The allocation of emergency- and elective patients to operating rooms

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Foreword and acknowledgements

This master thesis project concludes my study Industrial Engineering and Management. About one year ago, I was looking for a master thesis project. Two of the courses I enjoyed most during the IEM curriculum are the courses on discrete-event simulation. Both are teached by Durk-Jouke van der Zee and Jos Bokhorst. I went to Durk-Jouke asking him for a master thesis project. Durk-Jouke sent me to the UMCG and after the first meeting with "the boys" from Zorglogistiek and Innovatie I decided to graduate on this project. And I never regretted it..

Besides the excellent supervision of Peer Goudswaard, Igor van der Weide and Tjibbe Hoogstins, I also enjoyed their company. I would like to thank them for their time and also for involving me in activities from bedrijfsbureau Sector E (including volleybal, sailing, running and a couple of "borrels"). When I had a question, they always had time for me and I learned a lot from all three of them. Also I'd like to thank all other people from the UMCG that helped me with my thesis, including anesthesiologist Peter Meyer.

The visits to Durk-Jouke were very valuable. During important phases of my research, Durk-Jouke was willing to have a meeting with me each week. I especially appreciate his help on the structuring of my thesis and his knowledge of simulation. Jos Bokhorst, my second supervisor, I met a couple of times. His remarks on my work were very useful and are incorporated in this final version. I would like to make use of this foreword to really thank both my supervisors.

Finally, I would like to thank my parents for making this study possible for me. Also all my friends that helped me in any way during my study, I would like to thank.

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Summary

This study evaluates eighteen operating rooms (OR's) of the operating centre of the University Medical Center Groningen (UMCG). Each year, about ten thousand patients are scheduled in one of those operating rooms. Besides these scheduled patients (i.e. elective patients), also emergency patients have to be operated at this operating centre. In order to make sure that (a) these emergency patients can be operated shortly after their arrival and (b) the schedules of elective patients are not disturbed by the arrival of emergency patients; capacity needs to be reserved for these emergency patients (i.e. emergency capacity). However, reserving too much capacity for these patients may cause valuable OR capacity not being used. On the other hand, cancellations and overtime of the elective programme occurs if too little emergency capacity is used.

The emergency patients are classified at the UMCG based on how urgent the need for surgery is: "urgent" (have to be operated within 24 hours), "spoed" (within 6 hours) and "acuut" (as soon as possible).The current method to allocate these so called USA-patients to operating rooms is by using two operating rooms for these emergency patients preferably, i.e. dedicated emergency rooms.
A recent publication showed that the performance on overtime, utilization and waiting times for emergency patients can be increased by dividing capacity for emergency patients among several operating rooms (Wullink, 2007). These OR's are defined as versatile rooms and both emergency and elective capacity are allocated to these operating rooms. This publication and the observation that the currently used dedicated emergency rooms are often underutilized led to the problem statement of this thesis: *(How) can the logistical performance of the operating room centre of the University Medical Center Groningen be improved by changing the method to allocate (capacity for) elective and emergency patients to operating rooms?*

In a literature research, two important choices in allocating emergency and elective capacity to operating rooms are observed:

- The proportion of elective capacity versus emergency capacity that is allocated to each operating room.
- The existence of the possibility of either operate emergency patients within OR-capacity that was originally assigned to elective patients, or operate elective patients within OR-capacity that was originally assigned to emergency patients.

Four systems can be identified using these two choices:

1. Dedicated emergency rooms system
2. Versatile operating rooms system
3. Hybrid system (a combination of the above two systems)
4. Emergency rooms with standby patients (elective patients that are prepared for surgery and can be at the operating centre within short time)

Discrete-event simulation is used to compare the systems given the context of the UMCG. In this simulation also operational decisions are modeled and experimented with. A simulation model that represents the current system is the current scenario. By changing the operational and tactical variables in the simulation model, alternative scenario's can be created.

No scenario outperforms the others given the set of KPI's (Overtime frequency and duration, utilization, waiting time, number of surgeries started after timeslot, throughput and cancellations).

A trade-off between KPI's is observed and therefore not one, but three alternative systems are proposed that improve efficiency compared to the current system:

1. Using no dedicated emergency rooms and allocate 700 minutes of emergency capacity among 7 versatile operating rooms to increase throughput.
2. Using no dedicated emergency rooms and allocate 920 minutes of emergency capacity among 7 versatile operating rooms to decrease overtime.
3. Keep the dedicated emergency OR's, but fill the empty capacity with "standby patients". Each time there are no emergency patients a standby patient that requires a short procedure is called.

The first scenario contains 700 minutes of emergency capacity. This amount is selected because this will lead to an amount of overtime that is the same as the simulation model of the current scenario (i.e. base case). However in this scenario, 4% more elective patients are operated compared to the base case. The second scenario contains an amount of emergency capacity that is similar to the amount of capacity of two dedicated emergency rooms (i.e. the currently used amount of emergency capacity). In this scenario, the amount of operated elective patients is similar to the base case. The average overtime frequency in this scenario is reduced with: 7%. The third proposed scenario leads to an increase of 5% in elective surgeries (using patients that require a short procedure of one hour). Negative effect of this system is that overtime duration will slightly increase: 3%.

The simulation revealed another way to improve one or more performance indicators. Late start and planning deviation had significant impact on the results. Improving both factors could decrease average overtime up to 60% theoretically.

Glossary

Acuut	Emergency patient status, a patient that is assigned this status (i.e. an acute patient) has to be operated as soon as possible.
Dedicated emergency room	An operating room that is assigned only emergency capacity.
Dedicated operating rooms system	A capacity allocation system where at least one dedicated operating room is used and no versatile operating rooms.
Elective capacity	Time that is allocated to the operating rooms, that is used by departments to operate elective patients.
Elective patient	A patient that requires surgery, but the surgery can be postponed more than 24 hours.
Emergency capacity	Time that is allocated to the operating rooms, that is used by departments to operate emergency patients.
Emergency operating rooms	A dedicated operating rooms system where emergency capacity can be filled with standby patients.
Emergency patient	A patient that requires surgery within 24 hours.
Hybrid system	A capacity allocation system where at least one versatile operating room and at least one dedicated emergency room.
KPI	Key Performance indicator.
OKplus	The software package that is used at the UMCG to register surgeries.
OR	Operating room.
OR Day	Any combination of a date and operating room where, on that day, at least one surgery is performed.
OZO	Operatieve Zorg Organisatie.
Planning offices	The office that is responsible for the planning of elective patients of a certain department (“planbureaus”).
Planned overtime	Sometimes, departments are allowed to perform surgery that is anticipated to end after the end of the timeslot, this is planned overtime or “doorloop”
Planned slack	Capacity that is not assigned to a specific group of patients, it can be used to cope with variation in elective surgeries and arrival of emergency patients.
Planning deviation	The ratio between realized surgery duration and planned duration
Semi-emergent	Unofficial category at the UMCG. Patients that require surgery within a couple of days, but not specifically within 24 hours.
Spoed	Emergency patient status, a patient that is assigned this status (i.e. a spoed patient) has to be operated within 6 hours.
Sub-department	Most medical departments are divided upon a head department. The sub-department is a more specified characterization. (for a complete list of departments see Appendix I)
Timeslot	The time that is allocated either emergency or elective capacity. 7:50-15:30 (thursday-friday) or 8:10-15:30 (monday). In UMCG this is called a "sessie".
UMCG	Universitary Hospital Groningen.
Urgent	Emergency patient status, a patient that is assigned this status (i.e. an urgent patient)

	has to be operated within 24 hours.
USA-buffer	Emergency patients that have to be operated on an USA-OR will arrive here.
USA-patient	See emergency patient.
USA-OR	The term that indicates a dedicated emergency room at the UMCG.
Versatile operating room	An operating room that is allocated both elective and emergency capacity.
Versatile operating rooms system	A capacity allocation system where at least one versatile operating room is used and no dedicated emergency room.

1 Introduction

“Vergrijzing” is the Dutch term for the increase of the average age of the population. Google finds over 300.000 hits on this (Dutch) term, indicating it is an important issue in the Netherlands. The demand for healthcare will increase as an immediate result of this aging of the population. Another recent development is the changes in healthcare with respect to dbc’s (diagnosis-treatment combinations), leading to an increasing pressure for hospitals to treat more patients. Like all other hospitals the University Medical Centre Groningen (UMCG) has to cope with this situation.

Operating room centers typically generate a substantial amount of revenues and expenses of a hospital (about 42 % of revenues on average, Health Care Financial Management Association (2005)). Every single day a couple dozen people undergo surgery in one of the operating rooms in Groningen. Some people were waiting for weeks for this surgery; others were waking up in the morning without expecting they would end up in an operating room that same day. The operating room centre is an interesting field to Operation research, with lots of different researchers all trying to realize the same thing: improve the efficiency of operating rooms.

1.1 Company description

In 1797 Evert Jan Thomassen à Thuessink opened the Nosocomium Academicum. This would later grow to what we now know as the Universitary Medical Centre Groningen. Today, with over 10.000 employees and over 1300 beds, the UMCG is the largest hospital and employer of the region (UMCG.nl). Another aspect in which the UMCG differs from other hospitals is the patient mix: over 60 percent of the patients treated in Groningen are suffering from a rare or complicated disease. Besides treating patients, the UMCG has an education and research function.

Figure 1 Main entrance of the UMCG

1.1.1 Mission and Vision

The mission of the UMCG is defined as: building on the future of healthcare. The vision is threefold:

- Pioneering in research
- Sharing and verifying knowledge
- Taking care of people

1.1.1 Organizational chart

The organizational structure is shown in figure 2.
The department of Healthcare logistics and innovation initiated this research. This is a small department of four employees that (among other activities) aims to improve logistical processes at the UMCG. The department is located under sector E and has a staff function. Sector E also includes the "Operatieve Zorg Organisatie" (OZO). This department is responsible for the management of operating rooms and is also physically located at the operating room centre. Because this department is responsible for many of the relevant choices in this research, the organization chart is shown in figure 3.

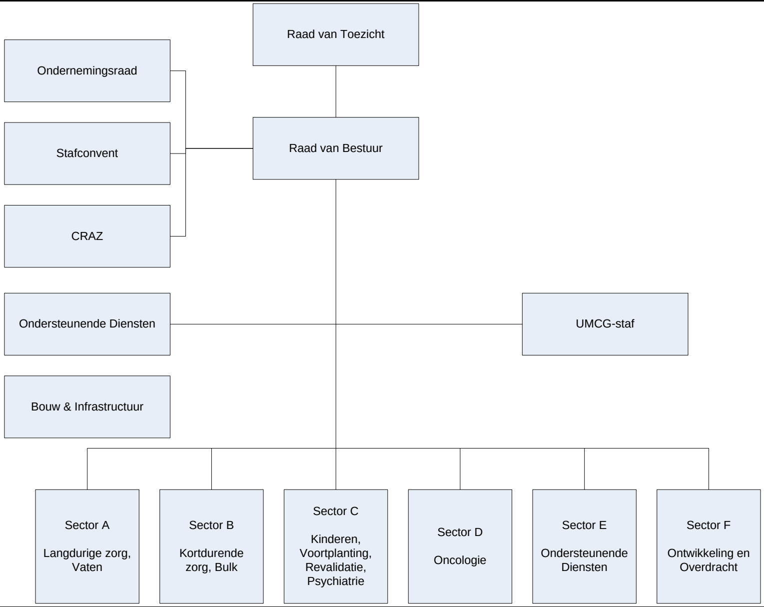


Figure 2 Managerial structure of the UMCG

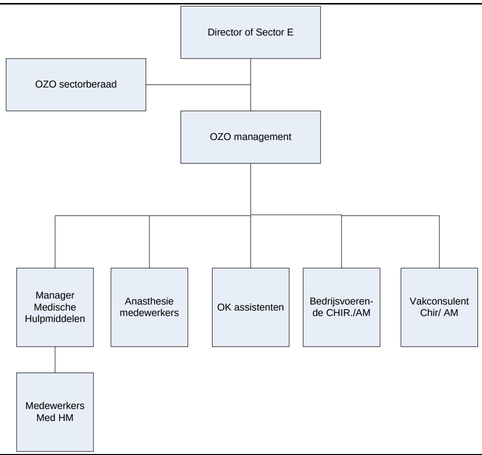


Figure 3 Organizational chart of Sector E

1.2 The operating room centre


Figure 4 Operating room

An operating (room) centre can be characterized by the arrival of two types of patients. For one group of patients the need for surgery is known for some time; they were diagnosed to require surgery and can wait a couple of weeks or even months before having this surgery. These patients can be scheduled well in advance: the elective patients. There are around 10.000 elective patients operated each year at the operating centre of the UMCG. The second group of patients consists of people that enter the hospital and require surgery within a few hours: emergency patients. These patients require surgery at the same operating room centre as the elective patients. Around 4000 emergency patients arrive at the UMCG each year.

The situation described above naturally leads to the following issue: capacity for the two groups of patients should be divided among the available operating rooms. The trade-off is simple: emergency patients should be treated within an adequate amount of time, but reserving too much capacity for emergency patients may lead to valuable unused operating room capacity. In this thesis different systems to allocate these two kinds of capacity to the operating rooms (from here: capacity allocation systems) are identified and the one that is most efficient for the UMCG is evaluated.

A more precise formulation of the problem is presented in the next chapter. Chapter 0 will provide an overview of current capacity allocation systems. In chapter 0 (qualitative analysis) and 0 (quantitative analysis), the current capacity allocation system of the UMCG is described in detail. Chapter 0 shows the performance of the current situation. In chapter 0 a redesign is proposed, this is realized by comparing different systems using discrete-event simulation. Technical details of the model can be found in Appendices II-V. Practical consequences of the proposed

system(s) are discussed in chapter 0. Finally the conclusions and recommendations are discussed in chapter 0 .

2 Research design

This chapter will present a framework for this study. The regulative cycle of van Strien (Van Strien, 1997) is selected to structure the research, because this methodology leads from the diagnosis of a problem to a redesign that is implemented to solve the problem, see figure 5.

It forces the researcher to review the problem critically. The different steps are a logical sequence to achieve this and form the structure of this chapter as well as this thesis. In the first section, the management question is presented. Next, the problem is diagnosed and it is evaluated whether the problem is a reality problem. A plan to redesign the system is formed in section 0. Finally, the implementation and evaluation are briefly discussed.

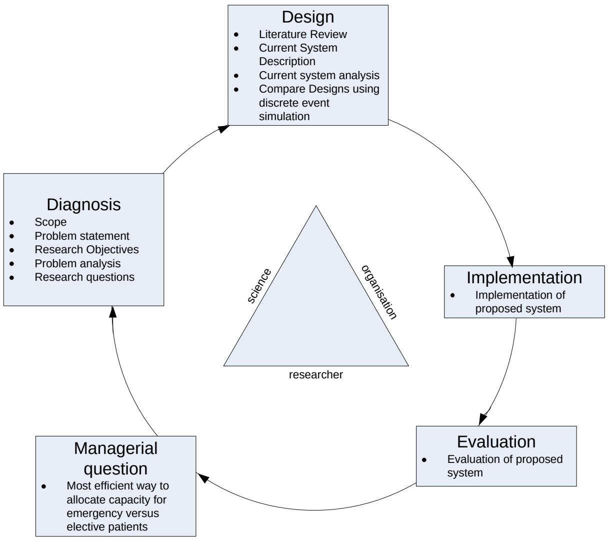


Figure 5 Regulative cycle adopted from (Van Strien, 1997)

2.1 Management question

The department "healthcare logistics and innovation" was founded in 2008 to improve logistical processes of various natures at the UMCG. The method of assigning elective and non-elective patients to operating rooms was brought to their attention by recent interesting developments in literature, including a newly introduced system at Erasmus hospital at Rotterdam. (Wullink G. V., 2007)

The members of healthcare logistics and innovation" want to know what system to allocate capacity for elective and non-elective patients to operating rooms leads to the best logistical performance at the UMCG. This question is relevant because allocating too much capacity for emergency patients can cause underutilization of the operating room, where allocating too little capacity will lead to long waiting times for emergency patients and a high degree of overtime (or many cancelled elective surgeries). A more precise formulation of the problem is stated in section 0.

2.2 Diagnosis

The aim of the diagnosis phase is to identify the problem and analyze this problem. The diagnosis will start by setting a scope to the environment and activities of the operating room centre. Then, within this scope, the problem is described.

2.2.1 System description and scope

The steering model of De Leeuw (2003) is applied to the operating room centre in order to gain insight in the different planning and control aspects taken place in and around the operating room centre, see figure 6.

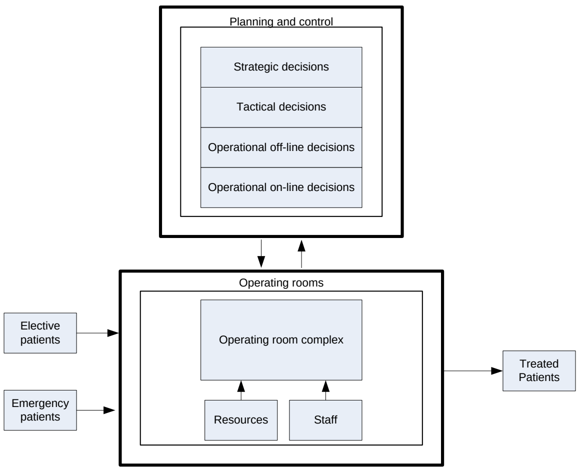


Figure 6 Planning and control steering of Operating rooms

Three factors can be distinct from the above model: patients, operating rooms and planning and control. For each of these aspects, the scope is described.

Operating rooms and patients
The operating room centre is divided into three sectors. Sector 1 is composed of the Thorax departments and consists of four operating rooms (numbered one to four). Thorax uses highly specialized equipment that is not installed in the other rooms. There are also different timeslot hours used in this sector and so thorax is excluded from this research. One operating room is used for Caesarean sections only (a procedure to deliver one or more babies) and is excluded from the research scope for the same reasoning. Finally one OR is not included in this research, because this operating room is the smallest OR of all operating rooms and it is not assigned elective capacity each working day.
The patients that are evaluated are all patients of the UMCG that require some kind of surgery at the operating room centre that is neither thorax, nor a Caesarean section.

Planning and control
Wullink, Houdenhoven, Hans, & Kazemier (2006) proposed a framework that further decomposes the planning and control of operating rooms. This is a decomposition of the planning and control system of the model and is shown in figure 7.

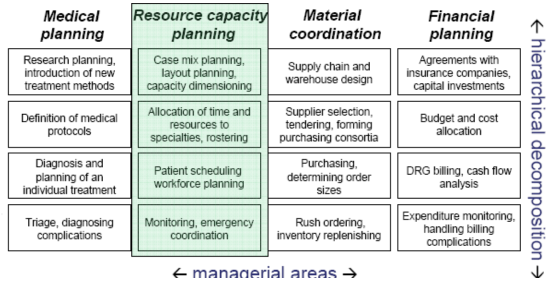


Figure 7 Framework of planning activities at hospitals

This figure provides a solid framework of all the planning activities taking place around the operating room centre. The focus of this thesis is on the resource capacity planning. The model of figure 7 proposes some activities that are executed at the hierarchical layers of resource capacity planning. In chapter four and five, the model will be adjusted to determine the scope of this research.

2.2.2 Problem statement and research objectives

The setting of a scope combined with the management question leads to the following problem statement:

(How) can the logistical performance of the operating room centre of the University Medical Center Groningen be improved by changing the system to allocate (capacity for) elective and emergency patients to operating rooms?

The goal of this thesis is two-fold:
- Present an overview of existing capacity allocation systems.
- Evaluate the system that allocates capacity for both elective and non-elective patients to operating rooms

that leads to the best logistic performance in the context of the UMCG.

These two points correspond with the deliverables: the literature search and the design of an improved planning system are deliverables.

2.2.3 Performance indicators

The best logistical performance is not an objective measurement. The perception and personal wishes of social actors in the system determine what they believe to be best logistical performance. A stakeholder analysis describes what the stakeholders regard important factors of the planning allocation system to them. Based on observation and interviews, **Table 1** shows all stakeholders and some of the (logistical) factors that may be important to them according to the researcher.

The criteria may differ for each individual stakeholder. Globally these are the performance criteria that are regarded as important by the stakeholders according to the researcher. Redundant performance criteria are filtered, leading to the performance criteria that are used in this thesis:

- Utilization
- Overtime (frequency and duration)
- Cancelled surgeries due to planning related causes
- Waiting time for emergency patients
- Throughput
- Patients treated outside time-slot hours

A precise definition of these performance indicators is included in Appendix I Departments making use of operating rooms.

