Emergencies in planning and planning emergencies

Research to the operating room planning for emergency patients at UMC Utrecht

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Operating room planning

UMC Utrecht Cancer Center

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Preface

Even though five years ago I deliberately decided not to study medicine, and went to Enschede for Industrial Engineering and Management instead, my time as a student still ends in a hospital. The past seven months I have been working in UMC Utrecht on a research project considering the operating room planning of DHS and Utrecht Cancer Center. This report describes the findings from this project, and is the final step in achieving my master degree in Industrial Engineering and Management. It faced me with many challenges, such as choosing a direction for my project, planning and managing a project over a longer period of time, and asking for help when necessary. I have learned a lot about the hospital, and specifically about operating room planning. But also anatomy lessons, by following surgeries real closely.

This would not have been possible without all the people that helped me understand the processes of operating room planning. I quickly found out that I was fortunate to work on a very actual and relevant topic, and that some (medical) specialists could talk about operating rooms for hours. Too many people have helped me to mention and thank them one by one, but the most important ones are my supervisors from both UMC Utrecht as well as from the University of Twente.

I would like to thank Miranda van den Oetelaar for her enthusiasm. You always made time to discuss my findings and problems, and kept me motivated till the end. Furthermore I would like to thank Gréanne Leeftink for her involvement in my project. Your knowledge and advices helped me to find my way during the project. I also would like to thank Ingrid Vliegen for her help. All the meetings, reading, feedback, and help in programming made this thesis what it is.

Finally, I would like to thank my parents and Wouter for their support and ongoing belief in me. This helped me a lot.

Marleen Sommers

Utrecht, September 2016

Management Summary

Background

UMC Utrecht has a large operating room complex, where annually over 15,000 surgeries are performed. In recent years the operating theatre is thoroughly renovated. This renovation restricted the available capacity. By the end of 2016 the renovation will be completed. This creates more capacity and flexibility in planning, allowing the specialties that use OR capacity to reconsider their wishes, choices, and planning rules. The surgical specialties division (DHS) and the Utrecht Cancer Center are the two divisions using the largest amount of operating room capacity. Together they perform 74% of the surgeries, and fill 69% of available surgery capacity. These two divisions share their capacity reserved for emergency surgeries. The past years they reserved six hours per day for emergency surgeries. The other hours of this OR program are filled with short elective surgeries.

Problem Statement

With the current available time and planning method for emergencies, the operating room cannot manage to operate all emergencies within their norm. UMC Utrecht aims to improve this. This results in the central question for this project:

What is the best method to consider emergency surgeries in the planning of elective surgery programs of DHS and Cancer Center?

We want to minimize the disruptions (movements and cancellations) of the elective programs caused by arriving emergency patients, while providing emergency patients with timely surgeries. In addition, there are organizational performance indicators. The OR complex is an expensive resource. Therefore hospitals strive for high utilization. But also overtime is expensive, and cancelled patients should be prevented.

Context Analysis

DHS and Cancer Center consists of nine and five specialties respectively. There are several planning desks to plan the patients from these specialties. The operating room performance for 2015 shows that 4.13% of the planned surgeries for the surgical specialties division and Cancer Center are cancelled on the planned day of surgery. 59.2% of those surgeries are cancelled due to program related reasons, which include previous surgeries that exceeded the planned duration, priority for emergency patients, and program changes. There were 1068 overtime hours, which means on average 23 minutes per operating room per day. The overall utilization, only considering surgery time, was 77%. At the beginning, during, and end of the day long periods of time without a patient in the operating room occur. The percentage of emergencies that had a surgery within their norm time was 92% for A-emergencies, 79% for B-emergencies, and 83% for C-emergencies.

Approach and results

To test and compare the different planning policies we used the Operating Room Manager, developed at the University of Twente. Using this simulation model we compared the effects of three planning policies in a scenario analysis. The first policy uses a dedicated emergency operating room that clusters all reserved time for emergency surgeries in one operating room. The second policy is a flexible planning policy, which reserves time for emergencies at the end of all elective programs. When emergencies arrive, the elective program is interrupted. The third policy is a combination of previous policies. It breaks in for emergencies in the elective programs, but if the next possibility to break is too far away, one of the OR's becomes emergency OR and stays empty to wait for emergencies. All those policies are tested with eight, ten, and twelve hours emergency slack.

We compare the planning policies based on the number of cancelled patients (C), the amount of overtime (O), the utilization of the operating rooms (U), and the percentage of emergency surgeries within their norm time. Furthermore we consider the number of elective and emergency surgeries performed. When more alternatives have a similar score on those four performance indicators, we consider other aspects, such as the number of interruptions in the elective programs and the number of operating rooms with overtime.

Table 1 shows the simulation results for the experiments with the amount of patients similar to 2015. The results indicated that a dedicated planning method would be the best planning method for DHS and Cancer Center surgeries. It is hard to choose between eight, ten, and twelve hours emergency slack, the differences between those variants are small. When preventing cancelled patients has priority the dedicated policy with eight hours performs best, when emergencies within the norm are the most important the dedicated policy with ten hours performs best. Because the differences in cancellation, overtime, utilization and emergency performance are very small, we can also consider other aspects of the scenario in our considerations. We could for example consider the ease of implementation, or the medical aspects of our planning decisions. On both these aspects a dedicated policy scores best, since a similar method is already used, it has few interruptions in the elective programs, and increases the likelihood of an experienced team for an emergency surgery.

2017	8 hours emergency slack	10 hours emergency slack	12 hours emergency slack
Dedicated	C: 0.4% O: 4% U: 81% Emergencies within norm: 97% # elective surgeries: 7598 # emergency surgeries: 1407 # Interruptions in elective pr: 275 # ORS with overtime: 693	C: 0.5% O: 4% U: 81% Emergencies within norm: 98% # elective surgeries: 7598 # emergency surgeries:1412 # Interruptions in elective pr: 213 # ORS with overtime: 706	C: 0.6% O: 4% U: 81% Emergencies within norm: 97% # elective surgeries:7573 # emergency surgeries:1419 # Interruptions in elective pr: 218 # ORS with overtime:737
Flexible	C: 0.8% O: 5% U: 81% Emergencies within norm: 98% # elective surgeries: 7548 # emergency surgeries: 1394 # Interruptions in elective pr: 403 # ORS with overtime: 772	C: 0.9% O: 5% U: 81% Emergencies within norm: 97% # elective surgeries: 7530 # emergency surgeries:1397 # Interruptions in elective pr: 420 # ORS with overtime: 753	C: 0.8% O: 5% U: 80% Emergencies within norm: 97% # elective surgeries: 7529 # emergency surgeries: 1389 # Interruptions in elective pr: 403 # ORS with overtime: 741
Combination	C: 1.0% O:5% U:81% Emergencies within norm: 98% # elective surgeries: 7537 # emergency surgeries:1423 # Interruptions in elective pr:417 # ORS with overtime: 783	C: 1.0% O: 5% U: 81% Emergencies within norm: 97% # elective surgeries: 7534 # emergency surgeries: 1384 # Interruptions in elective pr: 407 # ORS with overtime: 778	C: 1% O: 5% U:81% Emergencies within norm: 98% # elective surgeries: 7530 # emergency surgeries: 1398 # Interruptions in elective pr: 422 # ORS with overtime:790

Table 1: Overview of simulation results

Based on the simulation results we would recommend Cancer Center and DHS to use a dedicated policy with eight or ten hours reserved for emergencies. The differences between both variants are too small to distinguish only based on the simulation results. The choice between those two should depend on the other factors such as organizational and medical aspects.

