higher, and the overtime indicators are lower than for the current parameters). The second best results are obtained by intervention (ii).

An increase in the session duration leads to an increase in the utilization rate for each intervention, but gives the best results for intervention (v). Disadvantage of an increase in the session duration is that the overtime frequency is higher, and also the percentage of days that have more than one OR working in overtime is higher. Also, the number of cancellations grows according as the session duration increases.

Unlike we expected, the changeover times have large impact on the utilization rate and the overtime frequency of the OR department. If it can be reduced, this will positively influence the indicators. However, reducing the changeover time merely incorporates a change of the location where the work has to be performed and will therefore hardly contribute to a decrease of the workload.

Table 7.1 present the overall results of the proposed interventions.

Key performance indicator / **Intervention**	**Utilization rate**	**Overtime frequency**	**>1day overtime**	**Financial benefit**	**Current input**	**Overall results**
(i)	0,75	0	0	1	0,67	0,17
(ii)	0,81	0,73	0,50	0,93	1	1
(iii)	0	0,75	0,43	0	0,92	0
(iv)	0,26	1	1	0,44	0	0,32
(v)	1	0,76	0,78	0,29	0,38	0,59

Table 7.1: Overall results. A “0” means that this intervention scores the worst on this indicator. A “1” means that this intervention scores the best on this indicator. The remaining interventions are scaled based on their performance.

7.2 Recommendations

The focus of our research was the OR department. The OR department is, however, an integral part of the hospital and decisions made at the OR department have an influence on other departments. Specifically the ICU, and the wards are directly influenced by changes at the OR department. The board of MST should therefore take into account the influence of our recommendations on the performance of the rest of the hospital.

Based on the results of our simulation study, we recommend intervention (ii) to the management of the OR department. This intervention gives the best overall results, and is therefore the most robust to possible circumstances.

Because we have conflicting objective functions, the management should decide whether the separate indicators are equally important. Furthermore, the preferences of the personnel and the patients' preferences should also be carefully taken into account.

7.2.1 Recommendations for further research

It may be interesting to investigate whether there are seasonal influences on the type of surgeries and on the number of elective and emergency surgeries. However, for this to be possible we need data of multiple years.

We should investigate which of the input parameters (number of patients, change of the session duration) is difference in 2009. If the input parameters in 2009 show major differences, we possible should design and test additional interventions that contain combinations of the current designed interventions.

Currently, the OR department is dedicated to cardiothoracic surgery. The case mix of this specialty contains merely long sessions with high variability. The portfolio effect will hardly improve the surgery schedule. A more flexible hospital organization and cooperation between different surgical departments may improve the utilization rate of the OR department (van Houdenhoven et al., 2008). A drawback of shared capacity is that the use of ORs by various specialties has large organizational impact such as shared resources, the variety of personnel, and the dependence of other surgeon's session duration variability (van Houdenhoven et al., 2008).

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Appendices

Appendix A: Criteria for teaching hospitals

Teaching hospitals have to comply with several criteria related to research and teaching programs. The following 10 criteria are tested before a hospital is accredited as a teaching hospital:

1. The core business for the hospital is patient care. Every STZ-hospital offers high quality cure and care in a modernized and complete hospital, including regional center functions.

2. Top clinical care and top class care are important parts of the service of a hospital. The hospital has a ‘closed format IC’ with minimally one unit level 2 available.

3. Education and teaching is the second core business for the hospital.

4. The hospital guarantees trainings programs for co-assistants in minimally eight clinical disciplines. Also, training programs for research assistants must be available in at least 12 disciplines.

5. The hospital has professional teachers, trained by the ‘teach the teachers’ principle. There is an educational coordinator, and the facility must comply with several STZ criteria.

6. There is close cooperation with university medical centers during the education of research assistants and the co-assistants.

7. There is close cooperation with university medical centers and regional centers for education of nurses and paramedical education.

8. There are training programs for specialism’s which have high higher needs than the hospital can suffice, and for new education programs.

9. Scientific research is supported. There is space for clinical trials and patient related research, which result in scientific papers and recommendations.

10. Quality management is part of the policy of the hospital, in accordance with accepted systems for audit, management, accreditation and certifying, and patient satisfaction surveys.

Every STZ-hospital is tested by the STZ related to 22 criteria that are refining of above criteria.

Appendix B: Set of surgeries performed in 2008

At MST, surgeries are registered and planned via activity codes. Every activity code contains one or more codes that define the surgery performed. At the Thorax Center, around 60 workable codes exist. Normally, surgeries are registered via a single code. Because many complex surgeries are executed, it occurs that 2 or more activity codes are necessary to comprise all actions performed during surgery. Figure 1 displays the frequency of occurrence of all surgeries performed in 2008 that consist of 1 activity code. Figure 2 displays the frequency of occurrence of surgeries defined by 2 or more activity codes that occurs twice or more often. Finally, this appendix includes an overview of activity codes with their explanations.

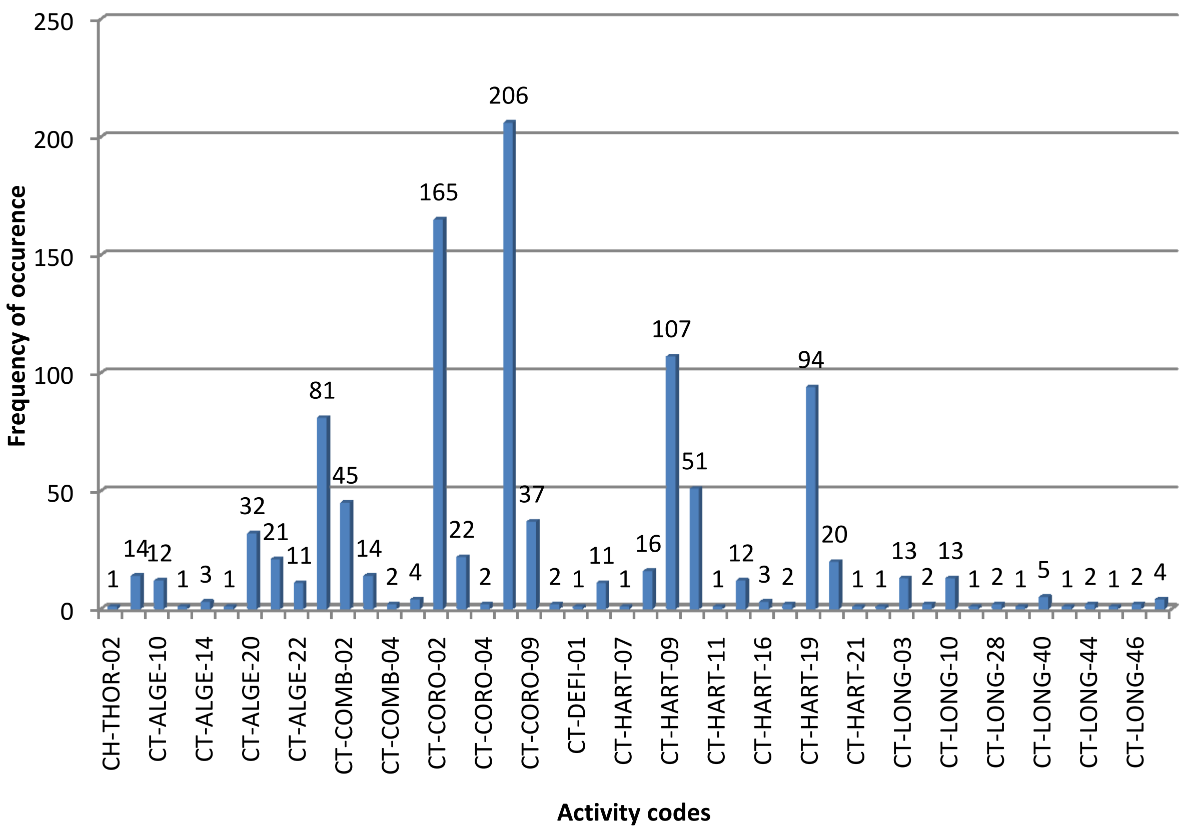

Figure 1: Frequency of occurrence per type of surgery. Only single types of surgeries are included. T=2008, n=1044. Source: Hospital data management system.