Stakeholder	role	Logistical performance interest
OZO-management	Operatieve zorgorganisatie management, coordinates surgeries.	Utilization, overtime, undertime, late and early start, number of cancelled surgeries, waiting times emergency patients
Surgeons	Have to perform the surgery in the operating rooms	Overtime, undertime, working hours, OR to perform the surgery.
OR staff	Have to assist the surgeon	Overtime
Elective patients	Require surgery	Admission time, number of cancellations
Emergency patients	Require surgery within a limited amount of time at the ORs.	Waiting time
Planbureau's	Plan patients within the available time in the ORs.	Utilization, overtime, undertime, cancelled surgeries
Hospital management	Operating room centre generate most of the costs and revenue of the hospital.	Throughput, overtime
Aftercare units	Treat the patients after they are transported out of the operating room complex	Smooth output flow of patients coming from the OC.
HC logistics and innovation	Improving logistic processes at the UMCG.	Utilization, over- and undertime, late- and early start, number of cancelled surgeries, waiting time for emergency patients, admission time

Table 1 Stakeholder analysis

2.2.4 Problem analysis

Before trying to find a solution to the problem statement, the problem has to be analyzed to check whether it is possible to improve one or more of the KPI's..

One indication that the KPI's of **Table 1** can be improved at the UMCG is the outcome of a research by Wullink (2007). He used a simulation model to research improvements at the operating room centre of Erasmus MC. One of the main improvements that is reached in this simulation model is that their proposed system decreases overtime. More on this proposed system in Chapter 0.

Another indication that the current logistical performance can be improved is shown by the calculation of overtime by the Dutch Project Benchmarking OK. This project, in which all Dutch university medical centre's participated, shows that the score on overtime of the UMCG is highest of all academic hospitals in the Netherlands in 2009 (overtime frequency is second highest and overtime duration highest (benchmarking OK)). Net utilization of the operating rooms is on average 83%, which is average compared to other UMC's. The utilization of an emergency room however is only 60%. This means that on average 40% of this OR's available time there is no patient in this room.

Whether the system that Wullink proposed is an improvement should be analyzed in further detail, this is questionable at this point, because of:

- The system that was implemented at Erasmus shows some problems: too little elective surgery capacity is planned, causing the opposite effect of what the simulation model showed (more overtime). This may be caused by start-up problems.
- The differences between the UMCG and the Erasmus MC may have influence on what the most efficient system is.

Because of the promising results of Wullink's simulation model and the better performance on a number of KPI's of the other UMC's, it is concluded that the system can perform better on some logistical criteria including: overtime, net utilization and waiting times for emergency patients by redesigning the way that the UMCG allocates patients to operating rooms.

All calculations in this section are justified in Chapter 5.

2.2.5 Research questions

The research questions are defined in this section. The methods and tools to answer these questions are given in section 2.3. By answering the questions in this order, an answer to the main research question can be given.

Theory oriented research:

1. What are possible methods to allocate capacity for non-elective and elective patients to operating rooms?

Practice oriented research:

2. At the UMC in Groningen, Which capacity allocation system is currently used?
3. How does the current system perform, with respect to a number of key performance indicators?
4. At the UMC in Groningen, which capacity allocation system is best regarding the relevant performance measures?
5. If a new system is designed; what are the practical implications of such a system?

2.3 Design

The sub questions are defined in a logical sequence. An answer to each sub question in this order provides a solution to the problem statement: the design of a new system to allocate capacity for emergency and elective patients to operating rooms. First a literature review is conducted to answer the first question. Relevant publications are selected from which different capacity allocation systems are extracted.

The evaluation of the current system is subject of the second research question. A qualitative analysis is made by observation and interviews. For the quantitative analysis most information can be found in the data that is registered in the software package used at the operating room centre (OKplus). By analyzing this data, in combination with observation and interviews, the second question can be answered.

The performance of the model that is described in the answer to the second question can be measured. Data analysis is the technique to answer question three. Most data is already analyzed for the project: Benchmarking OK's. This data is used in combination with data that is extracted from OKplus.

Discrete event simulation is the tool that is used to evaluate the fourth question. The results from question 2 are used to simulate the current situation. By applying the capacity allocation systems that were identified in the literature study, these different systems can be evaluated with respect to the performance indicators that are defined in section 0. For the discrete event simulation, the methodology of Robinson (2004) is used.

By defining intelligent performance measures that operationalize practical consequences of alternative systems, a statement can be made regarding question five. Also observation and interviews will provide input for the answer of this question.

2.4 Implementation and evaluation

The implementation is not part of the research. The research will lead to a set of recommendations and whether or not these recommendations are implemented is the responsibility of the UMCG. The evaluation of the implemented system is therefore also not part of this thesis. The fifth sub question will provide insight in the consequences for the (operational) management of the logistical process of the operating rooms.

3 Literature review

In the previous chapter, the research methodology is composed. The problem statement was defined and five research questions were presented. This chapter will evaluate the first research question:

What are possible methods to allocate capacity for non-elective and elective patients to operating rooms?

These methods to allocate capacity for non-elective (i.e. emergency patients) and elective patients to operating rooms are referred to as: capacity allocation systems.

The methodology to structure the literature review is as follows: the literature review will be based on the literature study by Cardoen (2009) in which four large scientific databases (see **Figure 8**) are searched on the subject of operating room planning and scheduling. This led to 247 articles. The articles described in this chapter are selected based on the categorization that is used by Cardoen. By comparing the 247 articles to the factors that are relevant to this thesis, the relevant publications are found. Publications that are not included in Cardoens literature study are added. The relevant literature is summarized in tab;e 2 .

3.1 Identifying the relevant body of literature

Since the total number of manuscripts in the large scientific databases on this topic is very large, Cardoen restricted the set of manuscripts to those published in or after 2000. This search led to 247 manuscripts. Cardoen proposes a taxonomy based on:

- Patient characteristics: elective and non-elective patients
- Performance measures: eight different performance criteria
- Decision delineation: the type of decision that has to be made (date, time, room or capacity) and whether this decision applies to a medical discipline, a surgeon or a patient (type).

All publications are categorized based on the above three factors. Publications that are relevant to this thesis are:

- Publications regarding both elective and non-elective patients.
- Research that evaluates at least one of the performance criteria determined in Chapter 2.
- Publications that concern tactical decisions.

The article of Cardoen was received by the publisher on the sixth of May 2008. Therefore the aforementioned databases will be searched for sources published after May 2008 to include most recent developments and manuscripts that are not included in this literature review. A summary of this filter is shown in figure 8.

A first distinction in the article of Cardoen is made between elective and non-elective patients. The writers of this article note that:

"One can question why the majority of the papers focuses on elective patients and ignores the problems caused by non-elective patients. This observation is even more striking when one realizes that the larger degree of uncertainty is the main reason why operating room scheduling urges other scheduling methodologies than the machine scheduling procedures developed for industrial systems.".

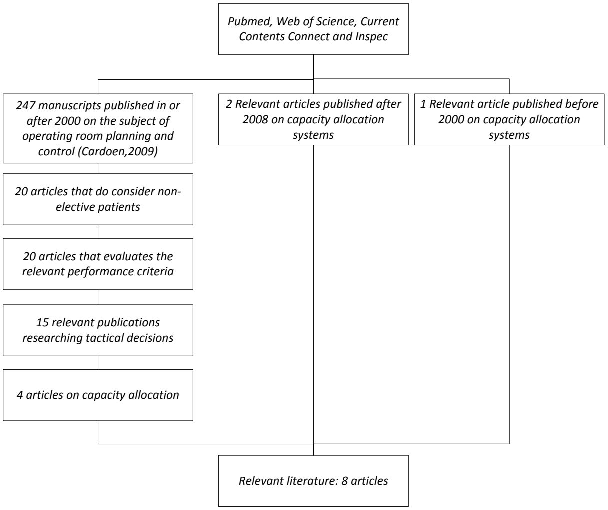


Figure 8 Literature filter

By filtering on the publications that do consider non-elective patients, the relevant amount of manuscripts reduce from 247 to only 20 works on the subject of allocation of elective patients and non-elective patients to operating rooms.

All twenty publications evaluate the operating room centre on one or more of the performance indicators that are used in this thesis (see 0). Five of the publications evaluated the operating room centre on a lower level of aggregation.

Not all fifteen remaining manuscripts are on the subject of allocating capacity to elective and non-elective patients. For a number of reasons, the relevant field of literature narrows down to only four manuscripts.

A search for literature that was not included in the literature review of Cardoen, led to three more articles that are relevant for this thesis. One article was not included in the literature review of Cardoen because it was not published after 2000 and two researches were published after May 2008. The publications are summarized in table *2*. A large proportion of these publications is on the research of the orthopedic department. Although this department is not representative for the entire operating room centre at the UMCG, these publications are selected for this literature research. Whether or not the proposed capacity allocation systems of these articles are efficient in the UMCG is not evaluated here. The application of these systems is evaluated in Chapter 7 using realistic UMCG data.

3.2 Systematical analysis of the relevant literature

All studies, that are left after applying the filter shown in figure 8 researched the allocation of emergency and elective patients to operating rooms. The results may depend on the environment of the researched operating room centre. In this section, a format (applied in table 2 is proposed to evaluate the contextual factors:

- Hospital: the most general description of the research.
- The number of operating rooms: different planning systems may be preferred depending on the size of the hospital.
- The arrival of emergency patients in a time-interval: the number of emergency patients directly influences the planning system. For example: a low rate emergency patient arrival could lead to underutilized dedicated emergency operating rooms.
- The type of surgeries (case mix): environments characterized by long- and high variance surgery times may require a different approach than a hospital with predictable short procedures.

The researchers propose a system based on the highest scores on different performance indicators. Because the researchers may have found different Key Performance Indicators (KPI's) to be most important, all KPI's are given for each research.
Finally the proposed format describes the capacity allocation system. The characteristics of the capacity

allocation system discussed here, follow from a comprehensive analysis of the publications.
The findings of this analysis are summarized in table 2 and will be discussed in section 0:

- Planning system. This will be discussed in the remainder of this chapter.
- Number of dedicated emergency operating rooms: the number of rooms in which capacity is reserved exclusively for emergency patients.
- Number of dedicated elective operating room: the number of rooms in which capacity reserved is exclusively for elective patients.
- Number of versatile operating rooms: the number of rooms in which capacity is reserved for both elective and non-elective patients.
- Operating rooms with use of standby patients: Number of operating rooms that are dedicated to emergency patients, but where elective patients are called in case of underutilization
- Sequencing: The sequencing rules that were used.

	Environment					Proposed Planning system					Sequencing	KPI	Method
Research	hospital	# ORs	Emergency patients	elective patients	Case mix	System[3]	#ded. Em. ORs	#ded. el.ORs	#Vers. ORs	Standby patients?			
(Bhattacharyya, 2006)	Massachusetts General Hospital	1	130/y	-	Two surgeries (predictable)	1	1	0	0	0	-	Cases performed < 5 PM.	Introduction of trauma OR
(Bowers, 2001)	Typical District General hospital (U.K.)	1	735 /y	2600/y	All orthopedic surgeries	2	0	0	1	0	Random (best) and LCF	Utilization and overrunning (trade-off)	Simulation
(Persson, 2009)	Blekinge Hosp. Sweden	2	1914 total/y		All orthopedic	2	0	1	0	yes	-	Meeting demand of emergency cases	Discrete-event simulation
(van der Lans, 2005)	Erasmus MC (Rotterdam)	V,4, 8 12	5.1 or 2.6/d	-	Two surgical case mixes	3	0	0	12[1]	0	BIM-optimization	Utilization, avg. overtime	Discrete-event simulation
(Wullink G. V., 2007)	Erasmus MC (Rotterdam)	12	5/d	32 a day	All surgeries	3	0	0	0	0	First-fit was used	Waiting time, overtime, financial	Discrete-event simulation
(Tancrez, 2009)	Theoretical	1-7	v (0-6)/d	0-20 a day	All surgeries	1	V[2]	0	v[2]	0	-	Overtime, waiting times	Markov Chain
(Wixted, 2008)	MMC Worcester, Massachusetts.	-	494/y	2046/y	All orthopedic surgeries	1	1	0	0	0	-	after-hours orthopedic surgery	Observational analysis

Table 2 Selected literature
[1]simulation study in which different scenarios are evaluated. In case of a 12 OR system, 12 versatile ORs are proposed.
[2] this parameter is a variable that is varied in this research.
[3] system number x refers to section 3.3.x (e.g. number 1: Dedicated emergency system)

3.3 Overview of capacity allocation systems

The differences among the capacity allocation systems can be characterized by two essential choices:

- The amount of elective capacity versus emergency capacity that is allocated to each operating room.
- The existence of the possibility of either operate emergency patients within OR-capacity that was originally assigned to elective patients, or operate elective patients within OR-capacity that was originally assigned to emergency patients.

The first choice leads to two different configurations:

1. Exclusively allocate an operating room with either elective or emergency capacity.

This capacity allocation system is called here: the dedicated operating rooms system. A dedicated emergency room is defined as an emergency room where the full capacity is allocated to emergency patients. A dedicated elective room is an OR that is allocated capacity for elective patients only.

2. Allocate both elective and emergency capacity to an operating room.

This system is called here: versatile operating rooms system. A versatile operating room is defined as an operating room that is allocated capacity for both elective and emergency patients.

In an environment with more than one operating room, a third possibility arises:

3. A combination of one or more dedicated operating rooms and one or more versatile OR's.

The system with one dedicated emergency OR and one or more OR's that are allocated both emergency- and elective capacity is called a hybrid system. The system with one or more dedicated elective operating rooms (i.e. operating rooms that are allocated elective capacity only) and one or more versatile operating rooms is considered to be also a versatile operating rooms system.

The choice of allowing emergency patients to be treated in elective capacity and vice versa provide more variations of capacity allocation systems. The possibility of treating emergency patients in elective OR-capacity is in practice assumed to be inevitable: this is caused by resource constraints. The possibility of operating elective patients within emergency capacity is interesting.

The flexibility of the usage of emergency capacity is not researched in the second system: versatile operating rooms are used by emergency- and elective patients by definition. There is no time-block in which the operating room is reserved for emergency patients only. The utilization of versatile rooms can be increased by increasing the elective capacity of these rooms. This option does not exist in a dedicated emergency room. Therefore this flexible use of emergency capacity is interesting only when dedicated emergency rooms are used, leading to the fourth system:

4. Emergency rooms with standby patients.

Elective patients that are suitable to be operated in emergency capacity are standby patients. These patients are ready for surgery but are not scheduled. If the emergency capacity is underutilized, the standby patients are operated.

3.3.1 The dedicated emergency operating room

The first method to allocate the two kinds of capacity to operating rooms is to use operating rooms that are dedicated to a specific group of patients (i.e. non-elective or elective patients). Two studies claim that this is the best strategic decision in their specific research environment and based on the performance indicators that they use. Their findings are summarized below.

Bhattacharyya (2006) analyzed the operating room planning in the Massachusetts General Hospital. The researchers collected OR time data on two common surgical cases (dynamic hip screw and closed femoral nailing) done before and after introduction of an unbooked orthopaedic trauma OR. The availability of an unbooked orthopaedic trauma room resulted in a measurable shift from performing “add-on” cases to daytime surgery and this may reduce medical complications according to results of the same study. They compared data of surgeries during the day and surgeries in the night and observed significantly more complications with patients operated during the night. In their conclusion they recommend that hospitals and orthopaedic trauma services commit resources toward having an open OR reserved for orthopaedic trauma (i.e. a dedicated emergency operating room).
One way to model the surgeries of elective patients in combination with emergencies is by the use of a Markov chain. Tancrez (2009) formulated a Markov Chain, shown in

figure 9. A Markov model consists of states and transition probabilities. In this case the states are composed of a variable number of patients that are being treated in an operating room. The arrival of patients and the duration of surgeries are the transition probabilities.

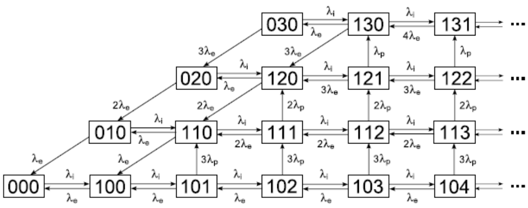


Figure 9 Markov Chain for a system with 1 dedicated emergency and 3 versatile operating rooms. (Tancrez, 2009)

The notation equals: emergencies under treatment in dedicated emergency room (with a maximum of one, as there is one dedicated OR), emergencies under treatment in versatile room (with a maximum of three) and patients in waiting list. The term "versatile operating room" is used here to indicate that both elective and emergency patients can be treated in one room.
The legend in figure 10 represents [#dedicated rooms#|versatile rooms]. The waiting times for emergency patients increase when no (or a few) versatile operating rooms are being used. Another conclusion in this article is that using fewer dedicated emergency operating rooms the probability of (expensive) overtime decreases.

Lemos (2007) researched the effect of dedicated emergency operating rooms on patient's health. They analyzed 245 patients who underwent the same surgery (hemiarthroplasty for displaced lowenergy subcapital hip fractures). They concluded that a dedicated trauma room significantly reduced postoperative morbidity (poor health). No significant difference in mortality (death) was found. This article thus favors this system, based on the health of patients. No additional literature on the effect of dedicated emergency operating rooms was found.
In a simple setting of two operating rooms, the dedicated emergency OR planning system is shown in figure 11.

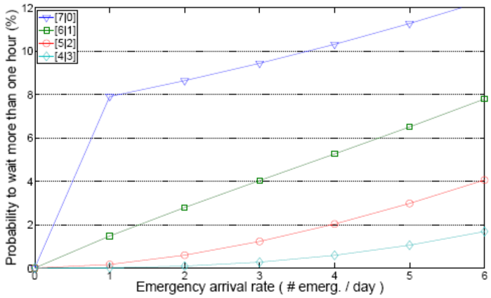


Figure 10 Relationship between the probability of a non-elective patient waiting for more than an hour and the emergency arrival rate. (Tancrez, 2009)

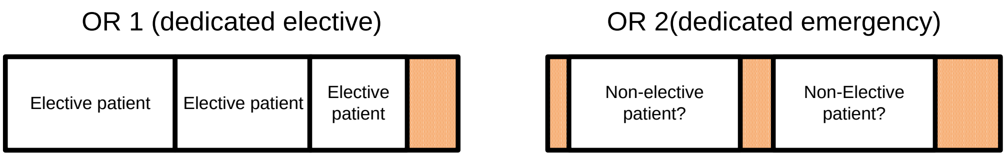


Figure 11 Graphical representation of the dedicated emergency OR planning system

3.3.2 Versatile operating rooms system

Instead of using a dedicated operating room for emergency patients, the capacity for emergency patients can be shared among a number of operating rooms. In this case, planned slack is used to deal with stochasticity in surgery durations and the arrival of emergency patients. Although the concept of planned slack exists for some time, it only recently showed up in a healthcare setting.

Van der Lans (2005) defines slack as: the difference between the planned capacity for elective patients and the total available capacity per operating room. Planning more slack leads to a decrease in probability of overtime. Planning less slack may lead to higher utilization, but can result in cancellations due to disruptions in regular schedules and emergency patients being treated outside the timeslot. When an emergency patient arrives at the hospital, the patient is operated when there is capacity at any OR that is allocated slack. When all OR's are occupied, the emergency patient has to wait. To minimize this waiting time, the researchers analyzed Break-In Moments (BIMs). These moments include the start and end of the occupied interval, as well as all completion times of surgeries within the occupied interval. The interval in between two subsequent BIMs is defined as a break-In-Interval (BII), see figure 12.

These moments are of great importance because an emergency surgery can only start at a BIM. To ensure minimum waiting times for emergency surgeries, the BIM's have to be spread equally over a day. This can be realized by scheduling the elective surgeries in such a way that the BII's are minimized. For a specified surgical case mix the results show great improvements, see figure 12

Table 3 and the results in the conclusion of van der Lans (2005) are relevant to this thesis. It seems that the waiting time decreases and the utilization increases when this planning allocation system is used instead of using dedicated operating rooms. BII interval optimalization leads to a further decrease in waiting times for emergency patients. This is realized using an algorithm that rearranges the surgeries over the operating rooms in order to spread the BIM evenly over the day. The feasibility of this tool is not discussed in the article.