Management Samenvatting

Achtergrond

Het UMC Utrecht heeft een groot operatiecomplex waar jaarlijks meer dan 15.000 operaties plaatsvinden. De afgelopen jaren is het operatiecomplex grondig verbouwd en gerenoveerd waardoor de fysieke capaciteit beperkend was in planning. Eind 2016 is de verbouwing afgerond. Dit is een moment waarop meer mogelijkheden ontstaan in planning en capaciteit waardoor de verschillende specialismen die de OK gebruiken op dit moment hun wensen, keuzes en planregels heroverwegen. De divisie heelkundige specialismen en het Cancer Center zijn de twee grootste OK gebruikende divisies. Samen voeren ze 74% van de operaties van het UMC Utrecht uit en vullen ze 69% van de operatieuren. Deze twee divisies reserveren gemeenschappelijke capaciteit voor spoedoperaties. Tijdens de verbouwing met beperkte capaciteit deden ze dat door elke dag in een verlengd programma (8:00-20:00) zes uur aan korte electieve ingrepen te plannen. De overige zes uur wordt vrij gehouden voor arriverende spoedpatiënten.

Probleemstelling

Met de huidige beschikbare tijd en planmethode lukt het niet goed om de spoedpatiënten binnen de norm te opereren. Dit wil het UMC Utrecht graag verbeteren. De hoofdvraag van dit onderzoek is daarom:

Wat is een goede manier om rekening te houden met spoedpatiënten in de planning van electieve OK-programma’s?

Spoedpatiënten zoude electieve programma’s zo min mogelijk moeten verstoren (weinig verschuiven, weinig afzeggen), maar wel binnen de geldende norm geopereerd moeten worden. Daarnaast spelen organisatorische prestatie-indicatoren een rol: de OK is een dure voorziening dus streven ziekenhuizen naar een hoge benutting, maar tegelijkertijd is overwerk ook duur en wil je uitloop voorkomen.

Context analyse

DHS bestaat uit negen specialismen, het Cancer Center uit vijf. Er zijn verschillende planbureaus die de operaties voor deze specialismen plannen. De OK prestatie in 2015 laat zien dat 4,13% van de geplande patiënten voor de DHS en het Cancer Center geannuleerd werd op de dag van OK. 59,2% van de annuleringen had een planning gerelateerde reden zoals voorrang voor spoedoperaties, eerdere operaties die langer duurden dan gepland of programma wijzigingen. Tevens was er 1068 uur uitloop, verspreid over de OK programma’s, dit betekent gemiddeld 23 minuten uitloop per OK per dag. De OK benutting was 77% wanneer alleen de operatietijden worden meegenomen. Zowel aan het begin, gedurende, als aan het eind van de dag komen lange perioden voor waarin niet geopereerd wordt. Het percentage spoedpatiënten dat binnen de gestelde norm geopereerd werd was 92% van de A-spoed, 79% van de B-spoed, en 83% van de C-spoed.

Aanpak en resultaten

Om verschillende planningsmethoden te testen hebben we gebruikt gemaakt van de Operating Room Manager, ontwikkeld door de Universiteit Twente. Met behulp van dit model hebben we de effecten van verschillende planmethoden vergeleken in een scenario analyse. De eerste planmethode clustert alle gereserveerde tijd voor spoed in een spoedOK (gespecialiseerd). De tweede planmethode is flexibel en reserveert tijd voor spoedoperaties aan het eind van alle electieve programma's (flexibel). De electieve programma's worden onderbroken om spoedpatiënten te opereren. De derde methode is een combinatie van bovenstaande methoden (combinatie). Deze methode onderbreekt het electieve programma voor spoedpatiënten, maar als de volgende mogelijkheid om het programma te onderbreken te ver weg is, wordt een van de OK's tijdelijk spoed-OK. Deze OK blijft dan tijdelijk leeg om te kunnen reageren op de aankomst van spoedpatiënten. Alle drie de planmethoden testen we voor acht, tien, en twaalf uur gereserveerd voor spoed.

We vergelijken de planmethoden op basis van het aantal annuleringen (A), de hoeveelheid uitloop (U), de benutting van OK's (B), en het aantal spoedpatiënten dat binnen de norm is geopereerd. Daarnaast bekijken we het aantal electieve en spoedoperaties om de context van de performance te geven. Indien meerdere alternatieven op deze vier prestatie-indicatoren gelijk scoren, kijken we naar andere aspecten, namelijk het aantal onderbrekingen van het electieve programma en het aantal OK's met uitloop.

Tabel 2 geeft de resultaten van de experimenten met het aantal patiënten gelijk aan 2015. De resultaten laten zien dat een gespecialiseerde spoed OK het beste resultaat geeft. Deze methode geeft op zowel annuleringen, uitloop, benutting, en spoed binnen de norm het beste (of evengoed) resultaat. De hoeveelheid reserveerde spoed tijd volgt niet eenduidig de simulatie resultaten. De keuze tussen de verschillende alternatieven hangt af van de voorkeuren van de kiezer: indien het voorkomen van annuleringen de hoogste prioriteit heeft wijst het model op een gespecialiseerde planmethode met acht uur gereserveerd voor spoed. Wanneer het realiseren van spoed binnen de norm hoogste prioriteit heeft is tien uur reserveren voor spoed optimaal. Omdat de verschillen in annuleringen, uitloop, benutting en spoed binnen de norm te klein zijn om de beslissing op te baseren, kunnen we naar andere aspecten van de verschillende scenario's kijken. We zouden bijvoorbeeld de implementatie en medische aspecten van de verschillende opties mee kunnen laten wegen. Op beide factoren scoort de gespecialiseerde methode goed. Deze methode wordt momenteel al gebruikt, en voor de spoed op de spoed-OK is een ervaren spoed team. Daarnaast scoort tien uur dan het best omdat daar minder onderbrekingen van hele electieve programma plaatsvinden.