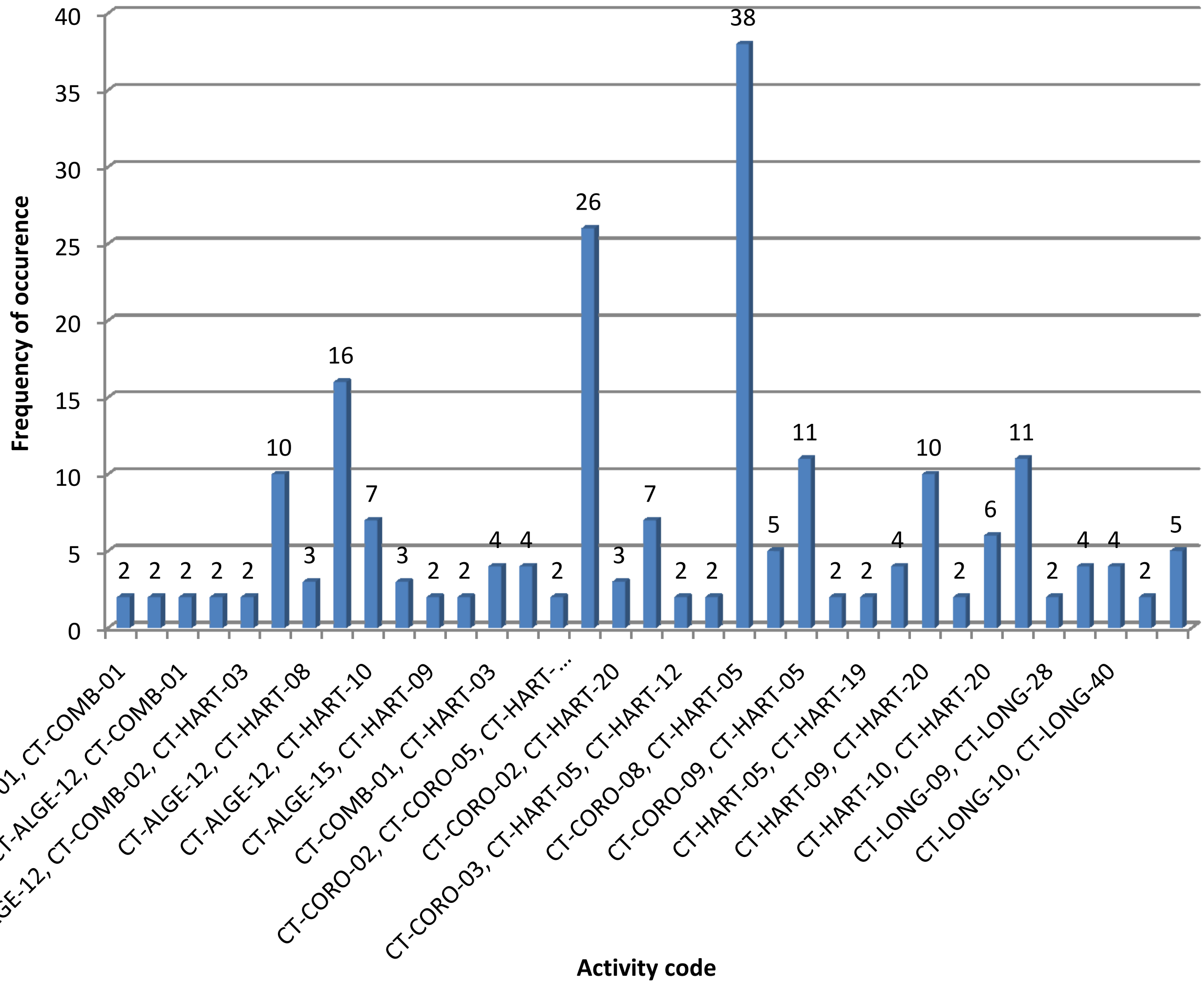

Figure 2: Frequency of occurrence per type of surgery. Only 2 activities or more are included. Combinations of activities that only occur once in 2008 are excluded. T=2008, n=283. Source: Hospital data management system

Thorax Center activity codes

CT-ALGE-01 = Reconstructie van de aorta of haar directe zijtakken zoals de arteria subclavia
CT-ALGE-02 = Operatie voor aneurysma(ta) of arterioveneuze fistel(s).
CT-ALGE-03 = Reconstructie van een perifere slagader dmv transplantaat endarteriectomie of patch
CT-ALGE-04 = Behandeling met cardioverter / Cardioversie
CT-ALGE-05 = Operatieve behandeling sternumfractuur.
CT-ALGE-06 = Correctie van een valvulaire aortastenose (commissurotomie)
CT-ALGE-07 = Correctie van een musculaire subvalvulaire aortastenose
CT-ALGE-08 = Correctie van partieel abnormale longvenen
CT-ALGE-09 = Correctie van abnormale coronairverbindingen o.a. fistels
CT-ALGE-10 = Thc – verv. aorta asc. en aortaboog en/of aorta desc. met of zonder aorta abdominalis
CT-ALGE-11 = Inbrengen electrode + uitwendige pacemaker door cardioloog of chirurg
CT-ALGE-12 = Toeslag bij recidief operatie (herh. van zelfde of gelijksoortige oper.) bij operaties met HLM
CT-ALGE-13 = Rethoracotomie met hart-longmachine tijdens dezelfde opname
CT-ALGE-14 = Aortadissectie met hart-longmachine
CT-ALGE-15 = Sluiten van een eenvoudig ventrikel-septum defect + plaatsen electrode(s)
CT-ALGE-16 = Correctie van een supravalvulaire aortastenose + plaatsen electrode(s)
CT-ALGE-17 = Correctie van een subvalvulaire membraneuze aortastenose + plaatsen electrode(s)
CT-ALGE-18 = Operatie recidief coarctatio aortae
CT-ALGE-19 = Reconstructie van perifere slagader zonder transplantaat.
CT-ALGE-20 = Wondtoilet
CT-ALGE-21 = Thoraxwandreconstructie / NUSS
CT-ALGE-22 = Staaldraden sternum verwijderen
CT-ALGE-23 = Aneurysma Aorta
CT-COMB-01 = Open Commissurotomie met plastiek van een klep + aortacoronaire bypass
CT-COMB-02 = Open Commissurotomie met vervanging van een klep + aortacoronaire bypass
CT-COMB-03 = Open Commissurotomie met plastiek of vervanging van 2 kleppen + aortacor. bypass
CT-COMB-04 = Open Commissurotomie met plastiek of vervanging van 3 kleppen + aortacor. bypass
CT-CORO-01 = Aortocoronaire bypass-graft enkelvoudig met hart-longmachine