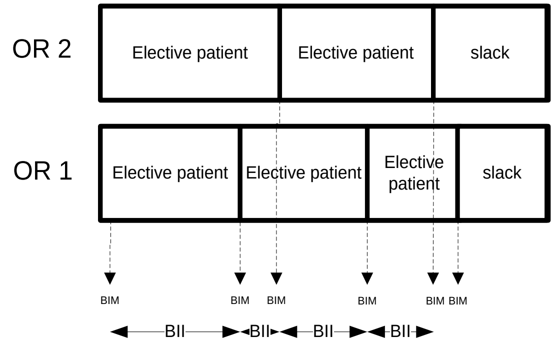


Figure 12 The definition of Break-In-Moments and Break-In-Interval. (van der Lans, 2005)

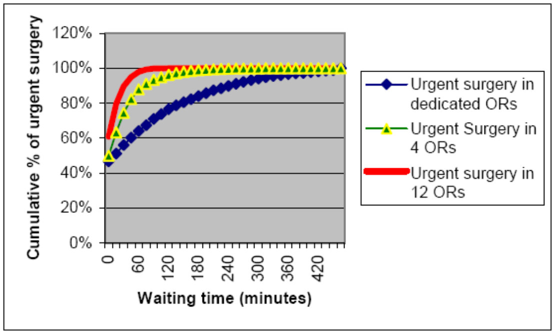


Figure 13 Cumulative percentage of surgeries completed within waiting time intervals. (van der Lans, 2005)

Slack for urgent surgery allocated to:	Surgical case mix A Planned utilization	 Realized utilization	Surgical case mix B Planned utilization	 Realized utilization
Dedicated room(s)	67.6%	73.6%	79.7%	81.7%
4 operating rooms	67.3%	74.9%	79.6%	82.3%
12 operating rooms	68.8%	76.7%	80.9%	83.2%

Table 3 Utilization for different scenarios (adopted from van der Lans, 2005).

The question whether or not to use a dedicated emergency OR is also the subject of a research by Wullink et. al. (Wullink., 2007).Wullink modeled the situation in Erasmus MC using two scenarios. The currently used situation is a dedicated emergency OR system with one OR being dedicated to emergencies and eleven ORs with capacity for elective patients only. In an alternative policy all twelve operating rooms contain capacity for both elective and non-elective surgery.

Discrete event simulation showed that the mean waiting time for emergency patients using policy 1 is 74(±4.4minutes). Policy 2 led to a mean waiting time of only 8(±0.5) minutes. Average utilization of all operating rooms for both policies was determined to be 74% and 77% respectively. The policy without a dedicated emergency OR outperforms the policy with a dedicated emergency OR on all performance measures that were used, explaining the title of this article:”Closing Emergency Operating Rooms Improves Efficiency”. This article is a chapter of dissertation of van Oostrum (2009).

This system is shown in a simple setting on the next page figure 14.

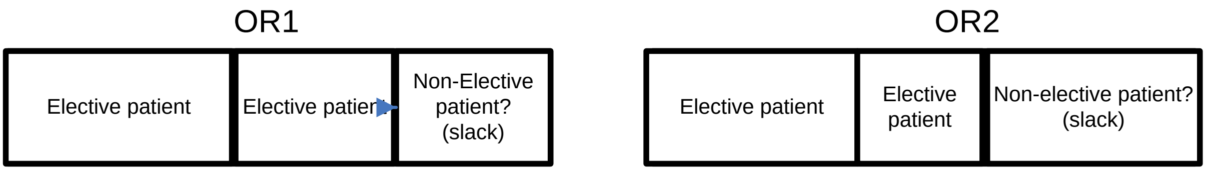


Figure 14 two versatile operating rooms

3.3.3 Hybrid systems

In large systems (e.g. twelve operating rooms or more) the dedicated emergency room planning system and the versatile OR system can be combined. For example, a possible hybrid system could be: the use of one emergency operating room and allocate emergency capacity to a number of other operating rooms. This system is not discussed in any of the articles found.

3.3.4 Emergency operating rooms with standby patients

Bowers (2001) concludes that simulation provides a method for examining the design of orthopaedic trauma theatre sessions and the trade-off between utilization and overrunning (i.e. overtime). The researchers used discrete-event simulation to analyze the operating room planning in a typical District General Hospital in the United Kingdom. The model is developed to examine a policy of including planned, elective patients within a trauma session: it appears that if patients are willing to accept a possibility of their treatment being cancelled, substantially greater throughputs can be achieved. If a probability of postponement of 15% is acceptable a 2 hours elective list can be scheduled as part of the weekday 7 hours trauma session.

Persson (2009) analyzed the operating room planning at a department of orthopaedic surgery in Sweden. This department of orthopaedic surgery at Blekinge Hospital has two operating rooms to manage emergency and elective patients. In the current situation one OR is dedicated to elective patients and a large proportion (66,7%) of the other OR is dedicated to emergency patients. Discrete event simulation is used to evaluate another system. In this proposed system, the dedicated emergency OR is replaced by a system in which patients stand-by for surgery. A stand-by patient is prepared for surgery at home (or at work) and called upon when an opportunity occurs. This is especially suitable for waiting list management at an orthopaedic department due to the characteristics of orthopaedic disease and injuries and is frequently used at Blekinge Hospital. In their proposal, Persson also suggests a standby system for medical staff: in weekends the emergency staff stayed at home, reducing expensive employee costs.

The assumption was made that there are always enough patients that are suitable for- and willing to accept a standby status. The proposed scenario resulted in a significant decrease in surgery cancellation and overtime work, while fixed costs remained the same. Total costs however will decrease because of expensive overtime reduction. Negative effect of the proposed scenario is the increase in average waiting time. Both these effects are even stronger when an increase in hip-fractures of 30% is modeled. This is relevant as the general opinion is that the hip-joint surgeries will increase the coming years. Figure 15 shows an example of this system using standby patients in a setting with two operating rooms.

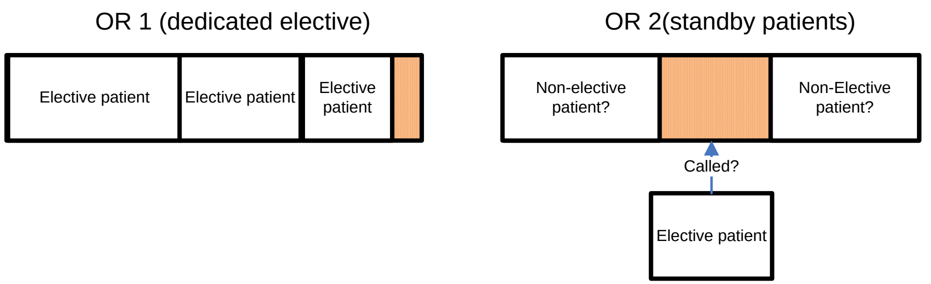


Figure 15 The emergency room with standby patients system in a simple setting

3.4 Summary

In this chapter, an overview of literature regarding operating room planning and scheduling is presented. Based on an existing literature review, relevant literature with respect to the problem statement is analyzed. It appears that although there is a large amount of literature available on planning and scheduling of elective patients, research on allocating capacity for non-elective patients to operating rooms is scarce.

Four different systems that allocate patients to OR's are identified:

- Dedicated operating rooms
- Versatile operating rooms
- Hybrid system
- Emergency operating rooms with standby patients

The discrete event simulation study of Wullink (2007) shows promising results by using versatile (i.e. a combination of capacity for elective and non-elective patients) operating rooms. This contradicts with the Markov model of Tancrez (2009) that shows that emergency waiting times decrease using a dedicated emergency OR. An explanation for this discrepancy could be the number of operating rooms. More (versatile) operating rooms, means that there are more break-in moments; this will automatically decrease waiting times for emergencies in the third system. So there must exist a minimum number of OR's and surgeries for planned slack to be superior to the use of a dedicated emergency OR. This turning point may also depend on the surgery durations and variance in durations. Wullink and Tancrez agree that probability of (costly) overtime decreases as more versatile rooms are used instead of dedicated emergency ORs.

This chapter answers the first sub question. It provides input for the scenarios used during the simulation study and proposed a format that can be used to describe the situation at the UMCG (sub question 2).

4 Current system description

In this chapter, the current system of the UMCG is described to provide an answer to the second sub question of this thesis:

At the UMC in Groningen, which capacity allocation system is currently used?

The question will be answered by a qualitative analysis in this chapter and a quantitative analysis in the next chapter. For qualitative data, the registered data is extracted from OKplus. OKplus is the software package (i.e. a combination of several computer programs developed by Chipsoft) in which all surgeries are planned and registered. This system was introduced in June 2005.

In chapter 2, the entire system was divided into: the operating rooms, planning and control and inputs (patients). Figure 16 shows these aspects of the system and the paragraph of this chapter in which this aspect is described. Only activities part of resource capacity planning are considered. The aspects outside the scope of this research will be mentioned and briefly described for completeness.

4.1 Patients

The human body is sometimes called the most complicated machine in the world. One can imagine that there are many possible surgeries that may be necessary to "keep the machine working". From a planning and scheduling perspective it is interesting to divide the pool of highly different patients into groups based on the urgency of surgery. The patients that require surgery least urgent are the elective patients. These patients can be scheduled within the planning horizon. The UMCG generally aims to perform surgery within seven weeks after the moment that it is decided that a patient requires surgery (following the "treeknorm" (De Treeknorm)). Patients that require surgery soon are less flexible from a planning perspective: in the worst case they have to undergo surgery as soon as possible in order to survive. The patients will be described in order of their flexibility within the planning system, as classified by the UMCG. Once elective patients are awaiting surgery inside the hospital, their flexibility declines: they should be in the OR as soon as possible.

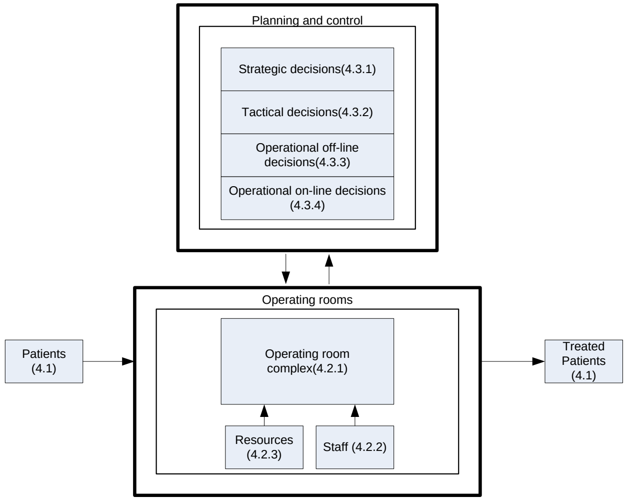


Figure 16 Steering model of operating room centre

4.1.1 Categorization based on urgency of surgery

All elective patients have in common that they need to undergo some kind of surgery. This surgery is not emergent, i.e. the patients can wait for surgery a couple of weeks after the patient is diagnosed to require surgery. An example of an elective patient is a person with a torn meniscus (common knee injury). This person typically was sent to the orthopedic department and underwent several types of examinations. After the diagnosis is established, the patient is placed on a waiting list and is treated on a surgery table (for an arthroscopy in this example) within a couple of weeks.

A special category within the elective patients is known as “semi-spoed” (semi-emergency). These patients can be treated after 24 hours; hence they formally are not emergency patients. However, semi-spoed patients do require surgery within a couple of days, which distinguishes them from elective patients. The semi-emergent patients require a different planning method than the elective patients. At the UMCG these patients are classified as being elective and thus should be scheduled and operated within the elective rooms. They should also be registered in the registration system as being elective. In this thesis, all "semi-spoed" patients are assumed to be part of the elective planning process.

Contrary to the elective patients, the emergency patients have to be operated on short notice. When the surgery cannot start within the specified time interval, the patient may have increased chances on morbidity or even mortality (N. Sicard, 2007). At the UMCG, the emergency patients are categorized based on their condition as either:

- Urgente (urgent) patients: have to be treated within 24 hours.
- Spoed (emergent) patients: have to be treated within 6 hours.
- Acute (acute) patients: have to be treated as soon as possible.

These three groups together will be called USA-patients (synonymous to emergency patients). Many USA-patients arrive at the hospital at the emergency department ("CSO"), here the status of the patient is determined based on their condition. Also it is determined which department(s) should perform the surgery.

Although this classification seems well defined, there exists a discrepancy between the above theoretic classification and daily practice. Patients classified as “spoed” may in practice wait longer than 6 hours. Also sometimes "semi-spoed" patients are, against the policy of OZO, classified as urgent or spoed.

Medical categorization of patients

Next to the urgency of a patient, there is diversity in the department that needs to treat a specific patient. Departments that were assigned elective capacity in one of the operating rooms are described in Appendix I.

4.2 Operating rooms

All patients described in the previous section will enter an operating room at one time. The operating room consist of the operating room and the resources that are needed to perform the right surgery by an operating team.

4.2.1 Operating rooms

The eighteen operating rooms included in the scope of this thesis are opened each working day. Different departments are assigned one or more OR days in the week, this policy is in literature called: block-booking (Dexter et. al. 1999). For example KNO makes use of OR 5 and OR6 each working day, where their specific equipment is installed.

4.2.2 Resources

Each surgery requires specific equipment. Most of these equipment can be moved to the OR where a surgery takes place. The operating rooms of “Keel-neus-oor” and “oogheelkunde” contain equipment that is installed only at these rooms. Therefore many emergency patients of these departments cannot be treated at the dedicated emergency rooms. Also there are two neuro-chambers that contain highly specialized equipment.

4.2.3 Staff

Numerous different people are working at the operating rooms. The anesthesiologist (supported by a nurse anesthesiologist) is responsible for delivering anesthesia safely to patients. The surgery is performed by one or more surgeon(s). OR assistants assist the operation. Because the UMCG is an academic hospital, students may also be assisting the operation. In case of complex operations, there may be surgeons from two or more departments cooperating.

4.3 Operating room planning and control

The highest level of aggregation in the planning levels contains the long-term decision, whereas on the lowest level the daily decisions are taken. For each of these planning levels, a number of activities are evaluated.

4.3.1 Strategic decisions

The strategic decisions consist of the long-term decisions. Typically these decisions are taken by the high management and relate to the question: "what is the range of services offered" (Vissers, 2001).

Case mix planning

- Responsibility: board of directors
- Activity: determine what type of patients are treated within the UMCG.
- UMCG decision: the board of directors of the UMCG chose to focus on both complex and basis healthcare.

Lay-out planning

- Responsibility: board of directors
- Activity: determine the functional and physical lay-out of operating centre.
- UMCG decision: Sector two is located on the first floor and consists of 9 ORs (OR 5-13). Sector three is located on the second floor and consists of 11ORs (OR 14-24).

Capacity dimensioning

- Responsibility: board of directors
- Activity: determine the overall size of the operating centre
- UMCG decision: in total, twenty-four operating rooms are available, this is large in comparison to other Dutch hospitals. 18 operating rooms are evaluated in this study.

4.3.2 Tactical decisions

The second layer in the planning hierarchy focus more on intermediate-term issues and decisions are typically made by middle managers.

Block planning

- Responsibility: OZO-management and board of directors
- Activity: determine the amount of capacity that the departments may use.
- UMCG decision: each quarter the departments are assigned blocks of capacity (timeslot). The departments negotiate with the board of directors about the capacity they will receive. In practice it turns out very frequently that the blocks each quarter are similar to the quarter before.

Rostering

- Responsibility: departments
- Activity: determine roster
- UMCG decision: the planning offices ("planbureaus") plan their own surgeons. Anesthesia nurses and anesthesiologists are planned by the department of anesthesiology.

Planning allocation system

- Responsibility: OZO-management and departments
- Activity: determine the allocation of elective versus non-elective patients.
- UMCG decision: the planning allocation system is characterized using the proposed format of chapter 3 in Table 4. The planning allocation system that is used at the UMCG is not a strict dedicated operating room

system. Sometimes a limited amount of elective capacity is planned into an emergency operating room (corresponding to the system of section 3.2.2) and vice-versa, this is further analyzed in Chapter 5. Such a decision is an online operational decision . The standard policy is to use two operating rooms (i.e. 2 USA-OR's) for emergency patients preferably.

Planning allocation system				
Planning system	#dedicated em.ORs	#ded. el.ORs	# versatile	# ORs with standby patients
1	2	22	0	0

Table 4 Currently used planning system of the UMCG during working days.

4.3.3 Operational off-line decisions

Operational offline decisions concern the scheduling of elective patients.

Elective patient scheduling

- Responsibility: planning offices of departments, approved by OZO-management.
- Activity: determine schedule of elective patients (and semi-spoed)
- UMCG decision: within their assigned time-blocks, the departments are "free" to schedule according to their own methods. There are however some rules. These rules are documented in an internal UMCG document (OZO, 2008). Three decisions are important here: Which patients will be operated? How many surgeries are scheduled for the next day? and in what order will they be performed?

Some planning offices schedule patients immediately after they are diagnosed to require surgery. Based on average waiting times for these patients, they are scheduled. Other departments may use waiting lists.

To determine the amount of surgeries that will be scheduled for a working day, the departments have to estimate the total surgery time. The method to determine the time that a department reserves for a specific surgery differs per department. MHK and OHA for example make use of estimations of a specialist (Chef De Clinique) and historic data, respectively. OKplus provides a feature that can calculate average surgery times of a specific surgery for each surgeon. The planning office of OHA uses this option for each surgery. When a surgery is scheduled, the scheduler uses OKplus to show all similar surgeries performed by the surgeon. He then manually deselects surgeries that are not similar (because an extra procedure had been performed for example) and deselects the highest and lowest surgery duration. The estimated time for anesthesia is added to this average surgery duration and this is used in the schedule.

Some departments have learned that the estimations they make are often inaccurate, this is why sometimes only 70% of the capacity is planned. On the other hand, it occurs that more than 100% of the capacity is planned. For example, an experienced surgeon from MHK planned 5 standard surgeries, leading to a planned capacity of over 105%. This specific surgeon knows he can perform the surgeries in less than the planned time, justifying the fact that he planned in too much capacity.

The sequencing of surgeries is described by OZO-management (OZO, 2008). The sequencing should be based on:

- Age of patient (for children, youngest child first)
- Surgery duration (longest case first)
- Other diagnoses (diabetes and latex-allergic patients are given priority)
- First patient should preferably be given general anesthesia (instead of local)

Each working day before 14:00, the departments have to show OZO their schedule for the next day for approval. The planning for the elective time-slot the next day consists out of patients from the waiting list, complemented with the semi-spoed patients. The schedule is made final at 14:15, thus semi-spoed patients arriving at the UMCG after 14:15 will not be scheduled for the next day. Sometimes, departments can request more time to operate and the OZO-management will allow the schedule to end after 15:30. This is scheduled overtime (in UMCG this is called "doorloop") and OR teams will be scheduled accordingly.

4.3.4 Operational on-line decisions

The decisions that daily take place on the work floor are the operational on-line decisions. The employees of the OZO have to assign the patients to OR's. The higher aggregation planning levels provide guidelines and rules to do so.

Monitoring:

- Responsibility: OZO-management
- Activity: monitor the logistical process.
- UMCG decision: one of the features of OKplus is a screen with information about the current state of the system. Different phases of the surgery are displayed.

Emergency coordination

- Responsibility: OZO-management, surgeons
- Activity: allocate the emergency patients to operating rooms
- UMCG decision: here the decision is made at which OR the emergency patient will be operated and also in which sequence they will be operated. The emergency coordination is a complex process that is hard to describe in generic terms. A distinction has to be made between acute- on the one hand and spoed and urgent patients on the other hand.

Acute patients are often sent to the first operating room that is available if their condition is life-threatening. This is determined by the USA anesthesiologist. A large part of acute patients are treated on the elective room (of the department that performs surgery) or the USA-OR.

Spoed and urgent patients are most often treated on the USA-OR (a dedicated emergency OR of the UMCG). Some surgeries require resources that are "attached" to the operating room. This happens mostly at the departments of OHA, KNO and NCA. Another reason for USA-patients being treated at elective rooms (within the timeslot) is that there are a lot of USA-patients waiting to be treated on the USA-OR. When an elective schedule is finished early (and the elective OR is free), it may also occur that an USA-patient is treated at this elective room.

For the emergency patients that will be operated on the USA-OR, the sequence is determined by the following points in this order:

1. Highest medical urgency
2. Patients of their own sector, where efficiency can be the reason for the sequence.
3. First come, first serve

Urgent and spoed patients are sometimes forwarded to the next day. In weekends, there is no elective program and the USA-patients that were forwarded during the week are operated. This causes a "fresh start" on Monday.