2017	8 uur gereserveerd voor spoed	10 uur gereserveerd voor spoed	12 uur gereserveerd voor spoed
Gespeciliseerd	A: 0.4% U: 4% B: 81% Spoed binnen de norm: 97% # electieve operaties: 7598 # spoedoperaties: 1407 # Onderbrekingen electieve pr: 275 # OK's met uitloop: 693	A: 0.5% U: 4% B: 81% Spoed binnen de norm: 98% # electieve operaties: 7598 # spoedoperaties:1412 # Onderbrekingen electieve pr: 213 # OK's met uitloop: 706	A: 0.6% U: 4% B: 81% Spoed binnen de norm: 97% # electieve operaties:7573 # spoedoperaties:1419 # Onderbrekingen electieve pr: 218 # OK's met uitloop:737
Flexibel	A: 0.8% U: 5% B: 81% Spoed binnen de norm: 98% # electieve operaties: 7548 # spoedoperaties: 1394 # Onderbrekingen electieve pr: 403 # OK's met uitloop: 772	A: 0.9% U: 5% B: 81% Spoed binnen de norm: 97% # electieve operaties: 7530 # spoedoperaties:1397 # Onderbrekingen electieve pr: 420 # OK's met uitloop: 753	A: 0.8% U: 5% B: 80% Spoed binnen de norm: 97% # electieve operaties: 7529 # spoedoperaties: 1389 # Onderbrekingen electieve pr: 403 # OK's met uitloop: 741
Combinatie	A: 1.0% U:5% B:81% Spoed binnen de norm: 98% # electieve operaties: 7537 # spoedoperaties:1423 # Onderbrekingen electieve pr:417 # OK's met uitloop: 783	A: 1.0% U: 5% B: 81% Spoed binnen de norm: 97% # electieve operaties: 7534 # spoedoperaties: 1384 # Onderbrekingen electieve pr: 407 # OK's met uitloop: 778	A: 1% U: 5% B:81% Spoed binnen de norm: 98% # electieve operaties: 7530 # spoedoperaties: 1398 # Onderbrekingen electieve pr: 422 # OK's met uitloop:790

Table 2: Overview of simulation results

Op basis van de simulatie resultaten adviseren we het Cancer Center en de DHS om een dedicated planmethode te gebruiken met acht of tien uur gereserveerd voor spoed. De onderlinge verschillen tussen deze alternatieven zijn dusdanig klein dat de keuze gebaseerd zou moeten worden op andere factoren zoals organisatorische en medische aspecten.

Abbreviations and definitions

Abbreviation	Explanation	Explanation in Dutch
CHI	Surgery	Chirurgie
CTR	Surgical traumatology	Chirurgie Traumatologie
KAA	Maxillofacial surgery	Kaakchirurgie
KNO	Surgical otolaryngology	KNO
OOG	Ophthalmology	Oogheelkunde
ORT	Orthopaedics	Orthopedie
PLA	Plastic surgery	Plastische Chirurgie
TAN	Dentistry	Tandheelkunde
URO	Urology	Urologie
VAT	Vascular surgery	Vaatchirurgie
GON	Gynaecological oncology	Gynaecologische oncologie
QKN	Surgical oncological otolaryngology	Chirurgisch Oncologische KNO
QKA	Oncological maxillofacial surgery	Oncologische kaakchirurgie
QUR	Oncological urology	Urologische Oncologie
CGO	Surgical Gastroenterological Oncology	Chirurgische Gastro-enterologie & Oncologie
DHS	Surgical specialties division	Divisie Heelkundige Specialismen

OR	Operating room
DVF	Division vital functions
UMC Utrecht	University Medical Center Utrecht
BIM	Break In Moments

Session time	Released time-slots to different specialties
OR-Day	Total session time, from the start of the first session till the end of the last session, on one single operating room, on one single day
Surgery duration	Time between the arrival to and departure from OR of one patient
Elective surgery	Surgery without emergency code (A, B, C)
Emergency surgery	Surgery with emergency code (A, B, C)

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1. Introduction

University Medical Center Utrecht (UMC Utrecht) has a large operating room complex and performs many surgeries every day. The expectation is that this number will grow, because the demand for care increases (CBS, 2016). Meanwhile UMC Utrecht strives for excellent patient care, which means among other things timely care and a low cancellation rate. This brings challenges for the organisation of care.

In the past years UMC Utrecht extensively rebuilt the operating room complex. The renovation is finished by the end of 2016, and although there is not immediately more personnel, more physical capacity will become available. Therefore, this is a good moment to reconsider decisions regarding operating room planning.

This thesis addresses the current operating room planning methods used within UMC Utrecht, and proposes interventions to this planning process that reduce access times for emergencies, reduce cancellations, reduce overtime, and increase the utilization of resources.

This chapter provides background information about UMC Utrecht and describes the approach and objectives of this research. Section 1.1 describes the context of this research. Section 1.2 states the problem definition. Section 1.3 explains the goals and research questions of this study. Finally, Section 1.4 explains the expected challenges while solving the problem.

1.1 UMC Utrecht

UMC Utrecht is one of the eight University Medical Centres in the Netherlands. This means that the hospital has three main tasks. Of course one of those tasks is patient care, but also education and research are core business of UMC Utrecht. With more than 11,000 employees, 3,600 medical students, 1.042 beds, and about 31.000 hospitalizations per year (UMC Utrecht, 2014) UMC Utrecht is among the largest hospitals in the Netherlands. According to their mission:

'*UMC Utrecht is a prominent, international university medical center where knowledge about health, disease and care, for patient and society is created, tested, shared and applied*.' (UMC Utrecht, 2014)

The care is clustered in several divisions. UMC Utrecht has 12 divisions: surgical specialties, brain, heart & lungs, internal medicine & dermatology, mother & baby, children, imaging, biomedical genetics, julius center, vital functions, laboratory & pharmacy, and the cancer center.

Traditionally, most clusters are formed per organ type or used technique. The Cancer Center, however, is a unique division as it clusters all care for patients with cancer. In most hospitals oncological and non-oncological patients are part of the same specialty. Since cancer occurs in many different organs and treatment is usually multidisciplinary, cancer patients are then spread across many divisions.

Furthermore, the care pathways of patients involved many different locations, because different parts of the treatment (imaging, radiation therapy, surgery) occur at different locations. Since it is inconvenient for patients to see many different departments, and to keep explaining their story, UMC Utrecht decided to bring all cancer care together in one division and in time also on one location.

The Cancer Center is closely related with the surgical specialties division (DHS), because earlier most Cancer Center specialties belonged to this division.

1.2 Problem description

One of the promises of UMC Utrecht is to provide patients with excellent care. This is not an easy promise, because it is an ongoing discussion what is meant with excellent care. There are several institutions describing norms and definitions for the best care from different perspectives. From a logistical point of view the main topic is access time.

One of those institutions is the foundation for oncological collaboration (SONCOS). This is a platform for interdisciplinary dialogue and professional cooperation between the Dutch Society for Surgical Oncology (NVCO), the Dutch Society for Medical Oncology (NVMO), and the Dutch Society for Radiotherapy and Oncology (NVRO). Together these institutions determine what 'good care' for cancer patients entails. One of their norms describes that the time between first consultation and the start of treatment should be no more than four weeks for most patients (Soncos normeringsrapport 2016).

Furthermore there are 'Treek normen'. Those norms are agreements of healthcare providers and insurers on the maximum acceptable waiting times for patients for different types of care. For surgeries this norm is seven weeks (Ministerie van Volksgezondheid, 2014).

Emergency patients have their own set of norms. Within UMC Utrecht emergency patients are categorized as A-, B-, or C-emergency based on the urgency of the emergency. The corresponding norms are surgery within 2 hours after application for A-emergencies, within 8 hours for B-emergencies, and within 24 hours for C-emergencies.