CT-CORO-02 = Multipele aortocoronaire bypass-grafts (2 of 3) zonder hart-longmachine
CT-CORO-03 = Multipele aortocoronaire bypass-graft (2 of 3) met hart-longmachine
CT-CORO-04 = Res. aneurysma van de linker ventr. met hart-long machine
CT-CORO-05 = Resectie aneurysma van de linkerventrikel + plaatsen electrode(s)
CT-CORO-08 = Multipele aortocoronaire bypass-grafts (4 of meer) zonder hart-longmachine
CT-CORO-09 = Multipele aortocoronaire bypass-grafts (4 of meer) met hart-longmachine
CT-CORO-12 = Aortocoronaire bypass-graft enkelvoudig zonder hart-longmachine
CT-CORO-14 = Aortocoronaire bypass-graft in dezelfde zitting als andere verrichting met HLM
CT-DEFI-01 = Implanteren of vervangen ICD door chirurg
CT-DEFI-02 = Verwijderen ICD door chirurg
CT-HART-01 = Openen hartzakje zonder hartingreep evt. drainage v. pericarditis via een thoracotomie
CT-HART-02 = Open commissurotomie arteria pulmonalis of aorta
CT-HART-03 = Ballonpomp per punctie als bijkomende ingreep
CT-HART-05 = Plaatsen epicardiale electr. na openen pericard door chirurg + uitw. PM (tijdens oper
CT-HART-06 = Klepvervanging in dezelfde zitting als een andere verrichting met HLM + plaatsen electr
CT-HART-07 = Open commissurotomie met plastiek of verv. van 3 kleppen + plaatsen electrode(s)
CT-HART-08 = Open commissurotomie met plastiek of verv. van 2 kleppen + plaatsen electrode(s)
CT-HART-09 = Open commissurotomie met vervanging van een klep + plaatsen electrode(s)
CT-HART-10 = Open commissurotomie met plastiek van een klep + plaatsen electrode(s)
CT-HART-11 = Sluiten van een atrium-septum defect type 2 + plaatsen electrode(s)
CT-HART-12 = Ballonpomp per open procedure als bijkomende ingreep
CT-HART-13 = Ballonpomp per open procedure als zelfstandige ingreep
CT-HART-14 = Aortaklepvervanging + aneurysma aorta ascendens + plaatsen electrode(s)
CT-HART-15 = Ballonpomp per punctie als zelfstandige ingreep
CT-HART-16 = Partiële pericardresectie via vats.
CT-HART-17 = Partiële pericardresectie via thoracotomie.
CT-HART-18 = Subtotale pericardresectie via midsternaal.
CT-HART-19 = Rethoracotomie zonder hart-longmachine tijdens dezelfde opname.
CT-HART-20 = Maze cardio-invasieve interv. van hartritmestoorn. mbv cath. ablatie + plaatsen electr.
CT-HART-21 = Operatie wegens een perforerende hartverwonding.

CT-HART-22 = Operatie voor ziekte van ebstein inclusief klepvervanging
CT-HART-23 = Verwijderen tumor hartzakje
CT-HART-24 = Verwijderen tumor atrium (myxoom)
CT-HART-25 = Verwijderen tumor ventrikel (myxoom)
CT-LONG-01 = Trachearesectie eventueel met larynx mobilisatie.
CT-LONG-02 = Diagnostische thoracoscopie al dan niet met strengdoorbranding
CT-LONG-03 = Mediastinoscopie.
CT-LONG-04 = Hoofdcarina reconstructie.
CT-LONG-05 = Sleeve resectie.
CT-LONG-06 = Hechten bronchusruptuur.
CT-LONG-07 = Diagnostische bronchoscopie incl. afnemen materiaal voor onderzoek
CT-LONG-08 = Bilaterale bullectomie midsternaal.
CT-LONG-09 = Bullectomie met partiële pleurectomie
CT-LONG-10 = Lobectomie of segmentresectie
CT-LONG-11 = Wigresectie
CT-LONG-12 = Endoscopische longbiopsie
CT-LONG-13 = Endoscopische pneumonectomie met lymfklieruitruiming
CT-LONG-14 = Endoscopische pneumonectomie
CT-LONG-15 = Endoscopische pleuro-pneumonectomie evt. intracard.
CT-LONG-16 = Endoscopische wigresectie
CT-LONG-17 = Endoscopische lobectomie of segmentresectie
CT-LONG-18 = Endoscopische bullectomie met partiële pleurectomie
CT-LONG-19 = Para-aortale lymfklieruitruiming
CT-LONG-20 = Conservatieve behandeling eenvoudige halswervel fractuur.
CT-LONG-21 = Correctie van een infundibulaire en/of valvulaire pulmonalisstenose
CT-LONG-22 = Trachearesectie met inhechten prothese
CT-LONG-23 = Trachearesectie met re-implantatie linker hoofdbronchus
CT-LONG-24 = Sluiten bronchusfistel via vats
CT-LONG-25 = Sluiten bronchusfistel via thoracotomie
CT-LONG-26 = Sluiten bronchusfistel via bronchoscopie
CT-LONG-27 = Extrapleurale pneumolyse
CT-LONG-28 = VATS (video-assisted thoracic surgery)
CT-LONG-29 = Endoscopische decorticatie long

CT-LONG-30 = Endoscopische verw. corpora aliena pleuraholte
CT-LONG-31 = Proefthoracoscopie
CT-LONG-32 = Endoscopische ok empyema thoracis
CT-LONG-33 = Bilaterale resectie midsternaal.
CT-LONG-34 = Pleuro-pneumonectomie evt. intracardiaal
CT-LONG-35 = Pneumonectomie
CT-LONG-36 = Pneumonectomie met lymfklieruitruiming
CT-LONG-37 = Aanleggen pneumothorax
CT-LONG-38 = Open longbiopsie.
CT-LONG-39 = Ok empyema thoracis
CT-LONG-40 = Proefthoracotomie.
CT-LONG-41 = Het spoelen van een empyeemholte mbv intrathoracale zuigdrain
CT-LONG-42 = Sluiten bronchusfistel eventueel midsternaal.
CT-LONG-43 = Verwijderen corpora aliena pleuraholte
CT-LONG-44 = Mediastinotomie.
CT-LONG-45 = Operatie van een of meerdere mediastinumtumoren
CT-LONG-46 = Decorticatie long
CT-LONG-47 = Sluiten open thoraxverwonding.
CT-LONG-48 = Pleurabiopsie.
CT-LONG-49 = Diagnostische pleurapunctie.
CT-PACE-01 = Plaatsen epicardiale electrode na openen pericard door chirurg
CT-PACE-02 = Plaatsen epicardiale electrode na openen pericard door cardioloog
CT-PACE-03 = Inbrengen electrode + subcutane pacemaker door cardioloog of
CT-PACE-04 = Aandeel cardioloog - inbrengen electrode + subcutane pacemaker
CT-PACE-05 = Aandeel chirurg - inbrengen electrode + subcutane pacemaker
CT-PACE-06 = Aandeel cardioloog - bevestigen electrode op epicard na openen
CT-PACE-07 = Aandeel chirurg - bevestigen electrode op epicard na openen
CT-PACE-08 = Inbrengen 2 electroden + subcutaan geplaatste pacemaker door chirurg
CT-PACE-09 = Inbrengen 2 electroden + subcutaan geplaatste pacemaker door cardioloog
CT-PACE-10 = Aandeel cardioloog - Inbrengen 2 electroden + aansluiten subcut
CT-PACE-11 = Aandeel chirurg - Inbrengen 2 electroden + aansluiten subcut
CT-PACE-12 = Aandeel cardioloog - plaatsen 2 electroden op epicard na openen
CT-PACE-13 = Aandeel chirurg - plaatsen 2 electroden op epicard na openen

CT-PACE-14 = Vervangen of verwijderen pacemaker door chirurg
CT-PACE-15 = Vervangen of verwijderen pacemaker door cardioloog
CT-PACE-16 = Plaatsen epicard electrode + subcutane pacemaker door cardioloog
CT-PACE-17 = Pacemaker (declaratie voor ziekenhuis)
CT-PACE-18 = 1 draads pacemaker (declaratie voor ziekenhuis)
CT-PACE-19 = 2 draads pacemaker (declaratie voor ziekenhuis)
CT-PACE-20 = Biventriculaire pacemaker (declaratie voor ziekenhuis)