Cancellation of elective surgeries

- Responsibility: OZO-management, surgeons
- Activity: Decision to cancel an elective surgery.
- UMCG decision: There can be various reasons to cancel a surgery of an elective patient, varying from a patient that dies before surgery to insufficient intensive care capacity. If the next surgery of the day is anticipated to end after 15:30, the OZO-management will decide whether or not to start this surgery based on the amount of available employees (OR assistants), anesthesiologist and USA-patients.

4.4 Summary

This chapter provided a general description of logistic and planning processes that occur at the operating room centre. The chapter begins with a description of the input of the system: patients. The UMCG chooses to categorize patients based on how urgent they require surgery,(in this order): elective, urgent, "spoed", acute are the

classifications. Different planning and control levels decide how to allocate these patients to the operating rooms. On a tactical level it is decided to use two dedicated emergency operating rooms; the other rooms are used by the departments to schedule elective (and semi-spoed) patients. On an operational level, these planning rules cannot always be applied. Several deviations from the tactical decisions occur frequently, see table 5.

Patient	Operated at USA-OR in case:	Operated at elective room in case:
Elective	• Elective patient is from a small department that is not assigned blocktime. • There is no USA-patient to be treated.	• Standard
Urgent	• Standard	• USA-OR is utilized • USA-OR does not possess the resource that is required by surgery type. The patient will be treated on the OR of the relevant department • An elective OR finishes early.
Spoed	• Standard	• USA-OR is utilized • usa-table does not possess the resource that is required by surgery type. The patient will be treated on the OR of the relevant department. • An elective OR finishes early.
Acute	• If the first available OR is an USA-OR (preferably)	• If the first available OR is an elective room.

Table 5 Flow of patient groups to elective and emergency ORs

5 Capacity allocation system analysis

The previous chapter provided a general description of many planning activities taken place at the operating room centre. Quantitative analysis is used to complete the answer on the sub question:
At the UMC in Groningen, which capacity allocation system is currently used?

In this chapter will be zoomed in on the activities that regard the allocation of elective and emergency capacity and the usage of both capacities. Those activities will be analyzed in detail to give a clear understanding of the current capacity allocation system (i.e. an answer to the second sub question).

In the OKplus data it is not registered which OR is an emergency room. Most data in this chapter is based on a database containing surgeries performed at the USA-OR on 251 working days in 2009. These records are created by manually registering which OR is the USA-OR. The structure of this chapter is shown below (see figure 17).

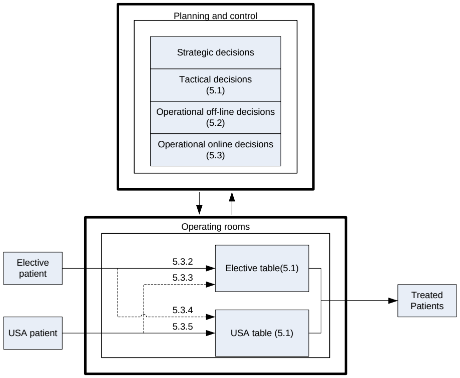


Figure 17 Steering model of operating room centre

In analyzing the dataset mentioned above, it becomes clear that it often happens that emergency patients are operated within elective capacity. The magnitude of these patients flows are shown in figure 18 .

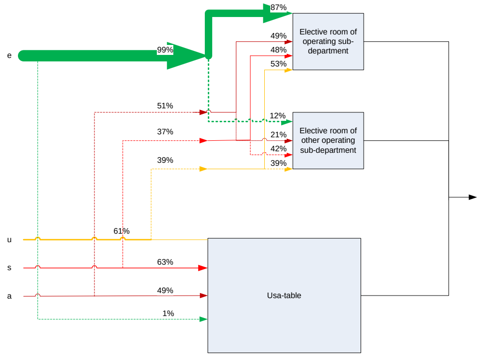


Figure 18 Patient flows through operating centre (data obtained from the dataset containing surgery data of the USA-OR's in 2009)

5.1 Operational offline decisions concerning capacity allocation

On an operational offline level, the elective patients are scheduled, i.e. they are assigned a time of surgery and an operating room. The amount of patients to be scheduled depends on the planned surgery durations.

5.1.1 Elective patient scheduling

From the OKplus-data of 2006-2009, the efficiency of planned capacity can be deducted. The data consist of all elective surgeries performed in one of the OR's defined in the scope of this research. Table 6 summarizes the planning deviation on the large departments. A limited number of highly unlikely values are filtered, including three negative realized surgery durations. The results of table 6 have to be interpreted with care: estimating surgery durations is complicated and may be harder for some departments. The first three column from the right side indicate the percentage of surgeries that took (10-,20- and 50 percent respectively) longer than the planned time. For example 39% of the realized surgery durations from CAB, exceeded the planned surgery time with over 50%.

Dpt.	records	average error (m.)	Stdev (m.)	Surgeries with Planning deviation of:		
				Over 10%	Over 20%	Over 50%
CAB	2159	58	80	87%	67%	39%
CHP	805	118	154	86%	64%	41%
CKC	1474	31	46	85%	62%	36%
CON	1465	50	73	85%	61%	34%
CPL	2114	41	65	84%	61%	35%
CTR	2007	42	55	86%	64%	38%
CTX	435	57	50	79%	61%	24%
CUR	2005	22	54	79%	43%	19%
CVA	1530	50	59	84%	65%	33%
KNO	5563	19	55	78%	42%	18%
MOA	1653	17	61	68%	31%	9%
NCA	4438	34	61	78%	50%	20%
OHA	3292	10	30	74%	36%	16%
ORA	3877	30	63	77%	47%	18%
VGY	977	28	59	76%	44%	17%
VON	1327	34	69	81%	47%	22%

Table 6 Planning deviation per department (OKplus data 2006-2009)

The positive average error for most departments indicates that it occurs very frequently that departments plan less time than is needed. In total 26242 (73%) times, the duration of an elective patient took longer than the planned time. In only 9775 (27%) operations, the actual surgery duration was smaller than the planned time.

The standard deviation is high for all departments. This can be expected because of the large amount of non-standard operations. The performance on planning of "Chirurgie Heelkunde" (departments C**)seems poor. Over 60% of these estimated surgery times contain an error of over 20% in the planned surgery time. The MO* ("mondheelkunde") use a specialist that estimates surgery times. The average error between planned and realized surgery durations is relatively small and 10 percent of all surgeries contained an error margin of over 50, which is also relatively low.OHA ("oogheelkunde") plans surgeries, based on historic data. The average error is only 10 minutes.

It is hard to compare the departments to each other, because there may be large differences in the surgery characteristics (e.g. times for long complicated surgeries may be harder to estimate than standard procedures). OHA for example performs a relatively large amount of standardized procedures.

5.2 Operational on-line decisions concerning capacity allocation

On this level, the actual allocation of patients to operating rooms is performed. Elective patients are scheduled according to the decisions taken at other planning levels. These rules however cannot always be applied, for example if the USA-OR's are occupied and an acute patient arrives at the operating centre.

5.2.1 Emergency coordination

The magnitude of the flows is obtained from data of 2009. The column containing " Operated on USA OR" in Table 7 presents the amount of surgeries that were located (so surgeries starting before 7:15 and end within the timeslot are included in the calculation) on an USA-OR within the time-slot. Operated in Elective room means that the surgery of a patient started during the time-slot or half hour before the start of the time-slot.

type	Patient	Operated on USA-table:	Operated in Elective room:	Total
Elective	Elective	74	9276	9350
USA	Urgent	674	431	1105
	Spoed	355	212	567
	Acute	50	53	103
NB		1	0	1
total		**1154**	**9972**	**11126**

Table 7 Magnitude of patient flows (data obtained from the dataset with 251 working days of surgery data in 2009)

The majority of USA-patients are operated at the USA-OR: 60%. Thus 40% of the USA-patients are operated in an elective room. Tabel 7 describes the allocation of different types of patients to different types of ORs. Each of these possibilities are described in the next sections.

Elective patients in elective rooms

The standard policy is to allocate elective patients to elective rooms. The majority of elective patients (99%) are operated at elective OR's.

Elective patients in USA-rooms

74 elective patients were scheduled in an USA-room according to the dataset. In Three reasons for placing elective patients in USA-room are discussed:

Small departments without block time

Obviously, departments that perform procedures that require an OR-setting only a few times a year are not awarded a full block in the quarter-year schedule. Sometimes these departments are assigned USA-OR capacity. 34 (45% of total elective patients at an USA-OR) procedures are performed by departments which are never allocated their own block time.

Unused capacity

A proportion of the remaining elective patients are operated in USA-rooms simply because there were no USA-patients to operate. To analyze this effect, the utilization of the USA-OR on this day for USA-patients only is calculated. On the days that 40 elective patients were operated at an USA-OR (not for the reason discussed above), the utilization of USA-OR by USA-patients was low: on average 33,3%. This low utilization could be caused by the fact that these elective patients were scheduled. However, assuming that USA-patients have priority, it is concluded that approximately 40 elective patients were operated at the USA-OR because of the low USA room utilization at that time.

Registration errors

Another reason for the records of elective patients in OKplus may be human errors. Some of the 74 elective patients on the USA-OR's may have been emergency patients registered as elective.

USA patients in elective rooms

40 percent (696 patients) of the USA-patients are operated in an elective room in 2009. Three reasons for placing USA-patients in elective rooms are discussed.

Resource restriction.

From the 696 USA-patients treated at elective rooms: 354 patients (50%) were treated within the time-slot of the exact same department that performed the surgery:

- 226 urgent
- 102 spoed
- 26 acute patients.

In addition, 6 acute, 40 spoed and 81 urgent patients were treated in an elective OR of the head-department. This may imply that a resource restriction caused this deviation from the tactical policy.74 patients were treated in an elective room of which the timeslot was not assigned to any specialism and for 30 records the operating department was unknown. Some patients of KNO, OHA and NCA can only be treated at their elective OR's.

141 emergency surgeries took place on an elective room that was assigned to another sub-department and head-department than the one that needed to perform that surgery. Reason could be that the USA-OR is occupied (i.e.

capacity restriction) or an elective OR was free (overcapacity of elective OR):

Capacity restrictions of USA-OR

The acute patients have to be operated as soon as possible. Six of the acute patients treated at elective rooms were not operated at the USA-OR because it was occupied. One acute patient arrived just before the end of the timeslot, thus multiple operating rooms (that finished their elective schedule for that day) were available. The reason for 5 acute patients being operated within the OR of the department that performed the operation remains unknown.

To evaluate whether the urgent and "spoed" patients were being operated at an elective room because of capacity restrictions, the utilization of USA-OR's on the day that the urgent or spoed patient was treated is analyzed. The utilization will be calculated for the entire day, e.g. if 2 USA-OR's were used that day, the average utilization of those 2 OR's is calculated. The average utilization of USA-OR's on days that USA-patients are treated at elective OR's of a department that did not perform the surgery is 65% with a median of 66%. This is actually higher than the average utilization.

Overcapacity of elective OR

When an elective schedule ends well before the end of the timeslot, USA-patients are sometimes treated on the elective OR's, because the OR is available.

USA-patients in USA-rooms

This is the standard policy, 60% of all USA-patients are treated on an USA-OR.

5.3 Summary

This chapter provided a quantitative analysis of the operating room of the UMCG. The framework presented in Chapter 2 is used to categorize all planning and control decisions into tactical, strategic and operational decisions.

At the tactical level it is observed that not all emergency patients are being operated at the dedicated emergency room. 40% of the emergency patients are operated in an elective OR. 68% of those emergency patients were treated in the elective OR of the department that needed to perform the surgery. Resource restrictions may be the reason of why they were not operated at the dedicated emergency room. A large proportion of patients from the departments OHA, KNO and NCA can only be operated at the elective OR due to resource restrictions. Approximately 14% of the emergency patients were treated at the elective OR for the reason that the dedicated emergency OR was occupied. Finally, registration errors may be a cause for the high proportion of emergency patients being operated at an elective OR.

A very small proportion (1%) of elective patients are operated at the dedicated emergency OR. 45% of the elective surgeries within emergency capacity were performed by a department that is never assigned elective capacity. At the time of the remaining 55% of elective surgeries in emergency capacity, it is observed that the utilization of the emergency OR was lower than average.

Quantitative analysis of the operational rules showed that the surgery durations are structurally underestimated for all departments. This could cause overtime.

The impact that these conclusions have on the performance of the system is described in the next chapter.

6 Performance of the system

The choices of the strategic, tactical and operational levels that are described in the previous two chapters leads to a certain logistical performance. This performance is subject of the third research question:

How does the current system perform, with respect to a number of key performance indicators?

Each subsection of this chapter describes one key performance indicator that was determined in chapter 2:

- Utilization
- Overtime (frequency and duration)
- Cancelled surgeries due to planning related causes
- Waiting time for emergency patients
- Throughput
- Patients treated outside time-slot hours

These parameters are described and linked to one or more of the tactical and operational decisions defined in the previous chapter. Then the calculation of the KPI is defined and the score on the KPI is given and analyzed. The score is evaluated using data from the Benchmarking OK project.

6.1 Net Utilization

In many production environments, utilization of a resource is an important parameter. This figure shows the ratio of the time that the resource was occupied and the total time that the resource was available.

Kpi: net utilization
Planning allocation influence: the elective scheduling process influences the utilization: we have seen in chapter 4 that the surgery times are structurally underestimated, this could lead to a higher utilization, because more elective patients are scheduled than the available time (the sum of planned surgery durations may fit within the timeslot, the sum of realized surgery durations may not). Assigning USA-patients to elective rooms can also increase this KPI. The utilization of USA-OR's is influenced by the amount of available USA-patients that can be treated at USA-OR's and can be increased by operating elective patients at USA-OR's.
Calculation: the data is available within the UMCG, the numbers in figure 19 are calculated based on the definition of Benchmarking OK project.
Value: the overall utilization is 83%. Detailed values are shown in the table below.

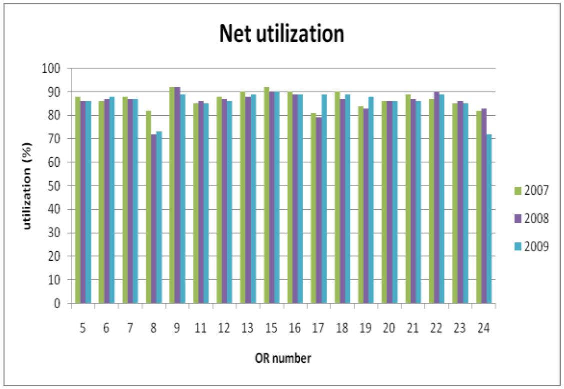


Figure 19 Net utilization of current operating room centre (OKplus data 2007-2009)

Score: OR 8 and 24 score relatively low in 2009. These rooms are most frequently used as the emergency OR's. The net utilization will be analyzed in more detail. The average utilization of all UMC's is 81%, thus the UMCG score is relatively good compared to the scores of other Dutch university medical hospitals.

6.1.1 Net utilization of dedicated emergency rooms

For the calculation of net utilization of USA-rooms only, the definition of utilization is adjusted: using the dataset containing data on USA-OR usage in 2009, there are 34 records found that started more than 30 minutes before the start of the time-slot and ended within the time-slot. Take for example a surgery that started 4:39, ended 14:20 and is marked USA; this surgery took a lot of capacity from the time-slot and cannot be neglected in the calculation of utilization of USA-OR's. At elective OR's, it rarely occurs that a patient will be treated more than 30 minutes before the timeslot starts.

The average net utilization over 483 OR days is: 60,0% with a standard deviation of 23,6%, median is 64,8%. Note that the difference between this figure and the 72% utilization in 2009 of OR24 (**Figure 19**) is explained by the fact that there were 30 days in the measured time interval with elective timeslots in OR 24. These elective timeslots will increase the average utilization of OR 8 and 24.

6.2 Gross norm utilization

A proportion of the time that there is no surgery taking place in an OR is due to turnover times. By adding these times to the numerator of the net utilization, the gross utilization is obtained. The Benchmarking project team determined an average of 10 minute changeover to be realistic for the calculation of gross norm utilization.

KPI: gross norm utilization
Planning allocation influence: see net utilization.
Calculation: see net utilization. Turnover times are added to the equation.
Value: the overall utilization is 89% Detailed values are shown in figure 20.
Tyler (2003) researched the optimum value of gross utilization of operating rooms: 85-90% was found to be the optimal value. According to this article and the benchmark, UMCG performs well with respect to this KPI . This does

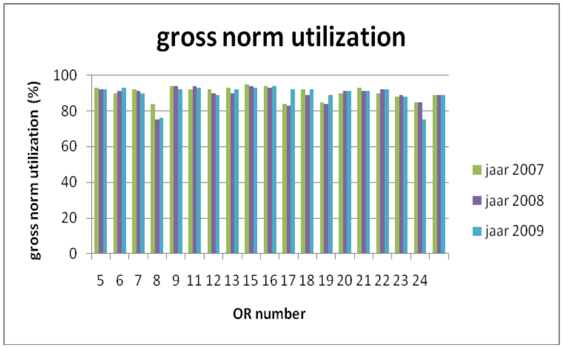


Figure 20 Gross norm utilization of current operating room centre (OKplus data 2007-2009)

mean that the OR's are rarely empty during a timeslot, however when utilization rates are too high, they may lead to an instable system.

6.3 Overtime

The UMCG decided to end the timeslot at 15:30. However in practice, it occurs very frequently that at this time there are still surgeries being performed in the operating rooms. There are two indicators that describe this effect: overtime frequency and duration. Duration is the average duration of overtime on days that overtime occurred and frequency is the ratio of OR days that overtime occurred and the total measured OR days. Sometimes, a department is allowed to operate after 15:30. This scheduled overtime will appear in these figures as overtime, see figure 21.

KPI: overtime
Planning allocation influence: elective patient planning may influence the chance of overtime by structurally underestimating surgery times. Departments that operate lots of USA-patients in their elective rooms may experience overtime frequently if too little capacity is reserved for emergency surgeries.
Calculation: the overtime frequency describes the frequency at which overtime occurs. The duration

describes the magnitude of overtime on days at which overtime occurred.
Value: mean of 2009 is 60 minutes, mean of all UMC's is 54 minutes.

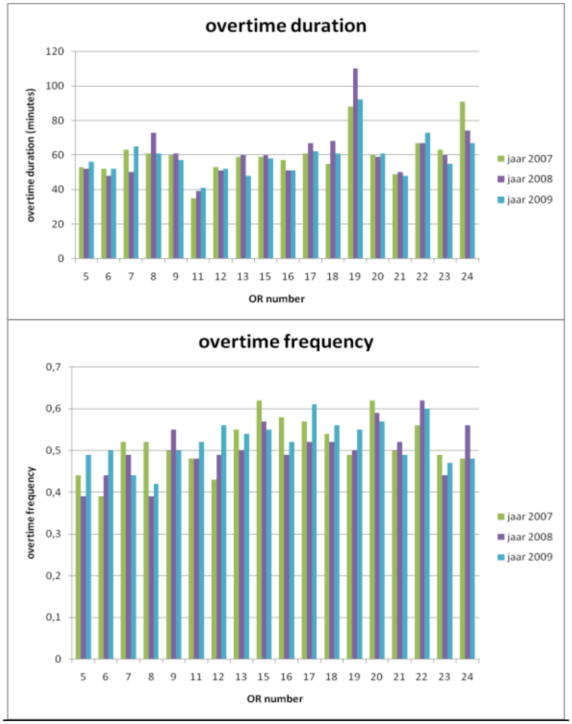


Figure 21 Performance indicators on overtime of current operating room centre (OKplus data 2007-2009)

Score: frequency of overtime at the UMCG is highest of all Dutch UMC's: 0,51 in 2009 (mean of all UMC's:0,4). Also the duration is high: 60 minutes. This is six minutes more than the mean of all UMC's. The score of the UMCG with respect to this KPI is poor. However, the scheduled overtime is also incorporated in these scores. So a proportion of the overtime is scheduled.

6.4 Cancellations

A dataset of all cancellations of surgeries in 2009 is used to determine the amount of cancellations: 921 surgeries in 2009 were registered to be cancelled on the same day that the surgery was planned. The reason for cancellation are not specified into great detail. Of 304 surgeries, the reason to cancel the surgery is not related to planning or capacity. Examples are patients that are ill (140 surgeries), patient no-show (25) or problems with materials (25).

The reasons registered for the remaining 617 cancellations may have been caused by the planning of surgeries. For 197 surgeries (21% of all cancellations in 2009), the reason was "Overtime OR". This indicated that the expected end time of that surgery caused too much overtime according to OZO-management. In 38 cancelled surgeries, the reason was registered as: because of emergency patient.