Currently UMC Utrecht cannot comply with the different norms for access time in many surgical cases. To provide excellent care to the patients, there is a desire to comply with the norms by decreasing the access times.

This project is started by the Cancer Center to improve operating room performance. A current issue within the Cancer Center is the decision how to accommodate emergency patients. Since the Cancer Center shares emergency capacity with the surgical specialties division (DHS), those two divisions are the scope of our research. T these divisions are the largest users of operating room capacity.

1.3 Goals and research questions

UMC Utrecht promises patients to deliver 'top care', which among other things means complying with the target times for emergency patients.

The goal of this research is to evaluate the way OR planning can contribute to the promise of 'Top care' for DHS and Cancer Center.

From this objective, we derive three main questions:

- How are surgeries currently planned, and why?
- What is the current planning performance?
- Which planning methods are efficient and effective for DHS and UMC Utrecht Cancer Center?

To answer those questions they are decomposed into several sub questions, which are answered in the different sections of this report.

1. *What is the current operating room planning process in UMC Utrecht?*

To answer this question, we perform a context analysis based on interviews and observations in the first part of Chapter 2. This analysis addresses the divisions and functions involved, and their interests and responsibilities, for the different managerial levels (strategic, tactical, and operational).

2. *What are the characteristics of the patients of DHS and Cancer Center?*

According to Cardoen (2010) a good description of the patient population provides a lot of information regarding uncertainty. That information is necessary for planning. The second part of Chapter 2 therefore analyses the characteristics of the patients, in order to distinguish patient groups with similar planning characteristics, for example specialty, surgeon, material requirements, and duration.

3. *What is the current OR performance?*

To answer this question we determine the performance indicators for OR-planning, by performing a literature review and interviews. These indicators determine what makes a planning a good planning. This incorporates the definitions of an effective and efficient planning. Based on these performance indicators, we perform a data analysis to determine the current OR-planning performance. We describe both the literature review and the data analysis in Chapter 2.

4. *What are suitable planning methods to improve the operating room performance?*

The current planning performance, as described in Chapter 3 shows opportunities for improvement. Chapter 4 explores different possible interventions to improve the planning performance in these areas.

5. *What is a suitable model to test the effect of the proposed planning methods?*

In Chapter 5 we select the best model to test the effect of the proposed interventions. After building the model we validate and verify the model.

6. *What is the effect of the suggested planning methods?*

Chapter 6 addresses the quantitative part of this thesis, by testing the effect of the proposed interventions and performing a sensitivity analysis on the results. To test the effect of the different interventions we perform a scenario analysis. For every planning method we create a scenario with the applicable planning rules. Furthermore we perform different experiments per scenario to see the effects of other parameter choices and different growth scenario's.

7. *What are the recommendations regarding the implementation of the suggested planning methods?*

Finally, in Chapter 7, we describe the recommendations and an implementation plan.

2. Context analysis

This chapter describes the research context and covers three subjects. Section 2.1 describes the surgery process, the involved people, and the surgery characteristics. Section 2.2 describes the planning and control involved in OR-planning. Section 2.3 describes the current performance of the operating room.

2.1 Process description

This section elaborates on the process. Section 2.1.1 describes the surgery planning process and involved terminology, Section 2.1.2 describes the involved staff and their roles and responsibilities, and Section 2.1.3 describes the patient characteristics.

2.1.1 Surgery procedure

For an individual patient the process starts when the operating room is ready and the patient is ordered from the ward or waiting room (Figure 1). After this, the patient is transported to the operating theatre. There the patient is welcomed at the holding, where he waits until he can continue to the operating room (OR). In the OR, the patient waits for the start of the inducing anaesthesia, followed by the induction itself. After induction there may be waiting time for the start of the actual surgery. The time needed for the surgery by the surgeon is the cutting time. Afterwards, the anaesthesiologist takes care of the anaesthesia wearing off and transports the patients to the recovery room. After recovery, the patient is moved to the hospital ward or goes home.

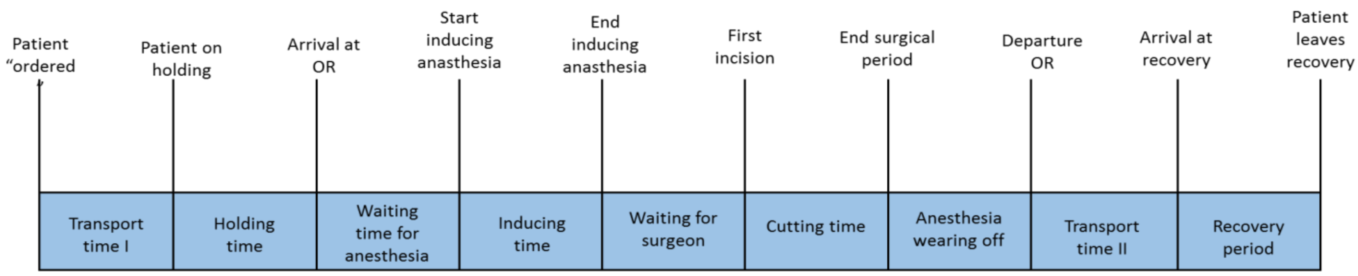


Figure 1: Surgery procedure and time registration (van Hoorn, 2005)

A standard OR-day starts with a briefing at 8:00 and ends at 16:00 (possibly extended to 20:00). One OR-day may be filled with one or more surgeries. If the first patient arrives later than 8:00 there is a start-up loss. Between the sessions there is also some loss, because of the changeover time. During the changeover time there is no patient in the operating room and the room is cleaned and prepared for a new patient or waiting for the arrival of a new patient. The next session starts with the arrival of a new patient. At the end of the day, the program may end before 16:00. In that case there is idle time, or the day may end after 16:00, then there is overtime.

2.1.2 Involved people

There are several people involved in a surgery. First there is a planner that plans the surgery in a session. During the actual surgery there are at least one surgeon, at least one OR assistant, one anaesthesiologist, and one nurse anaesthetist. This team may be extended with other people of interest for the treatment of the patient or in the context of training. The maximum number of people in an operating room due to hygiene is ten. (Gastenprotocol OK)

Furthermore there are some coordinators that monitor the situation in the different operating rooms and adjust the OR-program if necessary. Figure 2 states their functions and responsibilities.

Day coordinator OR

- Monitors progress of the OR program and plan emergency surgeries.

Coordinating surgeon

- Every specialty is represented by a planning doctor. Every day one of the planning doctors is the coordinating surgeon. When surgeries deviate from the program, the coordinating surgeon discusses the continuation of the program with the medical floor manager.

Medical floor manager

- Responsible for the execution of the OR-program and for the planning adjustments for emergency patients.

Floor manager OR

- Responsible for efficient deployment of personnel and resources in the operating theater to promote the progress of the OR-program

Figure 2: Functions and responsibilities of operating room coordinators

2.1.3 Patient characteristics

This section describes the surgical capacity and characteristics of the demand, such as number and duration of the surgeries for the involved divisions and specialties.