Appendix C: Organizational chart of MST

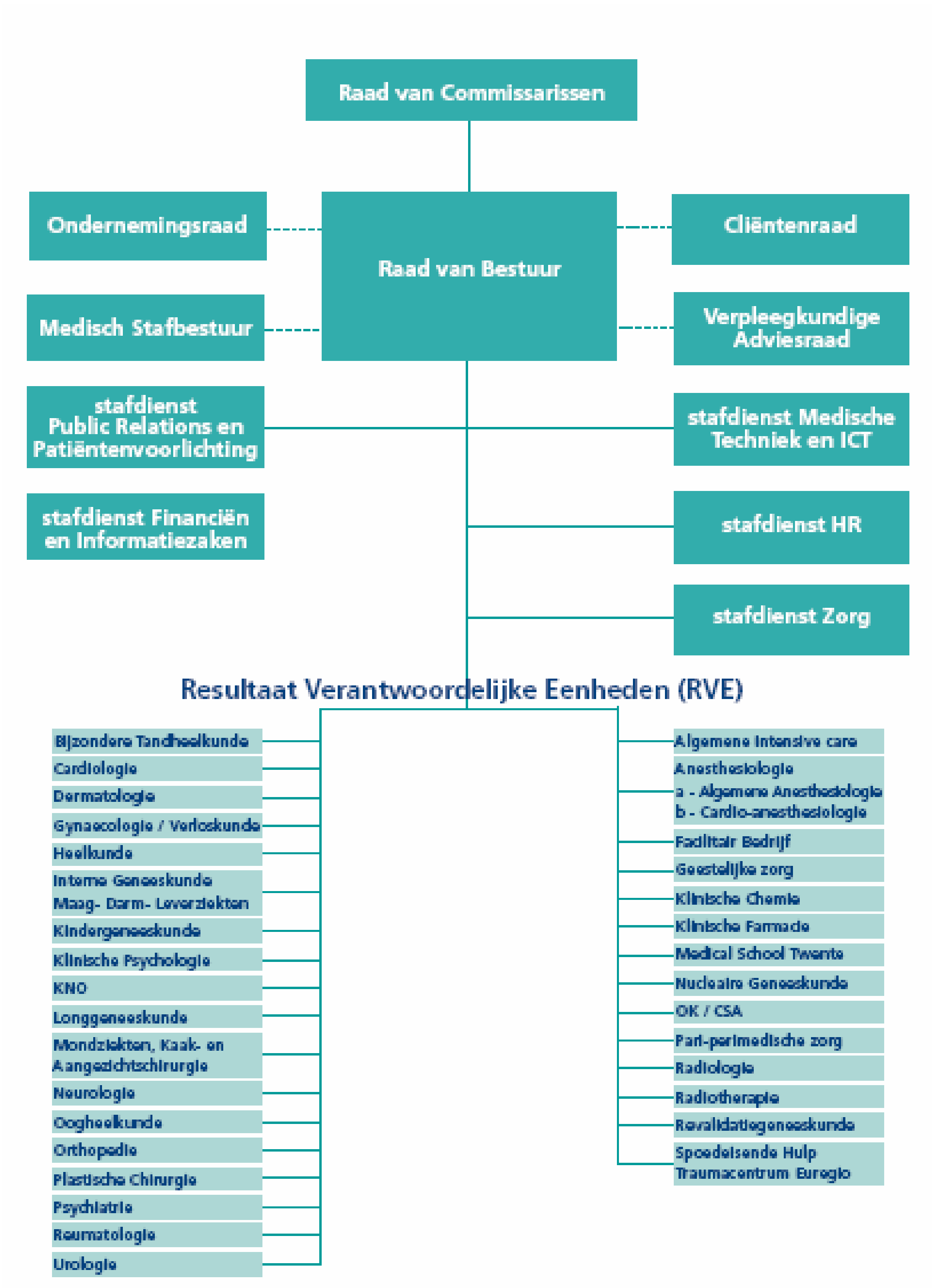

Figure 1: Organizational chart of MST, 2009.

Appendix D: Performance indicators

In this appendix definitions of performance indicators will be given. These performance indicators are used to determine the productivity of the operating department of the Thorax Center (Hoorn, 2008).

Parameters

$$T = days\ (t = 1, \dots, T) \quad [4]$$

$$K = ORs\ (k = 1, \dots, K) \quad [5]$$

$$C_{kt} = capacity\ of\ OR\ k\ on\ day\ t \quad [6]$$

$$I_{kt} = set\ of\ sessions\ of\ ORday\ (k,t)\ (i = 1, \dots, I_{kt}) \quad [7]$$

$$S_{ikt} = start\ time\ of\ session\ i\ of\ ORday\ (k,t) \quad [8]$$

$$D_{ikt} = realized\ surgery\ duration\ of\ session\ i\ of\ ORday\ (k,t) \quad [9]$$

$$E_{ikt} = S_{ikt} + D_{ikt}\ (\ departure\ time\ of\ patient\ of\ session\ i\ of\ ORday\ (k,t)) \quad [10]$$

$$B_{kt} = starting\ time\ of\ ORday\ (k,t) \quad [11]$$

$$X_{kt} = B_{kt} + C_{kt}\ (\ end\ of\ ORday\ (k,t)) \quad [12]$$

$$H_{ikt} = planned\ surgery\ duration\ of\ session\ i\ of\ ORday\ (k,t) \quad [13]$$

$$I'_{kt} = set\ of\ sessions\ for\ which\ \ B_{kt} < S_{ikt} \leq X_{kt} \quad [14]$$

$$N_{ikt} = \begin{cases} 1\ if\ S_{ikt} < B_{kt} \\ 0\ otherwise \end{cases} = early\ start\ of\ the\ day \quad [15]$$

$$M_{ikt} = \begin{cases} 1\ if\ S_{ikt} = \min\limits_{i \in I'_{kt}} S_{ikt} \\ 0\ otherwise \end{cases} \quad [16]$$

$$= late\ start\ of\ first\ session\ within\ regular\ working\ hours$$

$$O_{ikt} = \begin{cases} 1 \; if \; S_{ikt} \leq X_{kt} \cap E_{ikt} > X_{kt} \\ 0 \; otherwise \end{cases} = session \; in \; overtime \quad [17]$$

$$W_{ikt} = \begin{cases} 1 \; if \; i > 1 \cap \; X_{kt} \geq S_{ikt} \; \cap B_{kt} < E_{i-1,kt} \\ 0 \; otherwise \end{cases} \quad [18]$$

$$= changeover \; time \; between \; consecutive \; sessions \; on \; ORday \; (k, t)$$

$$W^{+}{}_{ikt} = \begin{cases} 1 \; if \; i > 1 \cap \; X_{kt} \geq S_{ikt} \; \cap B_{kt} < E_{i-1,kt} \; \cap S_{ikt} > E_{i-1,kt} \\ 0 \; otherwise \end{cases} \quad [19]$$

$$= \; positive \; changeover \; time \; between \; consecutive \; sessions \; on \; ORday \; (k, t)$$

$$Y_{ikt} = \begin{cases} 1 \; if B_{kt} - 30 \; minutes \; \leq \; S_{ikt} \leq \; X_{kt} \\ 0 \; otherwise \end{cases} \quad [20]$$

$$= start \; within \; regular \; working \; time (or \; 30 \; minutes \; before)$$

$$Z_{ikt} = \begin{cases} 1 \; if (B_{kt} \; \leq \; S_{ikt} \leq \; X_{kt} \cup B_{kt} \leq E_{ikt} \leq X_{kt}) \cup (S_{ikt} < B_{kt} \cap E_{ikt} > X_{kt}) \\ 0 \; otherwise \end{cases} \quad [21]$$

$$= session \; within \; regular \; working \; time$$

[note: in the above equations, a session is defined as a surgery performed on a patient on a single day, i.e. more than one activity can be performed in that session, and a patient can come for surgery more than once a day]