6.5 Waiting time of emergency patients

Waiting times of emergency patients are not analyzed in the benchmarking project. It is also not calculated at the UMCG. The time that an USA-patient arrives at the emergency department is registered. This time of arrival is registered in another information system than the surgery times. This performance indicator is evaluated at the simulation model in the next chapter using the simulation model.

6.6 Throughput

The Okplus dump of all surgeries from 2006-2009 at sector 2 and 3 (excluding OR 14) is used to extract the throughput data. See table 8.

6.7 Summary

In this chapter, each KPI that was determined to be important in Chapter 2 is evaluated. The score on KPI's is described and compared to the scores of other UMC's.

Average utilization of operating rooms overall is relatively good compared to the optimal value and scores of other UMC's. However it is observed that the utilization of the dedicated emergency OR's is significantly lower than the utilization of the elective OR's.
There is a high degree of overtime at the UMCG. A proportion of this overtime is not unwanted. This overtime is scheduled ("doorloop"). The (unwanted) overtime is caused by:

- Frequently underestimating surgery durations.
- Operating USA-patients in elective rooms, without reserving capacity for these patients.

Waiting times of emergency patients are not registered, according to literature these waiting times are important.

For the redesign in the next chapter this means that there is room for improvement on at least two points. Overtime is high and utilization of the dedicated emergency OR is low. Overtime can be reduced and the unused capacity of the dedicated emergency room could possibly be used more efficiently by changing operational and/or tactical decisions.

Year	Emergency patients	Elective patients	Total
2006	3864	8182	12046
2007	4028	8874	12902
2008	4037	9273	13310
2009	4208	9451	13695

Table 8 Throughput of operating rooms 5-24 (excluding OR 14) of current operating room centre (OKplus data 2007-2009)

7 System redesign

Using the knowledge of the previous chapters combined with discrete-event simulation, the fourth sub question is now evaluated:

At the UMC in Groningen, which capacity allocation system is best regarding the relevant performance measures?

In Chapter 2, discrete-simulation is selected to evaluate the different systems that allocate capacity for elective and emergency surgeries to operating rooms. The highly stochastic nature of the system is the main reason for this technique. In this chapter, first the methods and techniques to produce the simulation model are described. Next, from each of the four systems (identified in chapter 2) one scenario is selected and discussed. These four systems are evaluated in 7.3 and also alternative configurations of that system are evaluated. From all these scenarios, three configurations are selected: one scenario that performs well regarding throughput, one scenario that performs well regarding overtime and one scenario that is a good trade-off between all KPI's.

7.1 Methodology for the comparison of capacity allocation systems

The literature review provided a comparison of the different capacity allocation systems. The systems are evaluated in the UMCG environment using discrete-event simulation. By the development of a conceptual model (using the method described in the book of Robinson (Robinson, 2004)), the current operating room system is modeled. This is translated into a coded model in the software package Flexsim Healthcare. The base case scenario is a representation of the current operating room centre. By comparing this model to several input and output data of the real operating room system, the model is validated and verified in Appendix IV Model verification and validation. A screenshot of the model is shown in figure 22:

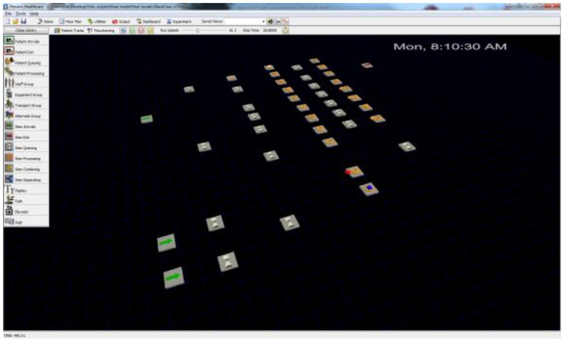


Figure 22 Model screenshot

By changing variables, numerous experiments, including the capacity allocation systems that are identified in chapter 3, can be implemented. The set of experiments is divided into the four capacity allocation systems. A scenario (or experiment) is a combination of values of the experimental variables, see table 9**.** Technical details of the model are placed in the appendices.

The factors that are not changed are the fixed factors (table 10). These values are determined in such a way that the real situation is approached the best and are applied to each scenario.

Category of experimental variables	*Experimental variable*	*Value*	*Value in base case*
Tactical	**Planning allocation system**	The variable takes on one of the values that are described in chapter 3: - Dedicated emergency rooms. - Versatile OR's - Hybrid system. - Dedicated emergency rooms with standby patients	Dedicated emergency rooms.
	Dedicated emergency rooms	The OR numbers that are used as emergency OR	8 and 24
	Versatile ORs	The Or numbers that are assigned both an elective schedule and emergency capacity.	-
	Alternative start time elective schedule	The times at which the first elective patient for the versatile operating rooms start. All ORs start at the aimed timeslot (plus late start) except OR 24 (and possibly 8 if two times are given for this variable) that will start at the time of this variable.	-
Operational	**Reasons to cancel elective surgeries:** **Max endtime** **Max number of overtime OR's**	If the current time added to the planned surgery time is above this variable, the surgery is cancelled. If there is overtime expected at more OR's than the value of this variable, the elective surgery is cancelled.	16:30 6
	Reasons to send USA-patients to elective rooms: **Endtime elective schedule** **safetybuffer**	If the elective schedule of an OR finishes before this value, and an USA-patient of the department that was assigned this OR is available, the USA patient will be send to this OR. If the current accumulated surgery times of USA-patients is larger than the USA-OR capacity added to this variable, the USA-patient is send to an elective OR.	15:00 240 minutes
	Spreaded starttime Starting time OR 8 & 24	The times at which the first elective patient is scheduled in OR 8 and 24.	-
	Standby-patients **max USA-patients** **surgery duration**	The decision of calling a standby patient based on whether the amount of waiting USA-patients is smaller than this variable The surgery durations of standby patients are long (200 m.), medium (120 m.) or short (60 m.).	- -

Table 9 Experimental variables of simulation model.

Component	Include/exclude	Comment
Patients	Include	
-department per patient	Include	Departments influence the average surgery time.
-USA patients	Include	Patients distributions
-USA patients that cannot be treated on USA-OR	Include	These patients have to be operated on the elective OR of the department.
-Elective patients	Include	List of patients with different duration.
-general characteristics (age, etc.)	Exclude	May influence the surgery durations, but this is already represented in average surgery times (drawn from a large sample).
-patients requiring sectio	Exclude	Majority treated in OR14, which is excluded
Operating rooms	Include	
-location	Include	Model the OR's on UMCG map.
-capacity	Include	Time slots, 1 patient/OR
-department	Include	Department is assigned an OR
-Late start	Include	The daily starttime of the OR determined by a empirical distribution.
Queue before OR's		
-capacity	Exclude	Capacity of queue is infinite.
-priority rules	Include	All patients arrive at the queue and are ordered by: 1. Patients status 2. Time to be operated for emergency patients

Table 10 Fixed variables of simulation model

Thousands of different configurations can be made by changing a single experimental variable. The selection procedure of the possible experiments is discussed in the next section.

7.2 Selection of scenario's

The complete set of experiments is shown in Appendix III Project specification. This broad range of experiments is selected by first changing the tactical experimental variables for each system. Then, both for dedicated and versatile rooms, the set of operational rules is changed.

In the previous chapter is concluded that overtime and emergency capacity utilization are the KPI's that can be improved. In determining the optimal scenarios the trade-off shown in figure 23 is observed in most scenarios. When the performance of the right side of the balance is

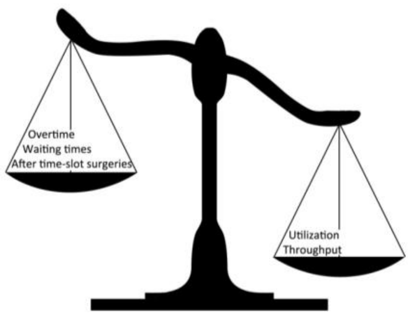


Figure 23 Trade-off between KPI's.

improved, one or more KPI's of the left side will decrease and vice versa. Thus, a choice has to be made between improving overtime, or utilization of the USA-room.

One initial scenario for each capacity allocation system is selected in this section. For this selection, the values on the left of the balance(waiting times, overtime and surgeries starting after 15:30) should remain similar to the base case and the right side (throughput and amount of elective surgeries) is optimalized. These scenarios are manually selected from the simulated scenarios by the researcher. Alternative scenario's, for example scenarios that perform well regarding overtime, are described in sections 7.3.x. All scenario's are compared to the model of the current system (i.e. base case), shown below.

The KPI's are calculated as defined in Appendix I, the waiting time is in the model calculated by measuring the time between arrival of the patient and the time that an OR is available. The amount of times that this time exceeds 30 minutes is the output variable: Waiting time>30 minutes. The scores of the KPI's of the base case are set at the index value of 100%. For the other scenario's, a favorable change of a KPI will lead to a score of over 100%. This is true for all KPI's. If a scenario performs worse on a KPI than the base case, the score of this KPI will always be less than 100%.

For example if overtime frequency in scenario is 0,54, the score on this KPI equals 0,56(value in base case)/0,54= 104%. The scenario's are numbered using 3 digits. The first digit denotes the system as described in chapter 3, i.e. [1xx] is a dedicated emergency rooms system,[2xx] versatile OR system, [3xx] a hybrid system and [4xx] a emergency rooms system with standby patients.

The exact configuration of all scenario's discussed in this chapter can be found in Appendix III Project Specification.

All experimental variables used in the text of this chapter are put in between quotes. A description of these variables are found in table 9.
A graph of the initial set of scenario's is presented in figure 24.

The forthcoming selection of scenario's consist of the scenario's (one of each capacity allocation system) that, given a similar score on-overtime, waiting time for emergency patients and surgeries started after 15:30- generate a larger throughput.

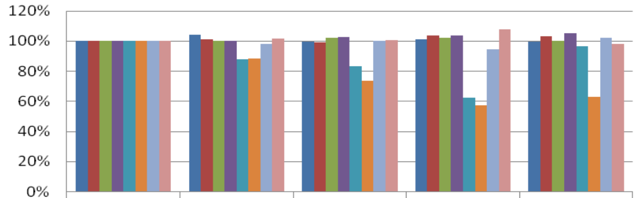
scenario	Overtime frequency	overtime duration	Net utilization	Throughput (elective patients)	Average waiting time in (m.) session	Waiting time Acuut >30 m.	Waiting time Acuut >60 m.	usa-patients outside timeslot	cancellations
101	56,29%	83	83,30%	49238	11,9	116	75	9808	10139

Table 11 Output of base case, 5 year run

The selected scenario's are as follows:

1. The dedicated OR system of scenario [108] uses the same configuration as the base model. However by decreasing the variable "safety buffer" (0) and "electivefinish" (14:00), more USA-patients are sent to the USA-OR instead of the elective OR.
2. The simulation model with seven versatile operating rooms is selected in which 700 minutes of emergency capacity is used: [231]. Operational rules are identical to the rules of the above described system. The starting time OR8" equals 10:30, "starting time of OR24" is 9:00. The choice of 700 minutes is discussed in section 0
3. Four versatile rooms and one dedicated emergency OR are used in scenario [307], with one versatile room starting at 9:00 to reduce waiting times. Again 700 minutes emergency capacity is used and operational rules are similar to the scenario described above.
4. Scenario [403] is equal to scenario [108] (described under 1.) but standby patients are added. Each time a patient leaves an USA-OR and there are no patients to be operated at the USA-OR; a standby is called and will arrive after 60 minutes. The surgery duration of all these patients (in this scenario) is set at "short" (i.e. 60 minutes.).

The scenario's above form the starting point of the description of the capacity allocation systems applied to the UMCG. For some stakeholders, decreasing overtime may be more important than increasing throughput. This is why, for each capacity allocation system, other scenarios are discussed including scenario's that will increase the performance on average overtime (i.e. decreasing overtime frequency and/or duration).



	[101] Base Case	[108] 2 Dedicated Ors	[231] 7 versatile Ors	[307] 1 ded. OR, 4 versatile Ors	[403] 2 dedicated rooms, standby patients
Overtime frequency	100%	104%	100%	101%	100%
Overtime duration	100%	101%	99%	104%	103%
Net utilization	100%	100%	102%	102%	100%
Throughput	100%	100%	103%	104%	105%
avg. Waiting time	100%	88%	83%	63%	97%
Waiting time>30 minutes	100%	89%	73%	57%	63%
after 15:30 surgeries	100%	98%	100%	95%	102%
Cancellations	100%	102%	101%	108%	98%

Figure 24 Selection of one configuration for each capacity allocation system

7.3 Comparison of capacity allocation systems at the UMCG

In the next four sections, each system is evaluated into more detail. Instead of aiming to improve throughput while keeping overtime scores similar (compared to the base case), scenario's that realize the opposite are evaluated too. In each section, the configuration of scenarios is described first, after which the system is discussed. For systems that contain a dedicated emergency room, also the utilization of OR 8 and 24 is calculated.

7.3.1 Performance of the dedicated emergency rooms

Four different configurations of the dedicated emergency rooms system are selected, all variables are equal to the base case unless indicated otherwise:

1. A stricter cancellation policy than the base case is used in [102]: the variable "maxendtime" is decreased to 16:15.
2. Scenario [106] is run to evaluate the theoretic scenario of never cancelling a surgery within a timeslot: "max endtime" and "max number of overtime ORs" are both set at infinity.
3. More USA-patients will go to the USA-OR in scenario [108] by decreasing the "safetybuffer" to 0 and "elective finish" to 14:00.

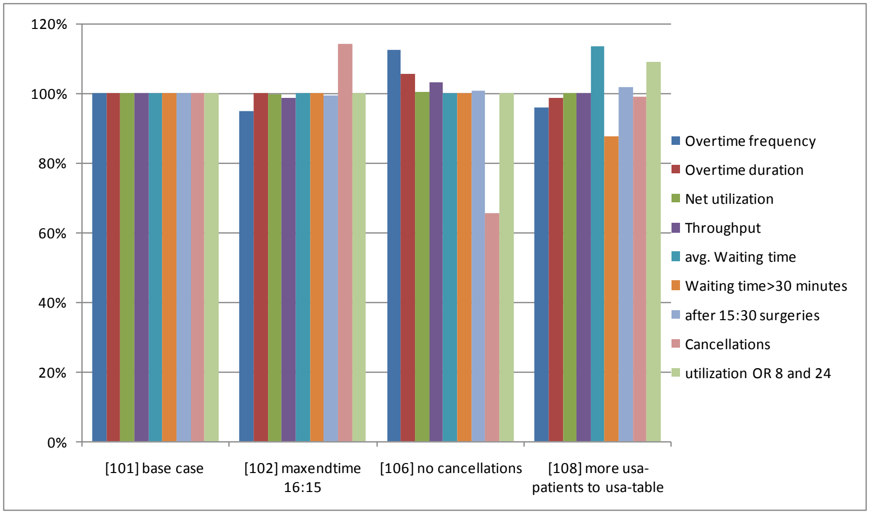


Figure 24 Performance of three variants of dedicated emergency rooms

Compared to the other systems, this system has the disadvantage of underutilization of the dedicated emergency rooms (see figure 25). The throughput of this system is less than many of the other systems because of this unused capacity. In the simulation model, the amount of emergency capacity is always 920 minutes on Thursday through Friday and 880 minutes on Monday even though this amount of capacity is rarely needed completely.

The USA-capacity model that is actually used is less than 920 minutes a day on 87% of the simulated days (see next section). One USA-OR would have had enough capacity for all USA-patients on 30% of total simulated days. This would lead to an unacceptable amount of overtime, so the scenario with only one USA-OR is not simulated.

The impact of the decision to send USA-patients to elective rooms on the performance is interesting: the simulation model generates less overtime, higher utilization and more throughput if more USA-patients are send to the USA-OR. This is realized in scenario [108] by decreasing the "safetybuffer" and "elective finish": if the capacity of the USA-OR in minutes subtracted by the accumulated surgery times of waiting USA-patients in minutes is larger than zero (this is the simulation variable "safetybuffer", 240 minutes in base case), the USA-patient will go to the USA-OR. If an elective schedule ends before 14:00 (this is the simulation variable "electivefinish", 15:00 in base case) and there is an USA-patient of this department available, this patient will be treated at the elective OR. Downside of this scenario is that the waiting time for acute patients is increased with 1,7 minutes compared to the base case.

7.3.2 Performance of the versatile OR system

Six configurations of this system are selected, see figure 25. In all configurations, "safetybuffer" equals 0 and "elective finish" is 14:00. The starting time of OR 8 is 10:30 and that of OR 24 is 9:00.

All other operational variables are equal to the base case:
1. The amount of emergency capacity in scenario [213] is 700 minutes, this capacity is allocated among four versatile ORs.
2. The amount of emergency capacity in scenario [219] is 700 minutes, this capacity is allocated among five versatile ORs.
3. The amount of emergency capacity in scenario [225] is 700 minutes, this capacity is allocated among six versatile ORs.
4. The amount of emergency capacity in scenario [231] is 700 minutes, this capacity is allocated among seven versatile ORs.
5. The amount of emergency capacity in scenario [237]is 700 minutes, this capacity is allocated among eight versatile ORs.
6. The amount of emergency capacity is 920 minutes in scenario [229] this is equal to the capacity of two dedicated emergency ORs. This capacity is allocated among eight versatile ORs.

The amount of emergency capacity is one of the most important decisions using this system: too much emergency capacity will cause underutilization and too little will cause many overtime. The size of planned slack in the research of Wullink (2007) is calculated based on the assumption that surgery durations are normally distributed. A maximum acceptable risk of overtime determined the size of the planned slack (this is easily calculated using the cumulative distribution function). In the simulation model of the UMCG, the surgery durations of emergency patients are not (near-)normally distributed. A simulation run of the base model shows that 626 minutes of emergency capacity is sufficient at exactly 50% of the simulated days.

The indication of figure 27 combined with the method of trial and error showed that 700 minutes of emergency capacity leads to an overtime that is similar to the overtime of the base scenario. On 41% of the simulated days, the cumulative emergency surgery durations was, or exceeded, 700 minutes. This amount of required capacity is calculated by adding the surgery durations of surgeries that actually were performed at the dedicated emergency room.

The amount of versatile OR's is another important tactical experimental variable. When four versatile OR's are used, 920/4=230 minutes emergency slack is allocated to each OR. Eight versatile ORs means that only 115 minutes of emergency slack for each operating room is used. This means that there are more break-in moments (decreasing waiting time for acute patients) but the chance on overtime will increase because the emergency surgeries will often not fit within the 115 minutes emergency capacity. In the initial set of experiments, a waiting time for acute patients (around 30 minutes) is observed that is much higher than the base case (11 minutes). This is caused by the emergency patients that arrive in the morning: because all rooms are occupied with elective patients, this patients has to wait until a surgery ends. This long waiting time is reduced by introducing two new operational variables that sets alternative starting times for one or more versatile OR's.