Number of surgeries

In 2015 UMC Utrecht performed 16,114 surgeries. Figure 3 shows that most of them belong to DHS, this division performed 9,659 surgeries that together took 16,695 hours. The Cancer Center is the division with the second largest number of surgeries and session hours with 2,288 surgeries and 6,188 hours. The other divisions that use the operating theatre are the division brain, heart and lungs (DH&L), mother and baby (DV&B) and incidentally the internal medicine (DIGD).

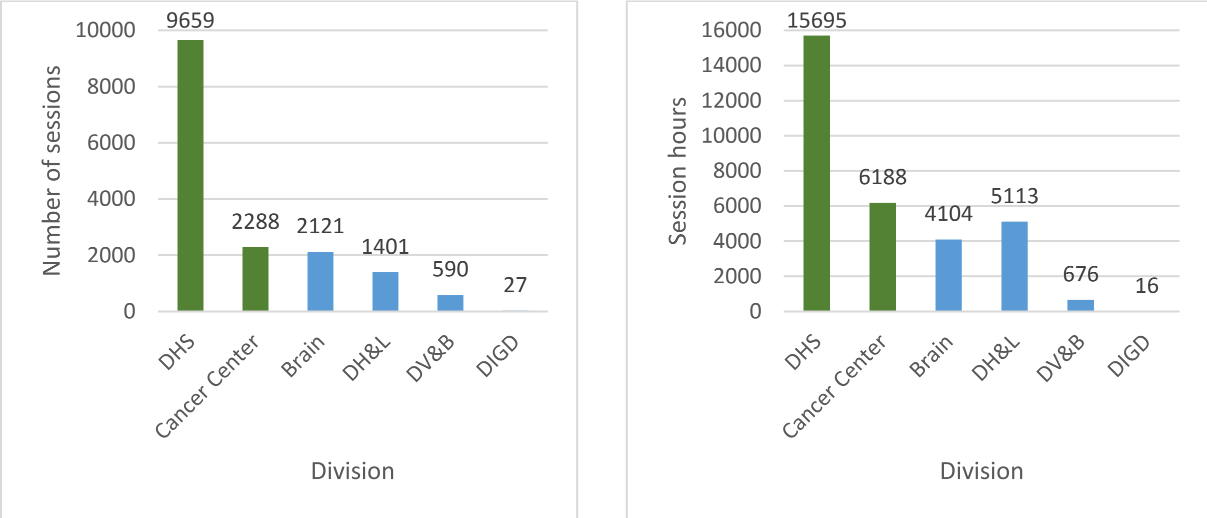


Figure 3: Production UMC Utrecht (Productie-informatie, 2015)

Figure 4 shows that the monthly number of session hours for UMC Utrecht in total fluctuates. In months with a lot of (public) holidays (May, July, August, December) the amount of surgery time is below the production level of the rest of the year.

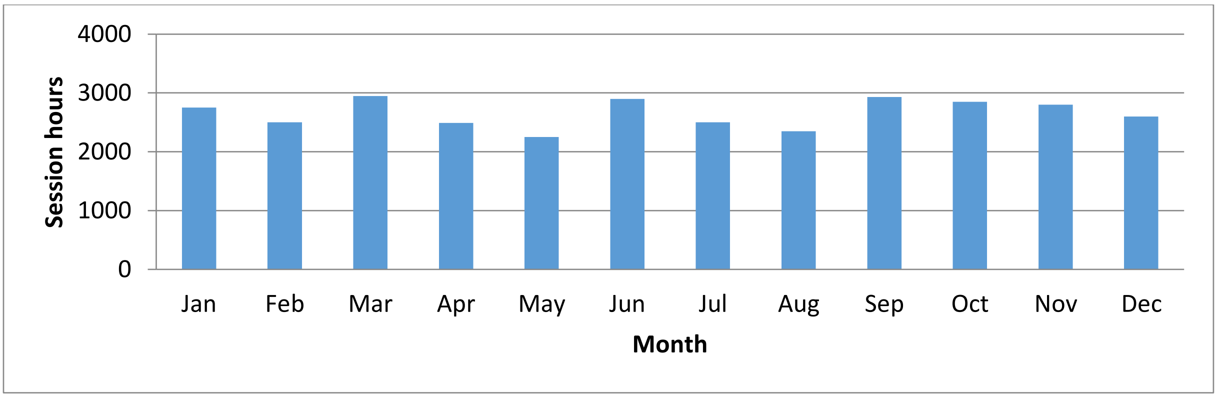


Figure 4: Production UMC Utrecht over the year (Productie-informatie, 2015)

The surgeries for DHS are performed by 10 different specialities: General surgery (CHI), Surgical Traumatology (CTR), Maxillofacial surgery (KAA), Surgical otolaryngology (KNO), Ophthalmology (OOG), Orthopaedics (ORT), Plastic surgery (PLA), Dentistry (TAN), Urology (URO), and Vascular surgery (VAT). The surgeries of the Cancer Center are performed by the five surgical specialties: Surgical Gastroenterological Oncology (CGO), Gynaecological oncology (GON), Oncological Oral and Maxillofacial surgery (QKA), Urological Oncology (QUR), and Ear, Nose, Throat Surgical Oncology (QKN).

Figure 5 shows the information split to the involved specialties of DHS and Cancer Center. This graph shows that OOG accounts for the largest number of surgeries, followed by ORT, PLA, CHI, and CGO.

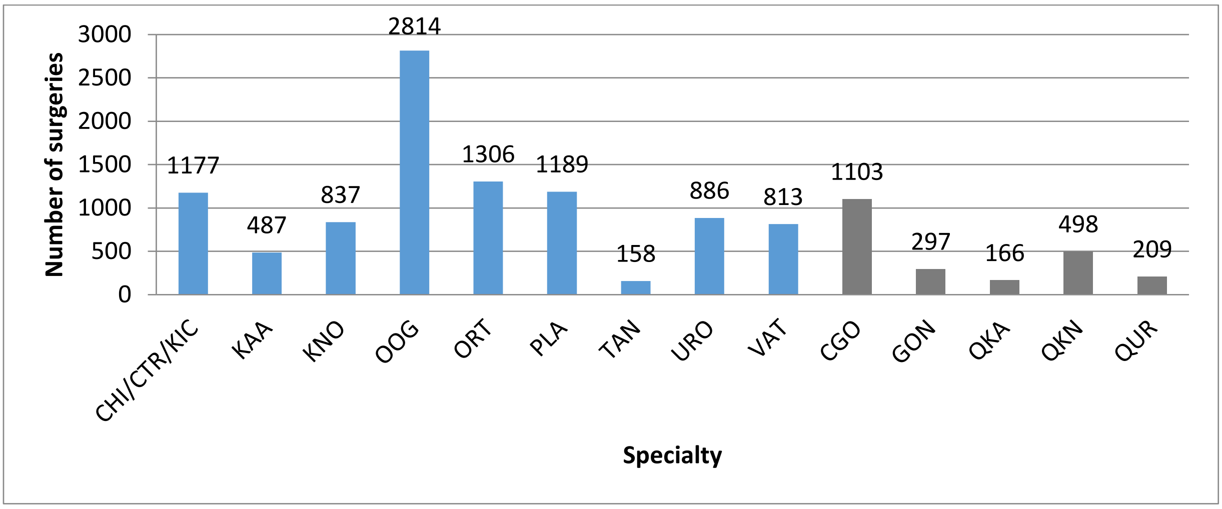


Figure 5: Production DHS and Cancer Center (2015) (Productie-informatie, 2015)

Figure 6 shows that CGO has the largest number of surgery hours, followed by OOG, ORT, CHI, and VAT. TAN, QUR, QKA, and GON are the specialties using the least operating room hours.