OR day

Combination of a date and an operating room at which at least one surgery is performed. Weekend are not taken into account.

$$OR_{kt} = \begin{cases} 1 \; if \; \sum_{i} Z_{ikt} > 0 \\ 0 \; otherwise \end{cases} \quad [22]$$

Net utilization

Numerator: duration of surgeries which start within regular working time or half an hour before. *(Duration counts within regular working time)*

Denumerator: difference between start and end of regular working time * number of OR days.

$$U_n = \frac{\sum_t \sum_k \sum_i Y_{ikt}\{min(X_{ikt}, E_{ikt}) - S_{ikt}\}}{\sum_t \sum_k C_{kt}} \quad [23]$$

Gross norm utilization

Numerator: cumulative session duration withing regular working time + number of sessions within regular working time - 1 *10 minutes.

Denumerator: difference between start and end of regular working time.

$$U_{gn} = \frac{\sum_t \sum_k (\sum_i Z_{ikt}(min(X_{ikt}, E_{ikt}) - max(S_{ikt}, B_{kt})) + ((\sum_i Z_{ikt}) - 1) * 10\ minutes)}{\sum_t \sum_k C_{kt}} \quad [24]$$

Gross utilization

Numerator: cumulative session duration withing regular working time + cumulative positive changing times within regular working time.

Denumerator: difference between start and end of regular working time.

$$U_g = \frac{\sum_k \sum_t (\sum_i Z_{ikt}(min(X_{ikt}, E_{ikt}) - max(S_{ikt}, B_{kt})) + \sum_i max(W^+{}_{ikt}, 0))}{\sum_t \sum_k C_{kt}} \quad [25]$$

Overtime duration

Numerator: sum of periods between end of regular working time and departure of operating room which start at last within regular working time.

Denumerator: number of OR days at which overtime occurs.

$$O_d = \frac{\sum_t \sum_k \sum_i O_{ikt}\ (E_{ikt} - X_{kt})}{\sum_t \sum_k \sum_i O_{ikt}} \quad [26]$$

Overtime frequency

Numerator: number of OR days at which overtime occurs.

Denumerator: number of OR days which count for utilization.

$$O_f = \frac{\sum_t \sum_k \sum_i O_{ikt}}{\sum_t \sum_k \max_{i \in I_{kt}} Z_{ikt}} \quad [27]$$

End-of-day vacancy duration

Numerator: sum of periods between departure of operating room and end of regular working time which start at last within regular working time.

Denumerator: number of OR days at which end-of-day vacancy is determined.

$$V_d = \frac{\sum_t \sum_k \left\{ \min_{i \in I_{kt}} (Z_{ikt}(1 - O_{ikt})(X_{kt} - E_{ikt})) \right\}}{\sum_t \sum_k (1 - \sum_i O_{ikt})} \quad [28]$$

End-of-day vacancy frequency

Numerator: number of OR days at which end-of-day vacancy is determined.

Denumerator: number of OR days which count for utilization.

$$V_f = \frac{\sum_t \sum_k (1 - \sum_i O_{ikt})}{\sum_t \sum_k \max_{i \in I_{kt}} Z_{ikt}} \quad [29]$$

Early start duration

Numerator: sum of periods between arrival of surgery and start regular working time from surgeries which start the first of that day.

Denumerator: number of day early start has been determined.

$$ES_d = \frac{\sum_t \sum_k \sum_i Z_{ikt} N_{ikt} (B_{kt} - S_{ikt})}{\sum_t \sum_k \sum_i Z_{ikt} N_{ikt}} \quad [30]$$

Late start frequency

Numerator: number of day late start has been determined.

Denumerator: number of OR days which count for utilization .

$$LS_f = \frac{\sum_t \sum_k \sum_i M_{ikt}}{\sum_t \sum_k \max_{i \in I_{kt}} Z_{ikt}} \qquad [31]$$

Late start duration

Numerator: sum of periods between start regular working time and arrival of surgery from surgeries which start the first of that day.

Denumerator: number of day late start has been determined.

$$LS_d = \frac{\sum_t \sum_k \sum_i M_{ikt}(S_{ikt} - B_{kt})}{\sum_t \sum_k \sum_i M_{ikt}} \qquad [32]$$

Late start frequency

Numerator: number of day late start has been determined.

Denumerator: number of OR days which count for utilization.

$$LS_f = \frac{\sum_t \sum_k \sum_i M_{ikt}}{\sum_t \sum_k \max_{i \in I_{kt}} Z_{ikt}} \qquad [33]$$

Changeover times positive

Numerator: sum of positive periods between departure of session i-1 and arrival of session i within regular working time.

Denumerator: number of times positive changeovers occurs within regular working time.

$$W_p = \frac{\sum_t \sum_k \sum_i {W^+}_{ikt}(S_{ikt} - E_{i-1,kt})}{\sum_t \sum_k \sum_i ({W^+}_{ikt})} \qquad [34]$$

Changeover times overall

Numerator: sum of periods between departure of session i-1 and arrival of session i within regular working time.

Denumerator: number of times changeover occurs within regular working time.

$$W_p = \frac{\sum_t \sum_k \sum_i W_{ikt}(S_{ikt} - E_{i-1,kt})}{\sum_t \sum_k \sum_i (W_{ikt})} \qquad [35]$$

Changeover frequency

Numerator: number of sessions within regular working time – number of OR days which count for utilization.

Denumerator: number of OR days which count for utilization.

$$W_f = \frac{\sum_k \sum_t \left\{ \left(\sum_i Z_{ikt}\right) - \max_{i \in I_{kt}} Z_{ikt} \right\}}{\sum_t \sum_k \max_{i \in I_{kt}} Z_{ikt}} \qquad [36]$$

Absolute deviation from planning

|realized – expected|/expected*100%

$$P_a = \frac{\sum_k \sum_t \sum_i |D_{ikt} - H_{ikt}|}{\sum_k \sum_t \sum_i H_{ikt}} * 100\% \qquad [37]$$

Average deviation from planning

(realization – expectation) /expected*100% for sessions that take place within regular working time.

$$P_m = \frac{\sum_k \sum_t \sum_i Z_{ikt}(D_{ikt} - H_{ikt}\ )}{\sum_k \sum_t \sum_i H_{ikt} Z_{ikt}} * 100\% \qquad [38]$$