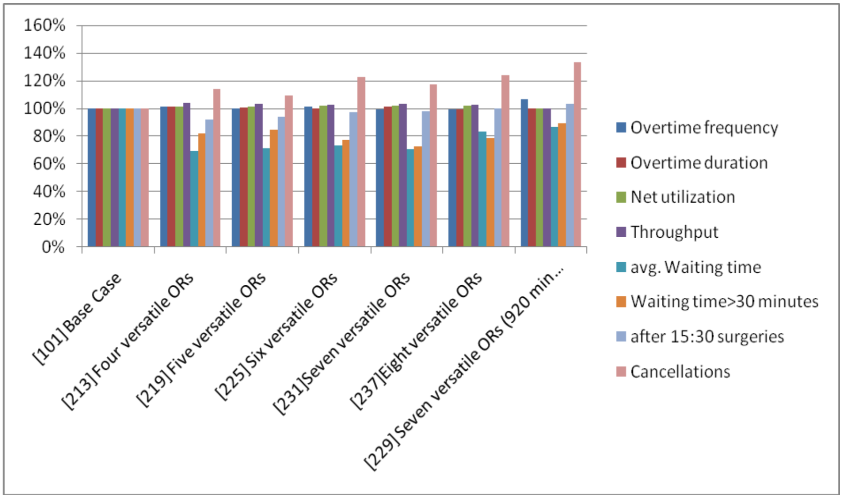


Figure 25 Selection of six configurations of the versatile rooms system

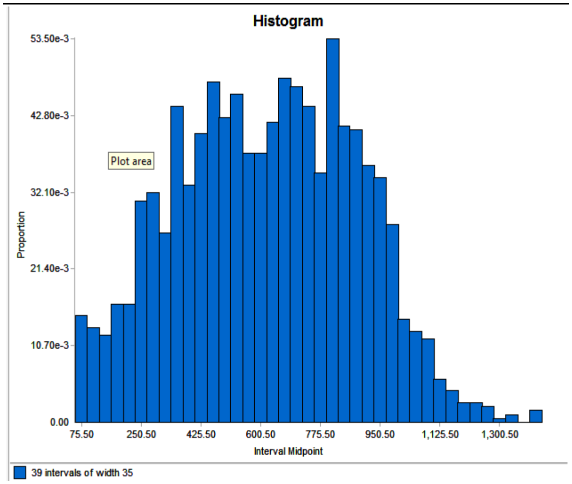


Figure 26 Histogram of average daily used emergency capacity in the simulation model (calculated using ExpertFit)

7.3.3 Performance of the hybrid system

Four scenarios are shown in figure 27 and all contain 700 minutes of emergency capacity and operational decisions are equal to base case scenario except for the "safety-buffer" (0) and "elective finish" (14:00):

1. Operating room 24 is used for emergency surgery only (i.e. dedicated emergency room) in scenario [307]. The remaining capacity of (700-460=)240 minutes is divided among four versatile ORs.
2. Operating room 24 is used for emergency surgery only (i.e. dedicated emergency room) in scenario [308]. The remaining capacity of 240 minutes is divided among three versatile ORs.
3. Operating room 24 is used for emergency surgery only (i.e. dedicated emergency room) in scenario [309]. The remaining capacity of 240 minutes is divided among two versatile ORs.
4. Operating room 24 is used for emergency surgery only (i.e. dedicated emergency room) in scenario [310]. The remaining capacity of 240 minutes is divided among one versatile OR.

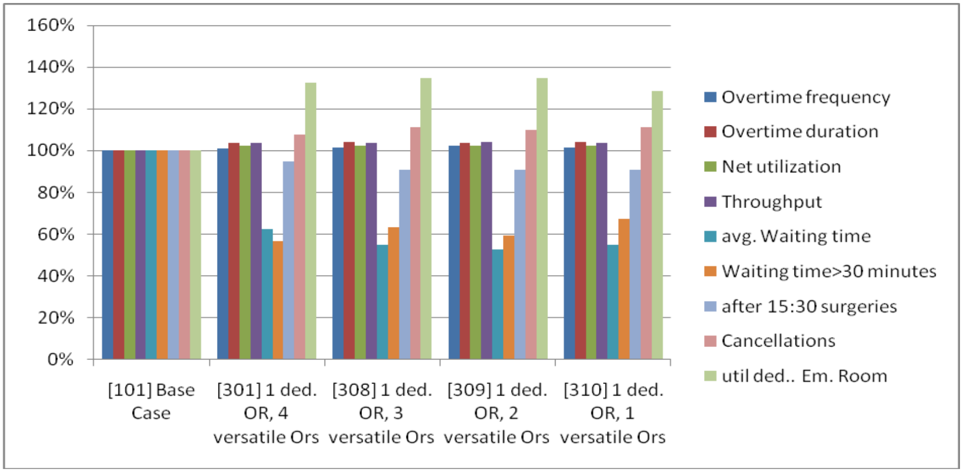


Figure 27 The performance of four hybrid systems

The main advantage of the hybrid system compared to the dedicated emergency rooms system is that the emergency capacity can be decreased. The effect of the amount of versatile OR's is the same as described in the previous section. Again, 700 minutes of emergency capacity will lead to a similar overtime as the base case, while throughput is increased.

7.3.4 Performance of the Emergency rooms with standby patients

All operational experimental variables of the scenarios in figure 28 are equal to scenario [108]. This means only the variables "safetybuffer" (0) and "elective finish" (14:00) are adjusted compared to the base case.

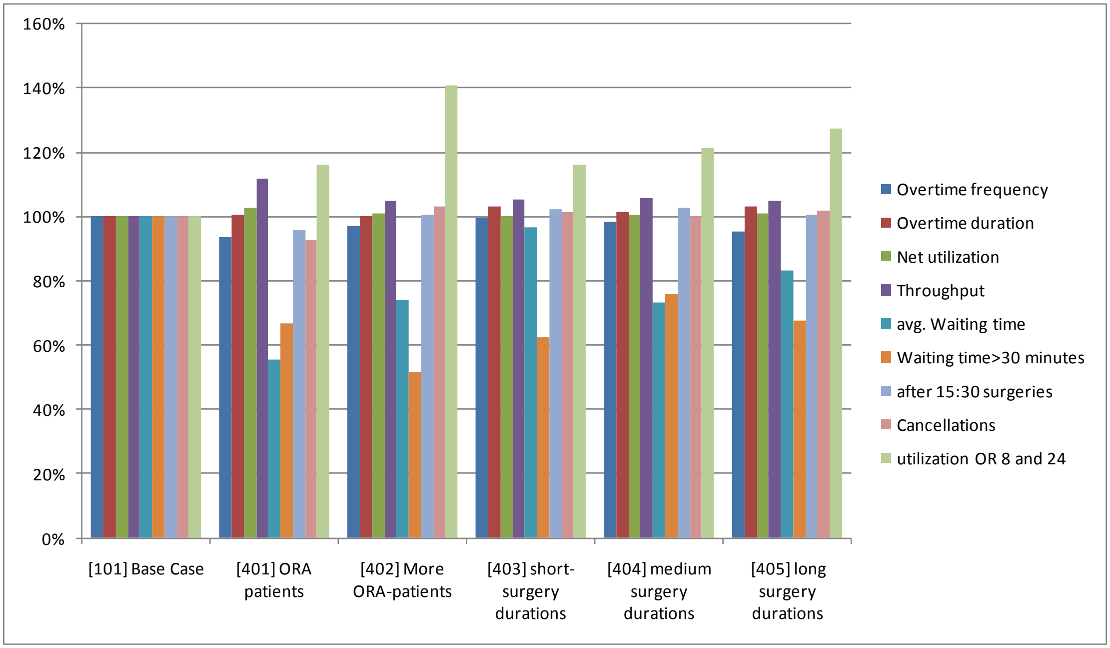


Figure 28 Performance of five scenario's making use of standby patients

1. In scenario [401], each time there is one or zero emergency patient waiting for the USA-OR, a standby patient is called. The surgery duration of the standby patient equals the surgery duration of an orthopedic patient.
2. In scenario [402], each time there are no patients waiting for the USA-OR, a standby patient is called. The surgery duration of the standby patient equals the surgery duration of an orthopedic patient.
3. In scenario [403], each time there are no patients waiting for the USA-OR, a standby patient is called. The surgery duration of the standby patient is short (60 minutes fixed).
4. In scenario [404], each time there are no patients waiting for the USA-OR, a standby patient is called. The surgery duration of the standby patient is medium (120 minutes fixed).
5. In scenario [405], each time there are no patients waiting for the USA-OR, a standby patient is called. The

surgery duration of the standby patient is long (200 minutes fixed).

The use of standby patients is a way to fill the underutilized USA-ORs. The effect of tactical and operational variables on the KPI's is the same as in the first system. The interesting experimental variables here are the variables that determine:
- When to call a standby patient
- What standby patient to use

In the simulation, each morning at 7:30 the available emergency patients are counted. If this amount equals the variable "minUSApatients" (equals 0 or 1 in the simulated scenarios), a standby patient is called. The same check is applied when a patient leaves an USA-OR. In some scenario's, a patient of the orthopedic department is called. Other scenarios contain a more abstract simulation of standby patients. Here the surgery duration of standby patients is fixed on short (60 m.), medium (120 m.) or long (200 m.) surgery durations.

It is easily observed that calling a standby patient each time that there is only one (or zero) patient in the USA-buffer leads to a very large increase in overtime. Calling one standby patient when there are no patient in the system leads to an improvement of all KPI's except waiting times for acute patients. This effect is strongest if patients are operated that require short surgeries.

7.4 Proposal for new design

The difference among the four systems depends on the set of tactical and operational decisions that is used. In general,

the systems that contain versatile operating rooms have the advantage of the possibility of adjusting the size of emergency capacity. On 60% of the simulated days, 700 minutes of emergency capacity is sufficient to operate all emergency patients. Using less emergency capacity (and thus more elective capacity), leads to an increase in utilization and throughput, but generally leads to higher waiting times, more surgeries starting after 15:30 and more overtime. This is the trade-off that is observed in most scenarios: throughput and utilization versus waiting times, overtime and surgeries after 15:30. Three different scenarios are proposed after evaluating all performance indicators that are used in this thesis. See **Table 12**.
- Seven versatile OR's with 700 minutes of emergency capacity in scenario [231].
- Seven versatile OR's with 920 minutes of emergency capacity in scenario [229].
- Dedicated emergency rooms with standby patients with short surgery durations in scenario [403].

The first scenario [231] is proposed because more elective patients can be operated given similar performance on overtime and patients treated after 15:30 as the current situation. Scenario [229] allows the same amount of patients to be operated as the current scenario, but overtime frequency decreases with 6,5%. The third scenario slightly decreases overtime duration, but throughput is increased with 5,4%.

7.5 Sensitivity to increase of emergency patient flow

Over the previous three years, the amount of emergency patients increased each year. Compared to 2007, 0,22% more emergency patients were operated. Compared to the previous year, the increase in 2009 was 4,2%. The three systems that are proposed are simulated again with an increase in emergency patients to evaluate if the systems can handle emergency patients increases in the future (see figure 30).

Scenario	Overtime frequency	Overtime duration	Net utilization	Throughput	avg. Waiting time	Waiting time>30 minutes	after 15:30 surgeries	Cancellations	utilization OR 8 and 24
[101] base case	100%	100%	100%	100%	100%	100%	100%	100%	100%
[231]Seven versatile ORs (700 min. emergency capacity)	99%	101%	102%	104%	70%	73%	98%	117%	-
[229] Seven versatile ORs (920 min emergency capacity)	107%	100%	100%	100%	87%	89%	104%	134%	-
[403] standby patients with short-surgery durations	100%	103%	100%	105%	97%	62%	102%	102%	116%

Table 12 Output of proposed scenarios

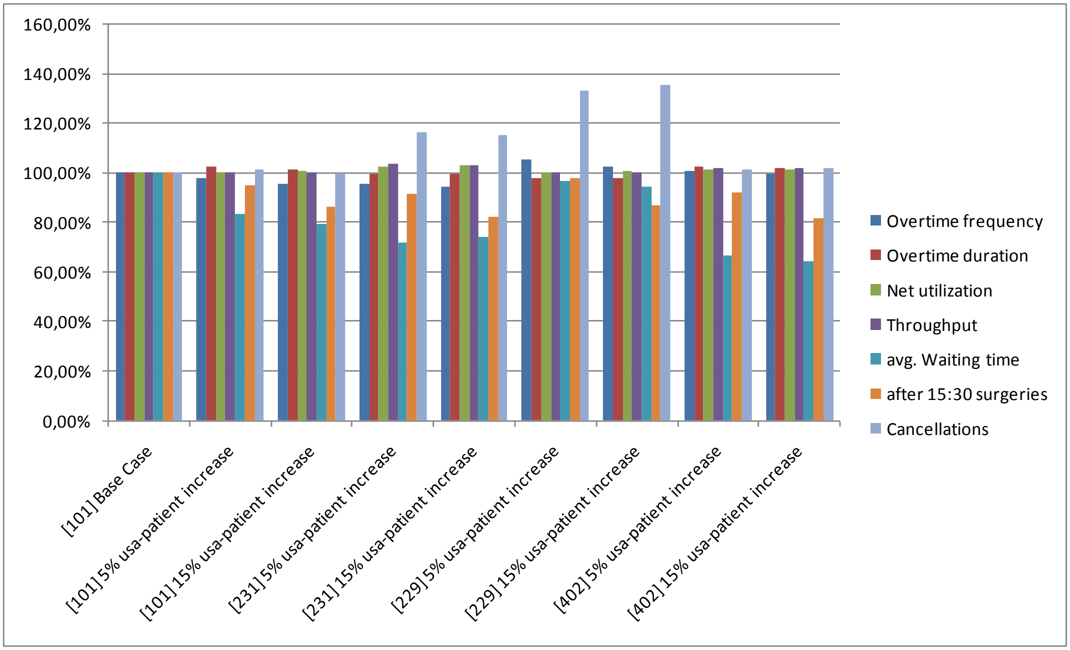


Figure 29 Impact of an increase in emergency patients on performance

The current system can handle an increase in emergency patients without a large increase in overtime. With an increase of 15% in USA-patients, the average waiting time will increase with about 20%. In the versatile OR system, overtime and average waiting time will increase even more when more emergency patients arrive. So, when more emergency patients arrive; 700 minutes of emergency capacity is not sufficient.

7.6 Additional improvements

The planning deviation and late start are independent of the capacity allocation system: selecting another capacity allocation system would improve nothing to the planning deviation and/or late start. Because these two factors do influence the logistical performance of this operating room centre and are incorporated in the simulated model, these effects are researched using the base model and are shown in figure 31.

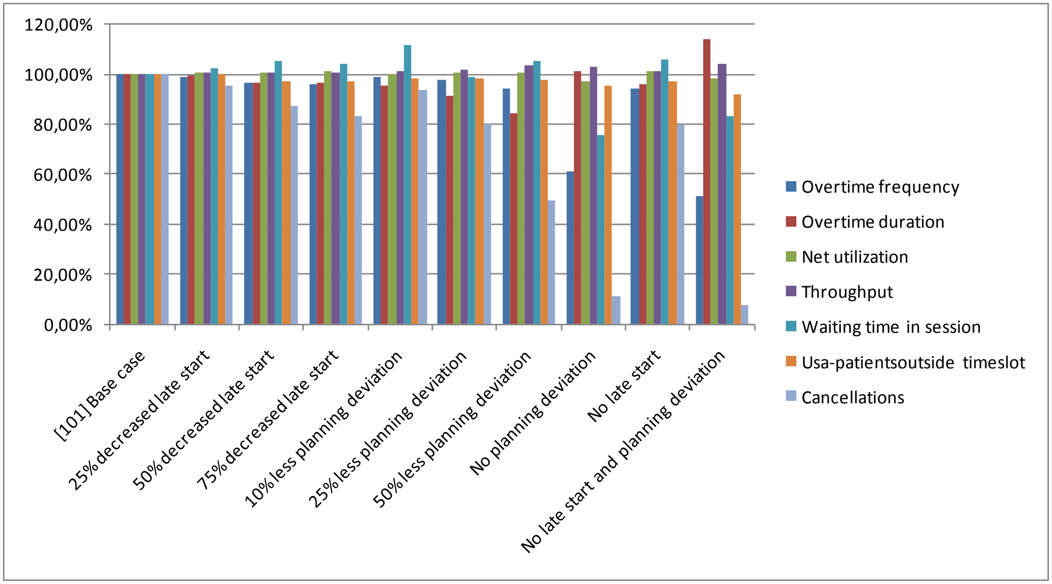


Figure 30 Impact of overtime and planning deviation on performance

In the theoretical case of always starting at the start of the timeslot, overtime frequency is reduced by 5.52%. The influence of planning deviation on overtime is even larger. When all planned times equal the realized times in this simulation model, overtime frequency would decrease with almost 40%.

7.7 Summary

In this chapter, different scenarios of the four systems are evaluated in the environment of the UMC Groningen. Discrete-event simulation is used to compare the output of these systems. Given the set of performance indicators there is no configuration of the tactical and operational variables that performs best on all KPI's: a trade-off between several KPI's is observed. The utilization of the current system can be improved, but this would negatively influence one or more of the following performance indicators: overtime, waiting time for acute patients and surgeries started after time-slot hours. Because no system outperforms the others on all KPI's, three scenarios are proposed by the researcher.

Regardless which planning system is used, the model revealed that a more accurate estimation of surgery durations and late start reduction would increase the performance with the magnitude shown in figure 31.

8 Practical considerations

The simulation model showed that the versatile operating rooms system has many advantages. Changing the dedicated operating room system into a system with versatile OR's only, as proposed in the previous chapter, would yield changes to the logistic process. In this chapter, the fifth research question is discussed:

If a new system is designed; what are the practical implications of such a system?

The application of the versatile OR system would yield the following changes:

- Planning offices of certain departments have to schedule surgeries in shorter timeslots.
- More often, the decision has to be made to either operate an USA-patient or the next elective patient.
- More often, an elective surgery will be postponed because an USA-patient arrived.
- Surgeons will have to travel to another operating room more often.
- The workload will increase because more patients are operated.

To research this effect, the simulation models are run again. This time the performance indicators are:

- Amount of elective surgeries being postponed because of emergency patient arrival
- Amount of elective patients that are cancelled because of emergency patient arrival
- Decisions to operate emergency patient or elective patient

The strict priority system will cause few elective patients being postponed or cancelled in all systems. This is because "spoed" and urgent patients can often be operated after the elective schedule, because these patients can wait 6 and 24 hours respectively. The decision of operating an USA-patient or the next elective patient is made almost three times as much in the versatile OR system.

The results of scenario [403] are equal to the base case. Yearly, there should be about 270 patients available for standby surgery that can be at the operating centre within one hour in order to apply this scenario. The surgery duration of those patients should be as short as possible.

Scenario	Postponements because of emergency patients	Cancellations because of emergency patients	Decisions to operate elective or emergency
[101]	373	312	8207
[229]	285	372	24873
[231]	364	512	25925

Table 13 Performance of scenario's on three alternative KPI's

9 Conclusion and Recommendations

In this chapter, the problem statement is discussed:

(How) can the logistical performance of the operating room centre of the University Medical Center Groningen be improved by changing the system to allocate (capacity for) elective and emergency patients to operating rooms?

Based on the findings of the sub questions, the above question is answered. In the second section of this chapter, recommendations are discussed. Finally suggestions for further research are made.

In the comprehensive literature study of Cardoen is stated that the literature on non-elective patients is scarce. No article was found that discussed different capacity allocation systems in detail. This research contributes to this.

9.1 Conclusion

The performance of the operating rooms centre of the UMCG can be improved by using a different allocation of emergency and elective capacity. This room for improvement exists mainly because of the current underutilization of the USA-OR's: 60% of daily capacity is used on average. This is surprising given the fact that only 60% of the USA-patients are actually operated at the USA-OR. Reasons for sending USA-patients to elective rooms include:

- Resource restrictions of emergency OR
- Capacity restriction of emergency OR
- Overcapacity of elective OR

Other reasons are unknown. Registration errors may cause this number to be higher than in reality. The simulation model showed that the scores in terms of overtime, utilization and throughput are increased if more of the USA-patients are operated on the USA-OR. Negative effect is that on average acute patients would have to wait longer for operating room capacity.

Using versatile operating rooms proved not to have the problem of underutilization of emergency capacity. An important advantage of versatile rooms is that the capacity that is used for emergency patients is utilized more efficient because demand and capacity can be balanced. 700 minutes of emergency capacity is found to be sufficient in 60% of total simulated days. Disadvantage is the waiting time for acute patients. In the current system USA-OR's are often not in use when an acute patient arrives combined with the possibility of operating this patient at an elective OR's; the average (theoretical) waiting time for acute patients is low.

These waiting times will not decrease using versatile ORs (contrary to the findings of Wullink (2007))because of the good score on average waiting times for acute patients in the current system: only 12 minutes in the simulation model.

In the current system, the utilization of elective rooms is close to the optimal score (Tyler, 2003), but there is a high degree of overtime. According to the simulation model, this is caused by (in this order, starting with the biggest cause for overtime in the base scenario simulation model):

1. Structural underestimation of surgery durations
2. Emergency patients operated at elective rooms
3. Late start

Scheduled overtime ("doorloop") may be incorporated in the scores of overtime. Scheduled overtime occurs if a department request to operate till after 15:30 and thus not all overtime is necessarily "unwanted". In the current registration system, it is hard to make a distinction between these two kinds of overtime.

The most suitable system to the UMCG depends on what performance indicators are regarded most important. Three systems are proposed, one scenario that increases performance on throughput, one scenario that increases performance on overtime and an alternative system that is a trade-off between overtime and throughput:

- Using no dedicated emergency rooms and divide 700 minutes of emergency capacity among 7 operating rooms to increase throughput.
- Using no dedicated emergency rooms and divide 920 minutes of emergency capacity among 7 operating rooms to decrease overtime.
- Keep the dedicated emergency OR, but fill the capacity with standby patients. Each time there are no emergency patients a standby patient requiring a short surgery is called.