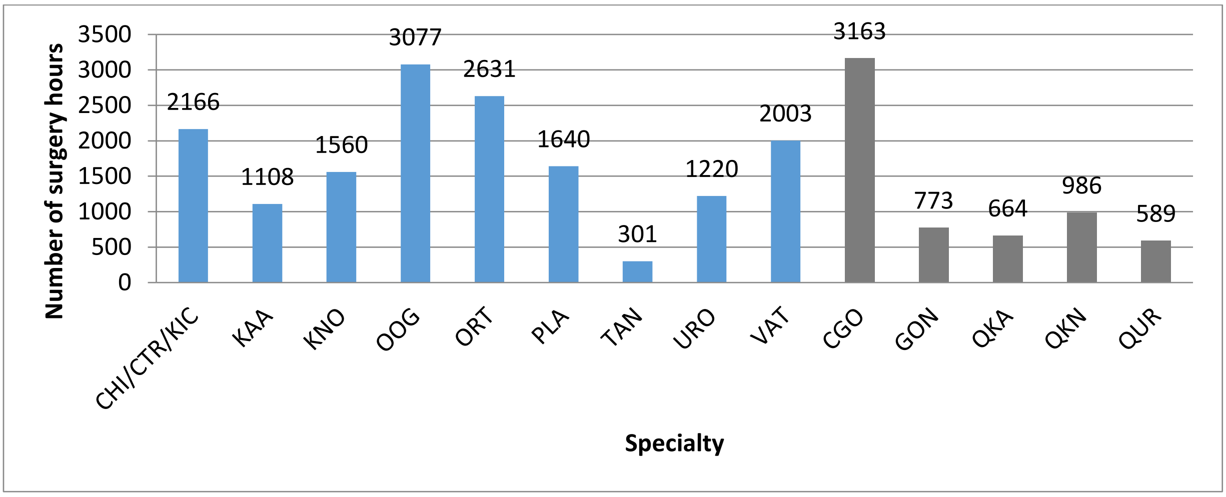


Figure 6: Production DHS and Cancer Center (2015) (Productie-informatie, 2015)

Surgery duration

Table 3 states the spread and average surgery duration per specialty. The colours in this table indicate the frequency of the deviations per category. The dark blue cells indicate a frequently occurring deviation. About half of the surgeries has a duration of less than two hours (55%). Some specialties have a lot of short surgeries that take less than an hour (OOG, PLA, URO, CHI), and others have longer surgeries. What is striking is that there are quite some extremely long surgeries, especially for the CGO, QKA, QKN, PLA, VAT and QUR.

	<60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-330	330-360	360-390	Total	Avg duration
CGO	151	173	204	146	78	48	52	37	40	24	24	123	1100	172
CHI	136	89	108	66	44	22	14	5	8	6	1	4	503	107
CTR	150	149	122	99	69	30	18	13	2	5	5	10	672	113
GON	77	30	26	30	22	16	10	20	10	16	19	13	289	159
KAA	50	101	99	68	60	41	29	15	8	5	1	10	487	137
KNO	167	206	136	121	95	57	23	12	4	7	1	3	832	112
OOG	1442	773	385	146	49	9	5	2	1	0	1	1	2814	66
ORT	425	183	145	163	120	70	51	32	30	19	7	23	1268	115
PLA	637	241	127	65	40	13	7	16	3	6	3	30	1188	83
QKA	20	18	15	25	9	9	14	4	4	7	5	36	166	240
QKN	250	86	33	21	12	15	9	8	5	11	10	38	498	119
QUR	49	24	12	19	25	21	9	17	7	5	1	20	209	169
TAN	5	43	49	35	20	3	2	0	0	0	0	1	158	114
URO	467	184	79	35	29	29	29	7	4	8	4	9	884	82
VAT	94	132	131	129	109	71	49	33	15	14	7	27	811	148
Total	4120	2432	1671	1168	781	454	321	221	141	133	89	348	11879	109

Table 3: Gross surgery duration DHS and Cancer Center surgeries per specialty (2015)

Deviations from the planned duration

Surgeries are complex procedures. This makes it is impossible to predict the exact duration of each individual surgery. That is why most surgeries have a deviation from the planned duration. Figure 7 shows the difference between the planned duration and the actual duration. Most surgeries are on the left side of the diagram, which means that these surgeries took longer than planned. Deviations from the planned duration may have different reasons. The day coordinators indicate for example that not all doctors plan surgery duration including time for anaesthesia.

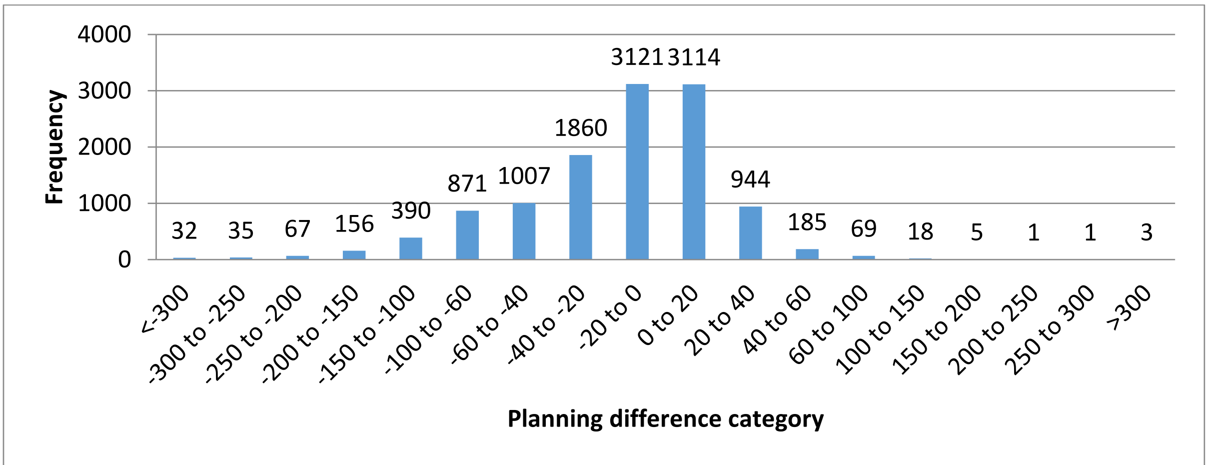


Figure 7: Deviations from the planned duration for DHS & UCC, planned – realized surgery duration (2015)

Table 4 shows the deviations for every specialty. The dark blue cells indicate that a large part of the sessions of that particular specialty is within that deviation category. Mainly for the Cancer Center specialties (CGO, QKA) there are surgeries that took much more time than planned. The surgeries for these specialties are generally long and unpredictable.