Appendix E: Performance measurements

E.1 Net Utilization per OR

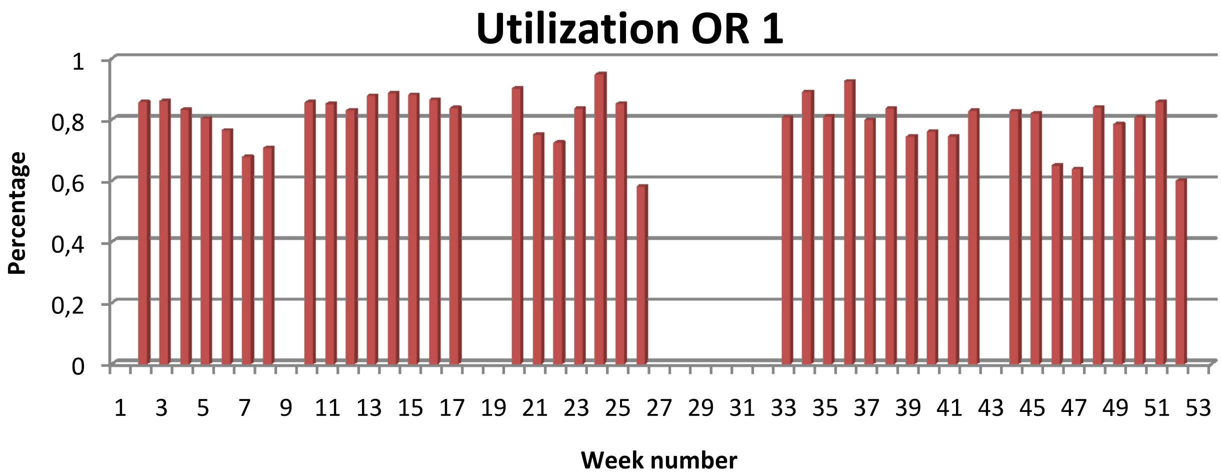

Figure 2: Net utilization rate of OR1. Reduction periods are not taken into account. T=2008, n=252. source: Hospital data management system

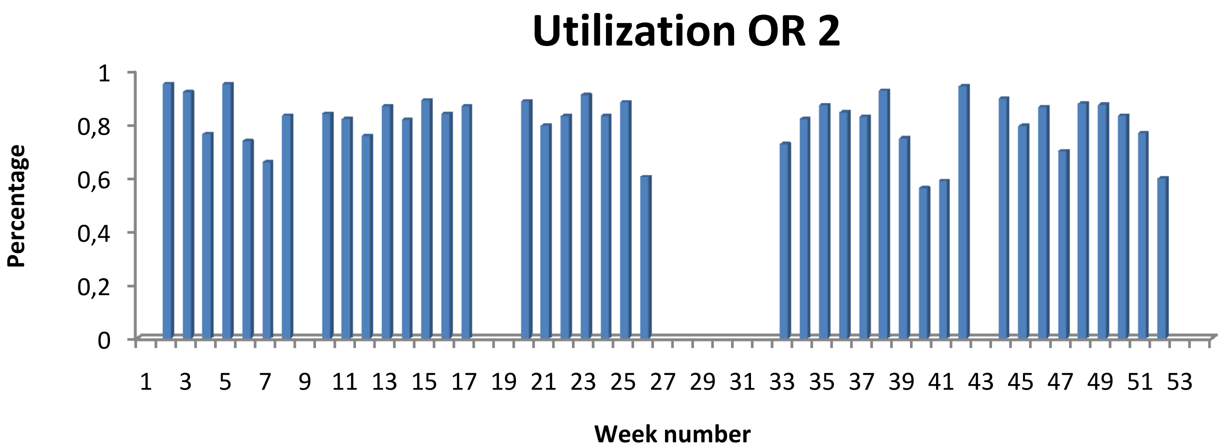

Figure 3: Net utilization rate of OR2. Reduction periods are not taken into account. T=2008, n=252. Source: Hospital data management system

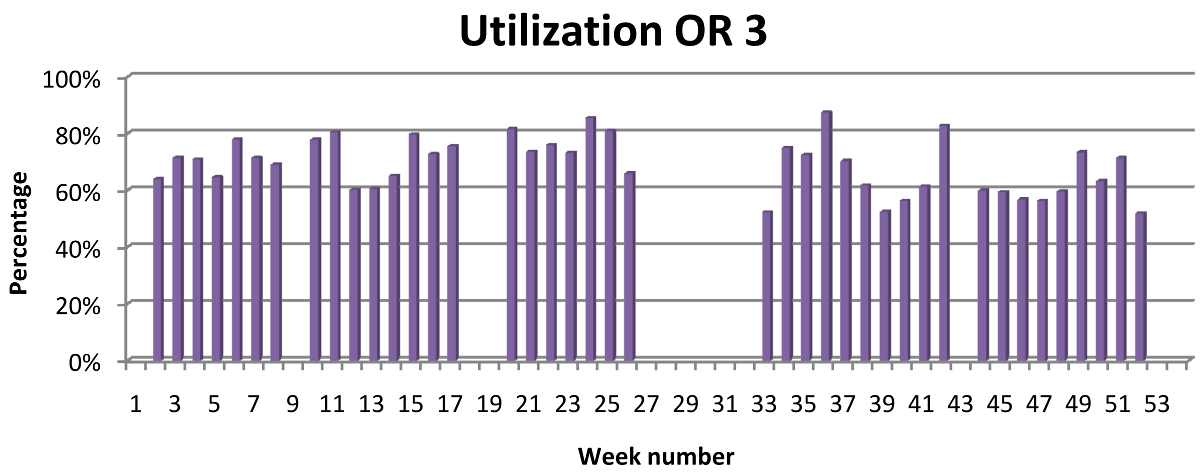

Figure 4: Net utilization rate of OR3. Reduction periods are not taken into account. T=2008, n=232. source: Hospital data management system.

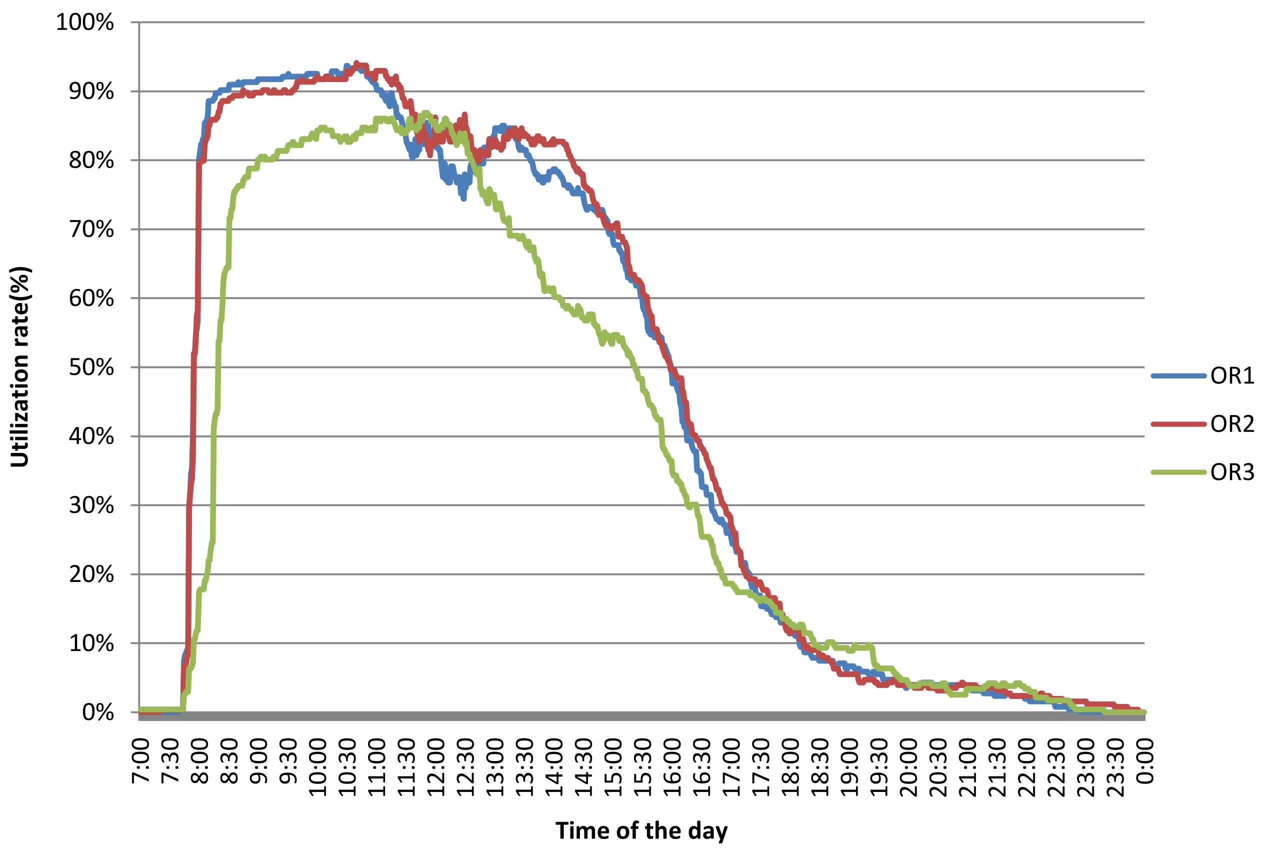

Figure 5: Net utilization rate per OR during the day. Nightly hours are not taken into account. T=2008, n=712. Source, hospital data management system