Regardless of the capacity allocation system, at least two possible additional improvements are identified:

- Decreasing late start
- Estimating surgery durations more accurately

Late start occurs if the first surgery starts after the start of the timeslot (7:50 or 8:10 at Monday). This late start is evaluated by applying empirical data to the simulation model. Always starting on time will reduce overtime frequency by 5% and cancellations (using the defined cancellation rules) with 20%. In the real system this effect may be smaller given the assumption made in the simulation model: late start is independent of the planned utilization.

Surgery durations are structurally underestimated. Lower planned utilization are used to compensate this effect. The simulation model showed that this is the main cause for overtime in the simulation model: average overtime would decrease with almost 40% if all surgery durations are estimated with perfect accuracy. However, this does decrease the throughput.

9.2 Recommendations

Besides the proposed scenario, some other recommendations by the researcher are:

- Registration of the time that an emergency patient arrives and is diagnosed to require surgery, will increase visibility of the system. Especially the magnitude and allocation of the group of semi-emergent patients is unclear.
- Register which OR is the USA-OR to gain more reliable data on the utilization of the USA-OR's.
- Planning offices should make more frequent use of the possibility in OKplus of estimating the surgery duration based on the average surgery duration of a number of previous surgeries. OHA performs well using this method.
- USA-patients that can be operated on the USA-OR in the timeslot should be operated there more frequently if possible.
- Cancelling surgeries because overtime is expected at too many operating rooms can be detrimental for departments that plan well. It would be better to impair departments that cause overtime by planning inefficient. An example of a method that works well is used at Medical Centre Leeuwarden.(N. Slager, 2007)
- Decreasing late start and planning deviation might improve results.
- Registration scheduled overtime ("doorloop") should bring more insight in the proportion of overtime that is "unwanted").

9.3 Suggestions for further research

Projects that might improve the operating centre efficiency and/or gain better insight in the process could be projects on the subject of:

- The arrival pattern of emergency patients
- The possibility of using standby patients
- Decreasing late start of operating rooms
- Decreasing planning deviation by more accurate surgery duration estimations
- The reason of many USA-patients being operated at elective rooms
- Improving the allocation of capacity for semi-emergency patient
- Adding other sections of the "supply chain" to the scope of analysis (e.g. expanding the simulation model with the intensive care).

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Appendix I Departments making use of operating rooms

Departments in each sector, those which do not operate frequently (e.g. Kindergeneeskunde of Psychiatrie) are not included. The data is extracted from OKplus and are the number of surgeries registered in 2006-2009.

Sector	Head department	Sub department		Elective Surgeries	USA surgery
1	Thoraxcardiologie	*TCA*	Cardiologie algemeen	260	11
		TCO	Cardiologie congenitaal	277	14
	Thorax chirurgie	*THA*	hartchirurgie	3999	892
		THC	Thorax chirurgie	108	10
		TLO	Longchirurgie	811	83
		TLX	longtransplantatie	0	17
2	Plastische chirurgie	*CPL*	Plastische chirurgie	2125	725
	KNO	*KNO*	Keel-,neus-en oorheelkunde	5572	821
	Mondheelkunde	*MBT*	Bijzondere tandheelkunde	9	2
		MOA	Algemeen	1657	355
		MOI	Orale Implantologie	59	0
		MOO	Oncologie	147	9
	Neurochirurgie	*NCA*	Neurochirurgie	4462	1908
	Oogheelkunde	*OHA*	Oogheelkunde	3299	660
3	Chirurgie Heelkunde	*CAB*	Abdominale chirurgie	2181	2824
		CHP	Chirurgie hepato biliair (lever en gal)	806	141
		CHE	Heelkunde	0	6
		CKC	kinderchirurgie	1479	1417
		CLT	Chirurgie levertransplantatie	10	342
		CON	Chirurgische oncologie	1469	281
		CTR	traumatologie	2024	2452
		CTX	transplantatie	442	588
		CVA	vaatchirurgie	1547	877
	Urologie	*CUR*	urologie	2019	284
	Orthopedie	*ORA*	Orthopedie	3887	929
	Obstetrie & Gynaecologie	*VGY*	gynaecologie	1031	448
		VON	oncologie	1334	42
		VVE	verloskunde	290	1775

Table 1 Departments making use of operating centre

Appendix II Terminology of measurement system and performance measures

The activities on an OR-day are shown below. An OR-day is any combination of a date and operating room where, on that day, at least one surgery is performed. In daily UMCG language, session is used to indicate a time-slot. This is confusing, as in the project, a session ("zitting") is defined as the time between arrival and departure of one patient.

The use of "session" will be avoided in this thesis. The time between arrival and departure of one patient at the operating room is denoted by: surgery. In the UMCG the time-slot normally starts 7:50 and ends 15:30. Due to education on Mondays, the time slot starts on 8:10 on that day.

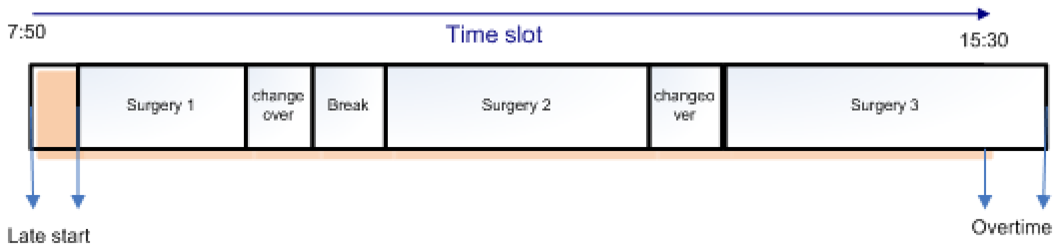

Figure 31 Measurement system

The opposite of a late start is an early start: this is in case the first surgery starts before 7:50. If the last patient leaves before 15:30, undertime occurs.
The performance measures used in this thesis are according to the Benchmarking project (A. Van Hoorn, 2008). Below a summary of these calculations based on the above measurement system.

Net utilization:

$$\frac{Cumulative\ surgery\ duration\ of\ surgeries\ starting\ timeslot}{timeslot\ duration}$$

Gross utilization

$$\frac{Cumulative\ surgery\ duration\ within\ timeslot}{timeslot\ duration}$$

Gross norm utilization

$$\frac{Cumulative\ surgery\ duration\ within\ timeslot + (numberof\ surgeries - 1) * 10}{timeslot\ duration}$$

Overtime Frequency

$$\frac{\text{number of OR days at which overtime occurred}}{\text{Number of total OR days at which utilization is calculated}}$$

Overtime duration

$$\frac{end\ time\ of\ last\ surgery\ of\ the\ day - 15{:}30}{\text{Number of total OR days at which overtime is observed}}$$

Cancellations

Amount of elective surgeries that are cancelled (or postponed) because of planning related causes.

Waiting time for emergency patients
Time at which the emergency patient enters the operating room-changeover time-time of arrival at the operating room centre.

Throughput
Number of elective patients treated in a time interval.

Patients treated outside time-slot hours
Number of surgeries that start after 15:30.

Appendix III Project specification

The output of the conceptual modeling is described in this project specification. This project specification can also create a shared understanding between the modeler and his clients.

Background of the problem situation
The operating room centre of the UMCG contains 24 Operating rooms where patients undergo surgery. The majority of these patients are patients that can be scheduled well in advance: the elective patients. The schedule of elective patients can each day be disrupted by the arrival of an emergency patient. An emergency patient requires surgery within a couple of hours, depending on the status that a surgeon assigns to this patient. The UMCG uses a categorization of these patients based on three classes of urgency: Urgent patients require surgery within 24 hours, "Spoed" patients within 6 hours and acute patients as soon as possible. The current method of the UMCG is to treat these USA-patients in two operating rooms that is not assigned to any specialism and is used for emergency surgeries. A literature research identified other strategic methods to allocate capacity for emergency patients to operating rooms that might improve the logistical performance on waiting times for emergency patients, utilization and overtime. A discrete-event simulation is used to evaluate these methods to handle emergency patients.

Objectives
The objectives of this simulation project are:
- Compare the logistic performance of the planning allocation systems and the current system
- Identify the system that has optimal logistic performance in the environment of the UMCG.
- Communicate the results in an understandable way.

Expected benefits
The benefits of this simulation study should include:
A fast, cheap and relative easy way to compare different planning allocation systems.
Visualization of the planning allocation system.
Another benefit is gaining more experience with the new simulation software package that will be used at the UMCG.

Conceptual model
Conceptual modeling is almost certainly the most important aspect of the simulation modeling process (Law & Kelton, 2000). Robinson defines a conceptual model as follows:
"The conceptual model is a non-software specific description of the simulation model that is to be developed, describing the objectives, inputs, outputs, content, assumptions and simplifications of the model."

Inputs:
Two groups of variables form the experimental variables. The operational decisions include the cancellation of surgeries on the day of surgery. The strategical variables determine the allocation of capacity for elective and emergency patients to the operating rooms.

Category of experimental variables	*Experimental variable*	*Value*	*Value in base case*
Tactical	**Planning allocation system**	The variable takes on one of the values that are described in chapter 3: • Dedicated emergency rooms. • Versatile OR's • Hybrid system. • Dedicated emergency rooms with standby patients	Dedicated emergency rooms.
	Dedicated emergency rooms	The OR numbers that are used as emergency OR	8 and 24
	Versatile ORs	The Or numbers that are assigned both an elective schedule and emergency capacity.	-
	Alternative start time elective schedule	The times at which the first elective patient for the versatile operating rooms start. All ORs start at the aimed timeslot (plus late start) except OR 24 (and possibly 8 if two times are given for this variable) that will start at the time of this variable.	-
Operational	**Reasons to cancel elective surgeries:** **Max endtime** **Max number of overtime OR's**	 If the current time added to the planned surgery time is above this variable, the surgery is cancelled. If there is overtime expected on more OR's than the value of this variable, the elective surgery is cancelled.	 16:30 6
	Reasons to send USA-patients to elective rooms: **Endtime elective schedule** **safetybuffer**	 If the elective schedule of an OR finishes before this value, and an USA-patient of the department that was assigned this OR is available, the USA patient will be send to this OR. If the current accumulated surgery times of USA-patients is larger than the USA-OR capacity added to this variable, the USA-patient is send to an elective OR.	 15:00 240 minutes
	Spreaded starttime Starting time OR 8 & 24	The times at which the first elective patient is scheduled in OR 8 and 24.	-
	Standby-patients **max USA-patients** **surgery duration**	 The decision of calling a standby patient based on whether the amount of waiting USA-patients is smaller than this variable The surgery durations of standby patients are long (200 m.), medium (120 m.) or short (60 m.).	- -

Table 15 Experimental variables of simulation model.

Outputs:
The KPI's that describe the efficiency of the system are described in Chapter 2 and this is the output of the system:

- Waiting times of acute patients.
  - average waiting times in minutes for acute patients
    - Percentage of USA patients per patient group not treated within the assigned time, e.g. urgent patients treated after 24 hours of arrival.
- Utilization (net/gross utilization for every room in %).
- cancellations of elective surgeries (number per year).
- overtime (frequency/duration in minutes for each OR).
- Amount of elective patients treated.
- Amount of USA-patients treated after 15:30.

Content (scope and level of detail)

Component	Include/exclude	Justification
Patients	Include	Flow through the process
Staff **Surgeon** **Team** **Anesthesiologist**	Exclude	Simulation model is on a strategic level, the individual employees are excluded (see also Assumptions and simplifications).
Operating rooms	Include	Patients enter these rooms and are "processed" here.
Pre-care	Exclude	Patient will arrive at the queue before the OR
After-care	Exclude	Outside the relevant system boundaries.
Queue before OR's	Include	Patients that arrive at the OR centre must wait in case of capacity shortage.
Equipment	Exclude	See simplifications

Table 16 Simulation model scope

Component	Include/exclude	Comment
Patients	Include	
-department per patient	Include	Department influences the average surgery time. (
-USA patients	Include	Patients distributions
-USA patients that cannot be treated on USA-OR	Include	These patients have to be operated on the elective OR of the department.
-Elective patients	Include	List of patients with different duration.
-general characteristics (age, etc.)	Exclude	May influence the surgery durations, but this is already represented in average surgery times (drawn from a large sample). Majority treated in OR14, which is excluded
-patients requiring sectio	Exclude	
Operating rooms	Include	
-location	Include	Model the OR's on UMCG map.
-capacity	Include	Time slots, 1 patient/OR
-department	Include	Department is assigned an OR
-Late start	Include	The starttime of the OR is each day determined by a empirical distribution.
Queue before OR's		
-capacity	Exclude	Capacity of queue is infinite.
-priority rules	Include	All patients arrive at the queue and are ordered by: Patients status Time to be operated for emergency patients

Table 2 simulation model level of detail

Assumptions and simplifications

A model is by definition a simplified representation of reality. This means that a number of assumptions and simplifications have to be made:

Patient flow:

When a patient leaves an OR, the patient in the buffer in front of this OR that has highest priority will go to the OR. 15 (or 30 for emergency patients) minutes before the start of surgery, the patient is assigned to this OR and this surgery cannot be cancelled. Even if a patient of higher priority enters the OC.

Acute patients will go to the suitable OR that is has the lowest EstEndTime label. Suitable ORs are OR's with an elective schedule that is from the same department that has to operate the acute patient. Also OR's that contain capacity for emergency patient are suitable ORs. For patients from one of the sub departments of Chirurgie, suitable ORs are all Chirurgie tables.

When a patient enters an OR, the EstEndTime label is increased by the planned surgery time of the entering patient. Planned surgery times of emergency patients equal their real surgery duration.

When a patient's surgery is finished, the patient will leave the model.

Planning of elective patients:

For each department, there are always elective patients requiring surgery available.

Planned surgery durations are generated from a discrete empirical distribution. Real surgery durations equal planned surgery time*planning deviation. The planning deviation is generated from a distribution, the product of these two parameters is the realized surgery duration. A maximum realized surgery duration is set, equal to the maximum observed value in real data.

Surgery durations are each day taken from the weekly list of surgeries. Based on a first-fit policy, surgeries are scheduled on the day schedule. The number of surgeries that are tried to fit in the day schedule depends on the real planned utilization of departments.

Longest case first is not explicitly modeled. Implicitly, the planning algorithm will cause the longer surgery durations often to be scheduled first. This represents that often longest case first is used, but frequently children or diabetes patients are scheduled first.

Fifteen minutes is planned in between two surgeries. The changeover time for elective patients is also 15 minutes.

Emergency patients

There exist a day and night pattern of emergency arrivals. Both interarrival times follow an exponential distribution with averages of 100 and 250 respectively.

For emergency patients that are not treated on the elective OR of their department changeover time is 30 minutes.

The surgery time of emergency patients differs from elective surgery durations, empirical data is used.

In three cases USA-patients may be treated on elective OR's:

Patients will go to elective OR's if the real ending time is before a certain value (15:00 in base case).

Patients of the departments OHA (100), KNO (90) and NCA (60).

If the capacity of the USA-OR's and the patients waiting to be treated on these OR's plus a safety margin exceeds the time in which an arriving patient has to be operated.

When a patient surgery can be performed on a number of (emergency) OR's, the patient is allocated to the OR that will end first in order to balance the workload.

Each day the USA-OR's are OR numbers 8 and 24 (in the base case).

Changeover time for emergency patients that are not treated at the elective OR is 30 minutes.

- *Cancelations of surgeries*

Surgeries of emergency patients are never cancelled

Elective surgeries are always cancelled if (and only if):

Expected endtime of the surgery is after a predefined time (exp. variable).

Overtime is expected on more than a predefined number of OR's (exp. variable)

Starttime of elective patients is after 15:30 or before 7:15

Experimentation

The set of experiments is shown in table 18 .

Data requirements

All parameters described under "Inputs" are analyzed in chapter 4. The data that is needed to include fixed factors in the model is described below.

A block schedule of OR days assigned to departments. A representative schedule is picked. The departments that are assigned time in this schedule are responsible for 92 percent of the surgeries that were performed from 2006-2009.

For each department:
planned surgery time per patient in minutes (empirical data)
planning deviation (distribution)
Late start data (distribution)
The planned utilization (per day)
Parentage of USA patients that require a specific resource that is installed at an elective OR.
General inputs:
inter-arrival times in minutes of emergency patients (distribution)
Patient urgency mix (percentages of: urgent, spoed and acuut)
USA-Patient department mix (percentages of departments)
changeover times
Late start

Time scale and milestones

This simulation study is part of a Master Thesis project. Within the assigned time interval of 840 hours, the thesis has to be completed including this simulation project.

Obtaining accurate simulation results

No warm-up period will be used. Each day can be seen as a replication itself, the initial conditions are set manually. That is, at the start of the model, there are no patients in the model.

Run length

The arrival of emergency patients is conituous: 24 hours per day, each day there are emergency patients arriving at the hospital. The model is therefore non-terminating (Robinson,2004). In such model, there are two options to obtain accurate results:

- one long run
- multiple (shorter) runs

The choice is made to use one long run. To determine an appropriate run length, the base model is run three times for 5 years, using three different random number streams.

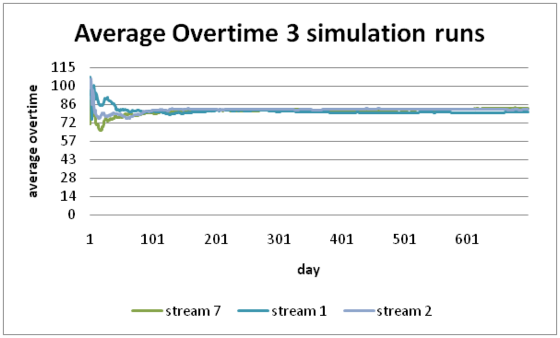

Figure 32 graphical comparison of overtime results using three different random number streams

After 131 days, a convergence percentage of fewer than 5% is reached. The simulation time is about 30 seconds a year (running flexsim HC 2.77 on personal computer with quadcore 3.2 Ghz, 4Gb DDR3 RAM). Because the model is this fast, a large margin is taken and each scenario will be run for five years. The net utilization has less variance and converges faster, see

Figure 32 graphical comparison of overtime results using three different random number streams.