	<-300	-300 to -250	-250 to -200	-200 to -150	-150 to -100	-100 to -60	-60 to -40	-40 to -20	-20 to 0	0 to 20	20 to 40	40 to 60	60 to 100	100 to 150	150 to 200	200 to 250	250 to 300	>300	Total
CGO	7	13	22	36	74	136	138	233	222	123	58	17	12	6	2	0	0	1	1100
CHI	0	1	2	7	16	55	73	97	130	99	21	0	2	0	0	0	0	0	503
CTR	3	2	8	24	50	97	100	158	138	68	19	4	1	0	0	0	0	0	672
GON	0	1	6	14	31	44	19	35	69	50	13	6	1	0	0	0	0	0	289
KAA	1	0	2	5	19	48	54	110	97	84	42	23	1	1	0	0	0	0	487
KNO	1	0	0	2	8	39	70	123	213	249	99	24	3	1	0	0	0	0	832
OOG	1	0	1	4	20	94	172	434	989	940	156	1	2	0	0	0	0	0	2814
ORT	0	1	3	11	40	102	98	137	288	380	159	34	13	1	1	0	0	0	1268
PLA	4	3	4	10	16	40	61	149	362	435	91	10	2	0	0	1	0	0	1188
QKA	2	4	6	8	16	24	12	25	23	27	10	6	1	1	0	0	0	1	166
QKN	2	3	2	9	15	33	32	58	121	151	56	9	3	2	1	0	1	0	498
QUR	2	0	1	2	5	9	26	20	33	43	32	14	16	4	1	0	0	1	209
TAN	0	0	0	1	0	4	9	31	34	43	28	8	0	0	0	0	0	0	158
URO	1	2	4	0	10	27	37	98	230	315	135	17	6	2	0	0	0	0	884
VAT	8	5	6	23	70	119	106	152	172	107	25	12	6	0	0	0	0	0	811
Total	32	35	67	156	390	871	1007	1860	3121	3114	944	185	69	18	5	1	1	3	11879

Table 4: Deviations from the planned duration for DHS & UCC per specialty, planned – realized surgery duration (2015)

Emergency patients

When emergency patients arrive, they quickly need treatment. To accommodate surgeries for emergency patients, time should be reserved, otherwise the elective programs will be severely affected. Figure 8 shows the amount of time needed per day to facilitate all arriving (A-, B-, and C-) emergencies surgeries for 2015 on the day of arrival. This time needed fluctuates between 1 and 25 hours. This fluctuation demonstrates that it is not obvious how much time should be reserved for emergency patients.

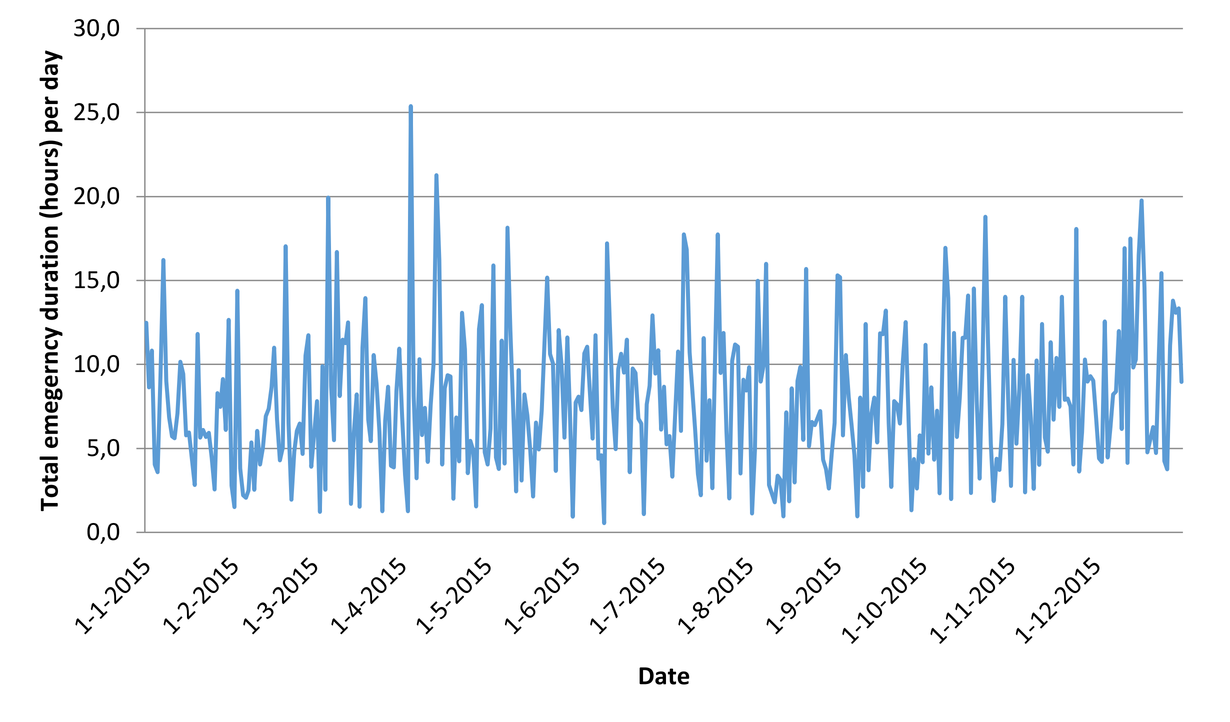


Figure 8: Sum of emergency surgery durations per day

Figure 9 shows the spread of surgery durations. On average an emergency surgery took 114 minutes. The majority of emergency surgeries (75%) took between half an hour and two and a half hour.