Appendix F. OR Division

		i			ii			iii			iv			v		
OR division		**min**	**start OR shift**	**End OR shift**	**min**	**start OR shift**	**End OR shift**	**min**	**start OR shift**	**End OR shift**	**min**	**start OR shift**	**End OR shift**	**min**	**start OR shift**	**End OR shift**
Monday	OR1	480	7:45	15:45	510	7:45	16:15	540	7:45	16:45	540	7:45	16:45	540	7:45	16:45
	OR2	480	7:45	15:45	510	7:45	16:15	540	7:45	16:45	540	7:45	16:45	540	7:45	16:45
	OR3	480	7:45	15:45	510	7:45	16:15	540	7:45	16:45				360	9:00	15:00
Tuesday	OR1	480	7:45	15:45	510	7:45	16:15	540	7:45	16:45	540	7:45	16:45	540	7:45	16:45
	OR2	480	7:45	15:45	510	7:45	16:15	540	7:45	16:45	540	7:45	16:45	540	7:45	16:45
	OR3	480	7:45	15:45	510	7:45	16:15	540	7:45	16:45	540	7:45	16:45	360	9:00	15:00
Wednesday	OR1	480	7:45	15:45	510	7:45	16:15	540	7:45	16:45	540	7:45	16:45	540	7:45	16:45
	OR2	480	7:45	15:45	510	7:45	16:15	540	7:45	16:45	540	7:45	16:45	540	7:45	16:45
	OR3	480	7:45	15:45	510	7:45	16:15							360	9:00	15:00
Thursday	OR1	480	7:45	15:45	510	7:45	16:15	540	7:45	16:45	540	7:45	16:45	540	7:45	16:45
	OR2	480	7:45	15:45	510	7:45	16:15	540	7:45	16:45	540	7:45	16:45	540	7:45	16:45
	OR3	480	7:45	15:45	510	7:45	16:15	540	7:45	16:45	540	7:45	16:45	360	9:00	15:00
Friday	OR1	480	7:45	15:45	510	7:45	16:15	540	7:45	16:45	540	7:45	16:45	540	7:45	16:45
	OR2	480	7:45	15:45	510	7:45	16:15	540	7:45	16:45	540	7:45	16:45	540	7:45	16:45
	OR3	480	7:45	15:45	510	7:45	16:15	540	7:45	16:45	540	7:45	16:45	360	9:00	15:00
Saturday																
Sunday																
Total capacity per week		**7200**			**7650**			**7560**			**7020**			**7200**		

Table 0.1: Or division for each interventions. The OR division specifies the openings hours and duration for every day during the week

Appendix G: Model building

G.1 Minimal capacity requirements

Currently, each operating room operates for precisely 540 minutes per day in regular working time. The management of the OR department has set the probability of approximately 67% that all surgeries are completed within regular time (33 % chance on overtime). We determine the necessary capacity as follows:

We have a set of surgeries I (with surgeries i), with μ_i and σ_i as the expected duration, and standard deviation of surgery i. X is the stochastic variable that represents the total surgery duration of all the surgeries in S. We assume that the surgery durations are mutually independent, and normally distributed. The expected total duration of the surgeries in S is:

$$E(X) = \sum_{i \in S} \mu_i \qquad [1]$$

The standard deviation of the duration of the surgeries in S is:

$$std(X) = \sqrt{\sum_{i \in S} \sigma_i^2} \qquad [2]$$

Because we assume that X is normally distributed, we can use equation [3] to determine the probability that surgeries are completed within regular working hours.

$$P(X \leq \sum_{i \in S} \mu_i + 0{,}43 * \sqrt{\sum_{i \in S} \sigma_i^2}) = 65{,}54\% \qquad [3]$$

To comply with a probability of 33% chance of overtime, the expected total surgery duration plus "α times the standard deviation of the total surgery duration" must not exceed the regular time of the OR (Hans, Douma, et al., 2008). In this case, we use a slack factor of 0,43 to comply with 33% chance of overtime.

In this capacity analysis, only session time is taken into account to determine the minimal capacity requirement. However, we have to include changeover time to get a realistic capacity approach. The current planning method does not give realistic changeover times; therefore we make the following assumptions:

The changeover time of a session varies from 10 until 30 minutes. We assume a normal distributed parameter, and we estimated parameters μ_i = 14,68 and σ_i = 6,08. Changeover times are independent of surgery type, and have the same frequency as the surgeries.

Equation [4] includes the changeover time.

$$P(\leq \sum_{i\in S}(\mu_i + \mu_{ichangeover}) + 0{,}43 * \sqrt{\sum_{i\in S}(\sigma_i^2 + \sigma_{ichangeover}^2)}) = 65{,}54\% \qquad [4]$$

Slack factor	Overtime probability (%)	Capacity requirement (minutes)
0,3	0,38	493,7
0,4	0,34	501,1
0,43	0,33	503,3
0,5	0,31	508,5
0,6	0,27	515,9

Table.0.2: Determination of the minimal capacity requirements per OR day based on different probabilities of overtime.

Table 1 indicates the minimal capacity requirements per OR day. These determinations include the emergency surgeries; nevertheless, they cannot be scheduled, and do not always occur in regular working hours. If we do not include the emergency surgeries in our capacity determination, we need an OR shift of 485, 12 minutes, with a 33% chance of overtime.

G.2 Set of surgeries

At MST, surgeries are registered and planned via activity codes. Every activity code contains one or more descriptions that define the surgery performed. At the Thorax Center, about 60 codes are being used. Usually, surgeries are registered via a single code. At the Thorax Center there are many surgery types that occur once or twice per year. These types mainly occur because of an unexpected intervention during the session. Accordingly, we do not know these interventions in advance, thus we label these surgery types as their main activity code.

Our data analysis showed a total of 1324 surgeries that has been performed in 2008. These 1324 surgeries can be subdivided in 151 different types. For our simulation model, we use clustering techniques that are used on the elective case mix to create a number of logistically and medically homogeneous surgery types. Logistical characteristics are length of stay and surgery duration; medical characteristics are diagnosis related groups and activity codes (van Oostrum, et al., 2009).

To define a set of recurrent standard case types we make the following assumptions:

- Each surgery type use the same type of resources
- Every surgery type, except for lung surgeries and the Nuss-procedure (minimally invasive pectus repair), can be executed by all surgeons
- Each surgery type has the same length-of-stay duration

These assumptions taken into account, we define our set of surgeries based on the activity code. Given an activity code, and the historical demand, we determine the percentage of occurrence per period. Table. 3 gives an overview of the set of surgeries we use in our simulation model.