	tactical rules						operational rules					
							cancellation rules		send USA to elective room			
	scenario	Dedicated OR	emergency capacity	versatile Ors	start OR24	start OR8	max endtime	max overtime	endtime elective schedule	safetybuffer	minUSApatients	standbysurgery
Dedicated ORs	[101	8,	920	-			16:30	6	15:00	24		
	[102	8,	920	-			**16:15**	6	15:00	24		
	[103	8,	920	-			**-**	6	15:00	24		
	[104	8,	920	-			**-**	**10**	15:00	24		
	[105	8,	920	-			**-**	**4**	15:00	24		
	[106	8,	920	-			**-**	-	15:00	24		
	[107	8,	920	-			16:30	6	15:00	**0**		
	[108	8,	920	-			16:30	6	**14:00**	**0**		
Planned slack (4 versatile ORs)	[201	-	920	8,24,13,22			16:30	6	15:00	24		
	[202	-	920	8,24,13,22			**16:15**	6	15:00	24		
	[203	-	920	8,24,13,22			**-**	6	15:00	24		
	[204	-	920	8,24,13,22			**-**	**10**	15:00	24		
	[205	-	920	8,24,13,22			**-**	**4**	15:00	24		
	[206	-	920	8,24,13,22			**-**	-	15:00	24		
	[207	-	920	8,24,13,22			16:30	6	15:00	**0**		
	[208	-	920	8,24,13,22			16:30	6	**14:00**	**0**		
	[209	-	920	8,24,13,22	**11:40**		16:30	6	15:00	24		
	[210	-	920	8,24,13,22	**11:40**	**11:40**	16:30	6	15:00	24		
	[211	-	920	8,24,13,22	**9:00**	**10:30**	16:30	6	**14:00**	**0**		
	[212	-	**800**	8,24,13,22	**9:00**	**10:30**	16:30	6	**14:00**	**0**		
	[213]	-	**700**	8,24,13,22	**9:00**	**10:30**	16:30	6	**14:00**	**0**		
Planned slack (5 versatile ORs)	[214]	-	920	8,24,13,22,23			16:30	6	15:00	240		
	[215]	-	920	8,24,13,22,23			16:30	6	**14:00**	**0**		
	[216]	-	920	8,24,13,22,23	**11:40**		16:30	6	**14:00**	**0**		
	[217]	-	920	8,24,13,22,23	**9:00**	**10:30**	16:30	6	**14:00**	**0**		
	[218]	-	**800**	8,24,13,22,23	**11:40**	**11:40**	16:30	6	**14:00**	**0**		

	tactical rules						operational rules					
							cancellation rules		send USA to elective room			
	scenario	Dedicated em OR	emergency capacity	versatile Ors	start OR24	start OR8	max enditime	max overtime	endtime elective schedule	safetybuffer	minUSApatients	standbysurgery
	[219]	-	**700**	8,24,13,22,23	**9:00**	**11:40**	16:30	6	**14:00**	**0**		
Planned slack (6 versatile ORs)	[220]	-	920	8,24,13,22,23,20			16:30	6	15:00	**0**		
	[221]	-	920	8,24,13,22,23,20			16:30	6	**14:00**	**0**		
	[222]	-	920	8,24,13,22,23,20	**11:40**		16:30	6	**14:00**	**0**		
	[223]	-	920	8,24,13,22,23,20	**9:00**	**10:30**	16:30	6	15:00	**0**		
	[224]	-	**800**	8,24,13,22,23,20	**9:00**	**10:30**	16:30	6	**14:00**	**0**		
	[225]	-	**700**	8,24,13,22,23,20	**9:00**	**10:30**	16:30	6	**14:00**	**0**		
Planned slack (7 versatile ORs)	[226]	-	920	8,24,13,22,23,20,12			16:30	6	15:00	**0**		
	[227]	-	920	8,24,13,22,23,20,12			16:30	6	**14:00**	**0**		
	[228]	-	920	8,24,13,22,23,20,12	**11:40**		16:30	6	**14:00**	**0**		
	[229]	-	920	8,24,13,22,23,20,12	**9:00**	**10:30**	16:30	6	15:00	**0**		
	[230]	-	**800**	8,24,13,22,23,20m1	**9:00**	**10:30**	16:30	6	15:00	**0**		
	[231]	-	**700**	8,24,13,22,23,20,12	**9:00**	**10:30**	16:30	6	15:00	**0**		
Planned slack (8 versatile ORs)	[232]	-	920	8,24,13,22,23,20,12			16:30	6	15:00	240		
	[233]	-	920	8,24,13,22,23,20,12	**11:40**		16:30	6	15:00	**0**		
	[234]	-	920	8,24,13,22,23,20,12	**11:40**		16:30	6	**14:00**	**0**		
	[235]	-	**800**	8,24,13,22,23,20,12	**11:40**		16:30	6	**14:00**	**0**		
	[236]	-	**700**	8,24,13,22,23,20,12	**11:40**		16:30	6	**14:00**	**0**		
	[237]											
Hybrid system	[301]	24	920	8,13,22			16:30	6	15:00	240		
	[302]	24	920	8,13,22,23			16:30	6	15:00	240		
	[303]	24	**700**	8,13,22			16:30	6	**14:00**	**0**		
	[304]	24	**700**	8,13,22,23			16:30	6	**14:00**	**0**		
	[305]	24	**700**	8,13,22,23,20			16:30	6	**14:00**	**0**		
	[306]	24	**700**	8,13			16:30	6	**14:00**	**0**		
	[307]	24	**700**	8,13,22,23		**9:00**	16:30	6	**14:00**	**0**		

	tactical rules						operational rules					
							cancellation rules		send USA to elective room			
	scenario	Dedicated em OR	emergency capacity	versatile Ors	start OR24	start OR8	max endtime	max overtime	endtime elective schedule	safetybuffer	minUSApatients	standbysurgery
	[308	24	**700**	8,13		**9:00**	16:30	6	**14:00**	**0**		
	[309	24	**700**	8,13,22		**9:00**	16:30	6	**14:00**	**0**		
	[310	24	**700**	8		**9:00**	16:30	6	**14:00**	**0**		
Emergency rooms with standby patients	[401	-	920	8,24,13,22			16:30	6	15:00	240	1	ORA
	[402	-	920	8,24,13,22			16:30	6	15:00	240	0	ORA
	[403	-	**700**	8,24,13,22			16:30	6	**14:00**	0	0	short
	[404	-	**700**	8,24,13,22			16:30	6	**14:00**	0	0	mediu
	[405	-	**700**	8,24,13,22			16:30	6	**14:00**	0	0	long

Table 18 Simulated scenarios

Appendix IV Model verification and validation

The technical details of model verification and validation are provided in this appendix. The most important performance indicators and input data are arranged in a table. The real values for this data is extracted from cognos from 2006-2009 data on all OR's excluding OR 1-4 and 14. The output of a 5 year simulation run is placed in the column next to the data. The percentual deviation is calculation for all data. All output is exported from Flexsim HC to Microsoft Excel to analyze the data.

Surgery durations of elective surgeries
The surgery duration are obtained by running the model and never cancel a surgery.

The average surgery durations correspond well. Now the extrema and measures on the shape of the distribution are compared.

Department	Realized surgery durations			Planned surgery durations		
	Real (2006-2009)	simulated	percentual	real(2006-	simulated	percentual
CAB	217	217	0,06	164	161	-2,1
CHP	400	402	0,39	283	285	0,5
CKC	114	116	2,03	81	83	2,7
CON	193	199	2,91	123	144	16,7
CPL	169	156	-7,43	129	131	1,3
CTR	145	151	3,81	105	103	-1,6
CTX	234	235	0,61	180	180	-0,1
CUR	151	153	1,37	124	129	4,4
CVA	186	188	1,22	139	136	-2,1
KNO	132	137	3,66	117	114	-2,2
MOA	187	191	1,92	161	173	7,7
NCA	193	201	3,92	159	160	0,4
OHA	92	93	1,30	81	82	0,7
ORA	164	170	3,50	138	138	0,1
VGY	173	177	2,51	133	146	9,9
Total	**183**	**186**	**1,45**	**141**	**144**	**2,3**

Table 19 Surgery durations in simulation model and real data

Department	planning deviation					
			over 250 minutes		over 500 minutes	
	Real (2006-	simulated	Real (2006-	simulated	Real (2006-	simulated
CAB	139	138	31	31	6	4
CHP	208	219	71	75	32	32
CKC	76	80	6	6	0	0
CON	120	121	23	29	3	2
CPL	126	116	14	15	4	3
CTR	78	92	8	10	0	1
CTX	52	51	35	33	0	0
CUR	108	113	16	20	1	2
CVA	97	90	20	20	1	1
KNO	118	121	12	14	2	2
MOA	141	121	17	19	5	3
NCA	119	148	25	31	3	4
OHA	41	45	0	1	0	0
ORA	105	105	15	15	1	1
VGY	111	97	12	14	3	2
Total	**109**	**111**	**20**	**22**	**4**	**4**

Table 20 Extrema and variation in surgery durations

Utilization of planned surgeries

By running the model for ten years without cancellations and without USA-patient arrivals, the planned utilization is calculated. The numbers are calculated by summing the planned surgery times and add 15 minute changeover times. This total is reduced by one changeover time (for the first surgery) and divided by the total session time.

USA-patients flow

39764 USA patients in ten years, of which 29015 were operated on an USA-OR. 20381 USA patients were treated within the timeslot (72.7). The yearly amount of 3976,4 patients is almost equal to the data from last three years.

Overtime

The Base case model is run without adjustments to obtain overtime data.

		Avg. Planned gross util		Avg. Patients a day	
Department	OR days	Real (2009)	simulated	real (2009)	simulated
KNO	10	86,60	87,06	3,1	3,2
CPL	5	76,60	78,15	2,3	2,5
NCA	10	86,20	88,10	2,2	2,4
OHA	5	99,20	92,34	4.4	4,6
MOA	5	84,00	83,97	2,1	2,2
ORA	9	87,10	87,48	2,5	2,8
CTR	3	79,70	81,50	2,7	3,3
CVA	4	75,40	77,76	2,1	2,5
CON	3	73,80	74,69	2,1	2,2
CTX	1	77,60	81,21	2	2,0
CHP	4	80,00	73,48	1,2	1,2
CAB	5	83,10	81,69	2	2,2
CKC	3	77,80	81,44	3,3	3,9
CUR	4	85,60	86,06	2,8	2,7
VGY	3	65,20	75,99	2	2,3
Total		**81,19**	**82,06**	**2,3**	**2,7**

Table 21 Planned utilization
*VGY operates in OR23, the average utilization of this OR is 80

	2005	2006	2007	2008	2009	Total	
OR	avg.	avg.	avg.	avg.	avg.	avg.	simulated
5	55	50	53	52	56	53	71
6	44	61	52	48	52	51	74
7	63	68	63	50	65	62	87
8	67	72	61	73	61	67	93
9	53	71	60	61	57	61	81
11	36	37	35	39	41	38	46
12	66	51	53	51	52	54	90
13	49	50	59	60	48	53	82
15	58	47	59	60	58	56	64
16	58	57	57	51	51	55	71
17	56	68	61	67	62	63	79
18	69	62	55	68	61	63	80
19	79	85	88	110	92	90	145
20	55	63	60	59	61	60	72
21	55	57	49	50	48	52	62
22	65	75	67	67	73	69	95
23			63	60	55	59	73
24			91	74	67	74	99
Total	59	63	60	61	60	61	81

Table 22 Overtime duration

	2005	2006	2007	2008	2009	Total	simulated
OR	avg.	avg.	avg.	avg.	avg.	avg.	avg.
5	0.45	0.49	0.44	0.39	0.49	**0.45**	**0,56**
6	0.44	0.44	0.39	0.44	0.5	**0.44**	**0,52**
7	0.44	0.6	0.52	0.49	0.44	**0.5**	**0,42**
8	0.52	0.59	0.52	0.39	0.42	**0.49**	**0,47**
9	0.56	0.59	0.5	0.55	0.5	**0.54**	**0,67**
11	0.38	0.5	0.48	0.48	0.52	**0.48**	**0,62**
12	0.43	0.5	0.43	0.49	0.56	**0.48**	**0,38**
13	0.56	0.53	0.55	0.5	0.54	**0.54**	**0,68**
15	0.55	0.62	0.62	0.57	0.55	**0.58**	**0,55**
16	0.56	0.49	0.58	0.49	0.52	**0.53**	**0,55**
17	0.53	0.53	0.57	0.52	0.61	**0.55**	**0,69**
18	0.55	0.56	0.54	0.52	0.56	**0.55**	**0,62**
19	0.51	0.51	0.49	0.5	0.55	**0.51**	**0,57**
20	0.5	0.58	0.62	0.59	0.57	**0.57**	**0,69**
21	0.45	0.53	0.5	0.52	0.49	**0.5**	**0,49**
22	0.5	0.54	0.56	0.62	0.6	**0.56**	**0,58**
23			0.49	0.44	0.47	**0.46**	**0,51**
24			0.48	0.56	0.48	**0.51**	**0,56**
Total	0.49	0.53	0.5	0.49	0.51	0.5	0,56

Table 23 Overtime frequency

The magnitude of overtime in the simulation model is much higher than the real system. Reasons for discrepancy:
Not all timeslots during the year assigned to these departments. For example OR 19 is assigned to CHP which is characterized by very long surgery durations. In reality also departments with smaller surgery durations were assigned to this OR.
For some ORs, including OR7 and 12, the overtime duration is much higher in the model, compared to real data. However overtime frequency is lower. Thus, the long surgeries were spread more evenly over the days in the real system. Such intelligence is not included in the system: two long surgery duration one 1 day will cause large overtime duration, but only at one day.
Cancellations due to various reasons are not simulated
The policy of cancelling elective surgeries after 16:30 may be too strict.
Late start is based on empirical data and this is determined every day. When a busy day is anticipated, late start may be less in practice.

Utilization

In the model, changeover time will always equal 15 minutes for elective and 30 minutes for emergency patients. The utilization will be verified by only looking at surgery durations and not changeovers.

	2005	2006	2007	2008	2009	Total	simulated
OR	avg.	avg.	avg.	avg.	avg.	avg.	avg.
5	88	89	88	86	86	87	86
6	87	86	86	87	88	87	86
7	87	91	88	87	87	88	80
8*	87	92	82	72	73	81	45
9	91	93	92	92	89	91	92
11	82	86	85	86	85	85	85
12	86	89	88	87	86	87	83
13	88	89	90	88	89	89	92
15	93	93	92	90	90	92	89
16	90	90	90	89	89	90	89
17	81	81	81	79	89	82	90
18	88	89	90	87	89	88	90
19	79	83	84	83	88	83	87
20	80	85	86	86	86	85	88
21	86	87	89	87	86	87	87
22	83	83	87	90	89	87	89
23			85	86	85	85	86
24	*		82	83	72	77	54
Total	85	86	86	86	86	86	83

Table 24 Net utilization

*In the simulation model, OR 8 and 24 are always used as the USA-OR. In reality, sometimes an elective session was held in one of these rooms, resulting in a higher utilization. The utilization of USA-OR's only was calculated in Chapter 4:60.04. The average net utilization of the above OR's excluding 8 and 24 is 86 in the real data versus 87 of the simulated data.

Validation

To check whether the model does exactly what is determined in the conceptual model, several techniques are used to validate the model:

Structured walk through with anesthesiologist that is also responsible for planning.

Structured walkthrough with two employees and chief of "zorglogistiek en innovatie"

Sum of inputs minus cancellations equal output.

Visual check

Comparing the analysis of output in different scenario's with expected results.

Verification of Second system

Several changes to the first simulation model are applied to simulate the second group of experiments. One major change is the elective capacity applied to OR 24 and 8. To ensure that the elective scheduling process is equal to the one described in the project specification, a verification of this model is executed.

The amount of USA-patients that are operated in one ten-year run in the second system is 39832. In the dedicated OR system, 39765 patients entered the system. The same distributions are used, the small difference is explained by the use random numbers. Because the difference between the planned slack system and the base case, the planned slack model is considered valid and verified.

	Real (2006-2009)	simulated	simulation 2nd system	percentual deviation
CAB	217	217	213	2,06
CHP	400	402	389	3,29
CKC	114	116	115	0,80
CON	193	199	192	3,57
CPL	169	156	154	1,57
CTR	145	151	145	4,26
CTX	234	235	234	0,35
CUR	151	153	159	-3,77
CVA	186	188	190	-1,18
KNO	132	137	138	-0,53
MOA	187	191	192	-0,76
NCA	193	201	195	3,10
OHA	92	93	94	-0,61
ORA	164	170	166	2,62
VGY	173	177	174	1,84
Total	183	186	183	1,49

Table 25 Average surgery durations of versatile OR system

Department	OR days	Real (2009)	simulated Base Case	simulated second system	difference base case and second system
KNO	10	86,60	87,06	86,77	0,34
CPL	5	76,60	78,15	77,64	0,65
NCA	10	86,20	88,10	87,75	0,40
OHA	5	99,20	92,34	91,33	1,11
MOA	5	84,00	83,97	87,41	-3,94
ORA	9	87,10	87,48	85,66	2,12
CTR	3	79,70	81,50	81,62	-0,14
CVA	4	75,40	77,76	76,10	2,19
CON	3	73,80	74,69	76,94	-2,93
CTX	1	77,60	81,21	81,52	-0,38
CHP	4	80,00	73,48	72,99	0,68
CAB	5	83,10	81,69	79,88	2,26
CKC	3	77,80	81,44	84,44	-3,55
CUR	4	85,60	86,06	85,87	0,22
VGY	3	65,20	75,99	77,06	-1,38
Total		81,19	82,06	82,20	-0,17

Table 3 Average planned utilization of versatile OR system

Appendix V simulation output

The scenario numbers of the table below correspond with the numbers in ***Table 18***. This is where the exact configuration of the scenario is found. All parameters are defined in appendix II. The value in column "Spoed" are the amount of emergency patients classified as spoed that were not treated within 6 hours. The column "Acuut" shows the amount of acuut patients not being treated within the hour.

scenario	Overtime frequency	overtime duration	net util	Spoed	Acuut	# elective	#USA	waiting time acuut patients	USA-patients outside timeslot	cancellations	standby patients
[101]	56%	83	83%	24	75	49238	19903	12	9808	4756	
[102]	53%	83	83%	24	75	48566	19903	12	9755	5428	
[103]	62%	88	84%	24	75	50637	19903	12	9869	3357	
[104]	63%	88	84%	24	75	50878	19903	12	9873	3116	
[105]	59%	87	83%	24	75	49733	19903	12	9813	4261	
[106]	63%	88	84%	24	75	50879	19903	12	9876	3115	
[107]	56%	83	83%	24	77	49239	19903	12	9906	4755	
[108]	54%	82	83%	7	83	49278	19903	14	9980	4716	
[109]	57%	81	84%	33	109	51614	20052	20	10093	4779	
[201]	55%	83	85%	45	143	50481	19879	27	9625	3935	
[202]	52%	82	84%	45	143	49877	19879	27	9612	4539	
[203]	60%	87	85%	45	143	51702	19879	27	9691	2714	
[204]	60%	87	85%	45	143	51805	19879	27	9691	2611	
[205]	57%	87	85%	45	143	51070	19879	27	9665	3346	
[206]	60%	87	85%	45	143	51805	19879	27	9691	2611	
[207]	55%	82	85%	41	145	50495	19879	27	9679	3921	
[208]	53%	81	85%	20	147	50532	19879	28	9849	3884	
[209]	56%	84	84%	38	73	50349	19879	15	9820	4067	
[210]	57%	84	83%	36	42	50149	19879	9	10026	4267	
[211]	55%	82	84%	13	77	50425	19879	15	10070	3991	
[212]	55%	81	85%	25	96	51102	19705	18	10413	4201	
[213]	56%	82	85%	35	98	51366	19778	17	10678	4168	
[214]	53%	84	85%	48	142	50416	19662	27	9376	3995	
[215]	52%	83	85%	28	132	50458	19662	26	9476	3953	
[216]	53%	84	83%	28	81	50065	19662	16	9603	4346	
[217]	54%	83	84%	31	67	50280	19662	13	9782	4131	
[218]	55%	84	84%	32	71	50883	19921	14	10256	4142	
[219]	56%	83	85%	38	79	50915	19850	17	10401	4347	

scenario	Overtime frequency	overtime duration	net util	Spoed	Acuut	# elective	#usa	waiting time acuut patients	USA-patients outside timeslot	cancellations	standby patients
[220]	50%	84	83%	56	149	48639	20069	25	9489	3216	
[221]	49%	83	83%	24	140	48656	20069	24	9582	3199	
[222]	50%	86	81%	21	65	48074	20069	12	9663	3781	
[223]	51%	83	82%	23	67	48405	20069	12	9854	3450	
[224]	54%	82	84%	29	94	50138	19730	17	9904	3577	
[225]	56%	83	85%	32	83	50693	19804	16	10089	3871	
[226]	51%	84	84%	38	148	49502	19742	26	9212	3355	
[227]	50%	83	84%	17	150	49538	19742	26	9238	3319	
[228]	52%	85	82%	14	76	48871	19742	13	9309	3986	
[229]	53%	83	83%	13	80	49295	19742	14	9476	3562	
[230]	55%	82	84%	28	61	50400	19775	14	9839	3756	
[231]	57%	82	85%	30	93	51039	19943	17	10016	4050	
[232]	53%	84	85%	64	129	50220	20067	24	9448	3297	
[233]	51%	83	85%	31	132	50251	20067	24	9473	3266	
[234]	53%	86	83%	29	50	49502	20067	9	9499	4015	
[235]	54%	84	84%	26	62	49872	20067	12	9685	3645	
[236]	55%	82	85%	32	66	50463	19913	13	9889	3960	
[237]	57%	84	85%	28	76	50620	19850	14	9788	3834	
[301]	54%	81	84%	59	122	50143	19844	22	9971	3963	
[302]	55%	83	85%	62	104	50484	19986	21	9931	4057	
[303]	55%	80	86%	39	152	51206	19984	28	10753	4189	
[304]	55%	80	86%	45	127	51260	19718	25	10286	4292	
[305]	56%	79	86%	44	120	51460	19639	24	10050	4014	
[306]	54%	80	86%	32	142	51225	19626	28	10672	4291	
[307]	56%	80	85%	42	101	51141	19718	19	10350	4411	
[308]	55%	80	85%	28	112	51183	19626	23	10792	4333	
[309]	55%	80	85%	39	121	51125	19984	22	10781	4270	
[310]	55%	81	85%	59	100	51087	20014	17	11208	4590	
[401]	60%	83	85%	37	118	51902	20009	21	10230	4787	3105
[402]	58%	83	84%	19	90	50438	19818	16	9741	4583	1200
[403]	55%	79	84%	8	97	50785	19942	17	10060	4645	1332
[404]	55%	79	84%	9	85	50557	19928	17	10117	4570	1127
[405]	56%	79	84%	9	87	50529	20016	18	10004	4605	1046

Table 27 Results of scenarios