Long name	**Short name (activity code)**	**ì (min)**	**ó (min)**	**Percentage**
Corrections main arteries	ALGE-10	386,33	127,52	1,97%
Valve recovery (1)/CABG	COMB-01	348,16	106,40	8,05%
Valve replacement (1)/CABG	COMB-02	313,60	90,24	4,27%
OPCAB	CORO-02	231,65	36,71	17,41%
CABG	CORO-09	278,18	58,63	7,14%
OPCAB	CORO-08	252,51	44,75	20,53%
Valve replacement (1)	HART-09	245,06	48,91	11,33%
Valve recovery (1)	HART-10	285,94	89,68	6,57%
Lung surgery	LONG	169,05	74,39	5,34%
Debridement	ALGE-21	156,39	48,13	1,89%
Heart surgeries-remaining	HART-OV	259,85	120,39	7,64%
Comb/Coro-remaining	COMB-OV	285,50	99,45	2,79%
Alge-remaining	ALGE-OV	77,92	45,33	5,09%

Table. 3: Set of standard recurring surgery types.

Appendix H: Calculations for the required number of FTE

In this appendix, we show the calculations that we performed to determine the required number of FTE for the OR department. For each intervention, this number is different. The first table for each intervention show the required numbed for the surgical personnel, the second table the required number for the anesthetic personnel. The last table gives the required number. Financial benefits are calculated in Section 5.5.

H.1 Current system (cs)

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
OR I	18	18	18	18	18		
OR II	18	18	18	18	18		
OR III	18	18	18	18	18		
Substitute	9	9	9	9	9		
OACV	9	9	9	9	9		
Weekend / Nightshift	19,56	19,56	19,56	19,56	19,56	30	30
Senior surgery complementary tasks	9	9					
	100,56	100,56	91,56	91,56	91,56	30	30

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
OR I	9	9	9	9	9		
OR II	9	9	9	9	9		
OR III	9	9	9	9	9		
Substitute	9	9	9	9	9		
Holding / ICD	9	9		9	9		
Weekend /	9,78	9,78	9,78	9,78	9,78	15	15
Senior anesthetic	9	9					
	63,78	63,78	54,78	54,78	54,78	15	15

	Surgery	Anesthetic
Total per week (hr)	535,8	321,9
Total per year(hr)	27.862	16.739
Net availability per FTE (hr/yr)	1.578	1.579
required number of FTE	17,66	10,60

H.2 Intervention i: shorten regular working hours

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
OR I	15	15	15	15	15		
OR II	15	15	15	15	15		
OR III	15	15	15	15	15		
Substitute	15	15	15	15	15		
OACV	7,5	7,5	7,5	7,5	7,5		
Weekend / Nightshift	16,56	16,56	16,56	16,56	16,56	30	30
Senior surgery complementary tasks	7,5	7,5					
	91,56	91,56	84,06	84,06	84,06	30	30

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
OR I	7,5	7,5	7,5	7,5	7,5		
OR II	7,5	7,5	7,5	7,5	7,5		
OR III	7,5	7,5	7,5	7,5	7,5		
Substitute	7,5	7,5	7,5	7,5	7,5		
Holding / ICD	7,5	7,5	7,5	7,5	7,5		
Weekend /	8,28	8,28	8,28	8,28	8,28	15	15
Senior anesthetic complementary	7,5	7,5					
	53,28	53,28	45,78	45,78	45,78	15	15

	Surgery	Anesthetic
Total per week (hr)	495,3	274,9
Total per year(hr)	25.756	14.243
Net availability per FTE (hr/yr)	1.578	1.578
required number of FTE	16,32	9,03

H.3 Intervention ii: shorten regular working hours

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
OR I	16	16	16	16	16		
OR II	16	16	16	16	16		
OR III	16	16	16	16	16		
Substitute	8	8	8	8	8		
OACV	8	8	8	8	8		
Weekend / Nightshift	17,56	17,56	17,56	17,56	17,56	30	30
Senior surgery complementary tasks	8	8					
	89,56	89,56	81,56	81,56	81,56	30	30

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
OR I	8	8	8	8	8		
OR II	8	8	8	8	8		
OR III	8	8	8	8	8		
Substitute	8	8	8	8	8		
Holding / ICD	8	8	8	8	8		
Weekend / Nightshift	8,78	8,78	8,78	8,78	8,78	15	15
Senior anesthetic complementary tasks	8	8					
	56,78	56,78	48,78	48,78	48,78	15	15

	Surgery	Anesthetic
Total per week (hr)	483,8	289,9
Total per year(hr)	25.158	15.075
Net availability per FTE (hr/yr)	1.578	1.578
Required number of FTE	15,94	9,55

H.4 Intervention iii: Decrease the number of OR days per week (14 days per week)

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
OR I	18	18	18	18	18		
OR II	18	18	18	18	18		
OR III	18	18		18	18		
Substitute	9	9	9	9	9		
OACV	9	9	9	9	9		
Weekend / Nightshift	19,56	19,56	19,56	19,56	19,56	30	30
Senior surgery complementary tasks	9	9					
	100,56	100,56	73,56	91,56	91,56	30	30

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
OR I	9	9	9	9	9		
OR II	9	9	9	9	9		
OR III	9	9		9	9		
Substitute	9	9	9	9	9		
Holding / ICD	9	9	9	9	9		
Weekend / Nightshift	9,78	9,78	9,78	9,78	9,78	15	15
Senior anesthetic complementary tasks	9	9					
	63,78	63,78	45,78	54,78	54,78	15	15

	Surgery	Anesthetic
Total per week (hr)	517,8	312,9
Total per year(hr)	26.926	16.271
Net availability per FTE (hr/yr)	1.578	1.578
required number of FTE	17,06	10,31

H.5 Intervention iv: Decrease the number of OR days per week (13 days per week)

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
OR I	18	18	18	18	18		
OR II	18	18	18	18	18		
OR III		18		18	18		
Substitute	9	9	9	9	9		
OACV	9	9	9	9	9		
Weekend / Nightshift	19,56	19,56	19,56	19,56	19,56	30	30
Senior surgery complementary tasks	9	9					
	82,56	100,56	73,56	91,56	91,56	30	30

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
OR I	9	9	9	9	9		
OR II	9	9	9	9	9		
OR III		9		9	9		
Substitute	9	9	9	9	9		
Holding / ICD	9	9	9	9	9		
Weekend / Nightshift	9,78	9,78	9,78	9,78	9,78	15	15
Senior anesthetic complementary tasks	9	9					
	54,78	63,78	45,78	54,78	54,78	15	15

	Surgery	Anesthetic
Total per week (hr)	499,8	303,9
Total per year(hr)	25.990	15.803
Net availability per FTE (hr/yr)	1.578	1.578
required number of FTE	16,47	10,01

H.6 Intervention v: Flexible OR, from 9:00 am to 3:00 pm

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
OR I	18	18	18	18	18		
OR II	18	18	18	18	18		
OR III	12	12	12	12	12		
Substitute	9	9	9	9	9		
OACV	9	9	9	9	9		
Weekend / Nightshift	19,56	19,56	19,56	19,56	19,56	30	30
Senior surgery complementary tasks	9	9					
	94,56	94,56	85,56	85,56	85,56	30	30

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
OR I	9	9	9	9	9		
OR II	9	9	9	9	9		
OR III	6	6	6	6	6		
Substitute	9	9	9	9	9		
Holding / ICD	9	9	9	9	9		
Weekend / Nightshift	9,78	9,78	9,78	9,78	9,78	15	15
Senior anesthetic complementary tasks	9	9					
	60,78	60,78	51,78	51,78	51,78	15	15

	Surgery	Anesthetic
Total per week (hr)	505,8	306,9
Total per year(hr)	26.302	15.959
Net availability per FTE (hr/yr)	1.578	1.578
required number of FTE	16,67	10,11