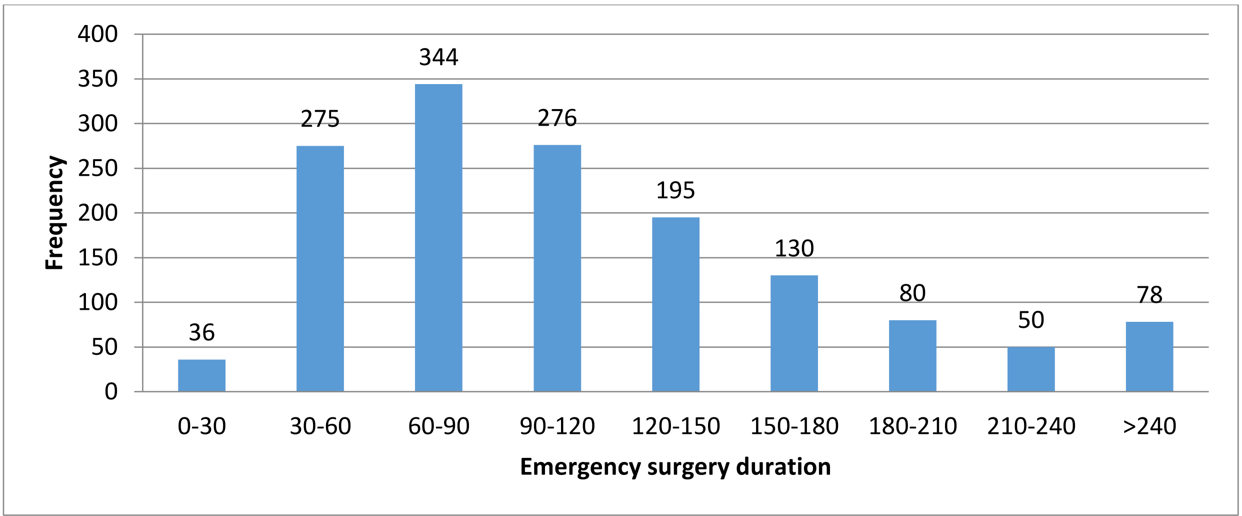


Figure 9: Histogram of emergency durations for DHS & CC

Table 5 shows that the largest part of the emergency patient is a B emergency (45%), followed by C emergencies (42%). Only 13% of the arriving emergency patients is categorized as A-emergency. CHO, CTR, and VAT have the largest share of emergency patients. GON and QKA hardly have any emergency surgeries.

	CGO	CHI	CTR	GON	KAA	KNO	OOG	ORT	PLA	QKA	QUR	URO	VAT	Total	%
A	26	19	37		5	13	1	6	11	5		7	55	185	13%
B	119	71	120	3	30	26	25	77	27	2	12	36	93	641	45%
C	67	55	107	1	59	16	8	77	42	3	14	55	93	597	42%
Total	212	145	264	4	94	55	34	160	80	10	26	98	241	1423	100%
%	15%	10%	19%	0%	7%	4%	2%	11%	6%	1%	2%	7%	17%	100%	

Table 5: Number of emergency patients for DHS & CC specialties (2015)

2.2 OR planning and control

This section describes the processes involved in OR planning. Hans *et al.* (2012) provide a framework to position processes in a managerial area and hierarchical level. Figure 10 provides an overview of this framework including examples. According to this framework there are four managerial areas: medical planning, resource planning, materials planning, and financial planning. Operating room planning belongs to the resource capacity planning area. This area addresses the dimensioning, planning, scheduling, monitoring, and control of resources. These include equipment and facilities (e.g. operating theatres), as well as staff. All managerial areas can be divided in four different hierarchical levels: strategic planning (Section 2.2.1), tactical planning (Section 2.2.2), offline operational planning (Section 2.2.3), and online operational planning (Section 2.2.4).

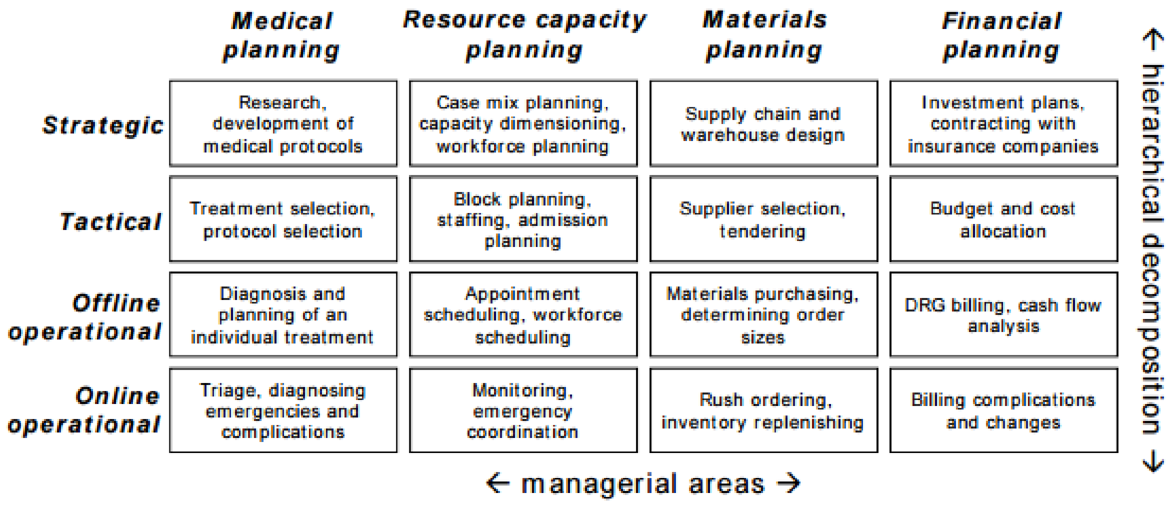


Figure 10: Framework for health care planning and control (Hans *et al.*, 2012)

2.2.1 Strategic level – production agreements

According to Hulshof *et al.* (2012) strategic planning covers long term decisions regarding case mix planning, capacity dimensioning, and workforce planning. Within the scope of this project, capacity dimensioning is the most relevant aspect.

One of the strategic choices regarding the operating rooms, is that UMC Utrecht has chosen to position surgical facilities in several locations. Another strategic choice was to start with renovation of the complete operating theatre. Because of this renovation there were temporarily only 17 operating rooms (ORs) available in 2015. These 17 ORs are spread across four different locations. After the completion of the renovation of the operating theatre in the end of 2016, there will be 23 ORs at three locations: nine at F0, twelve at F4, and two at E4 (Figure 11). F0 will host the facilities for ambulatory patients, F4 will focus on surgeries for patients that will be admitted in the hospital, and the operating rooms at E4 are primary for cardiac catheterization. It is still being debated which specialties will be working at which location.

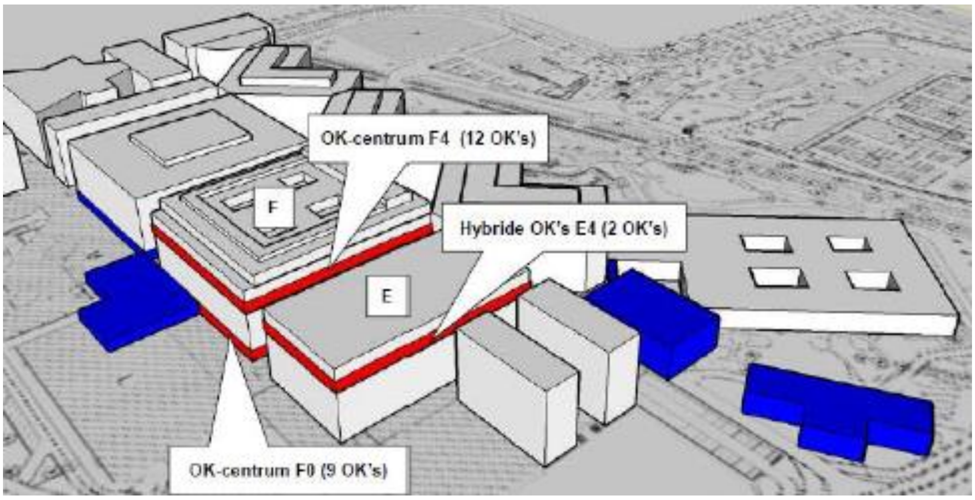


Figure 11: Operating room locations

2.2.2 Tactical level – assigning OR-days to specialties

According to Hulshof *et al.* (2012) the tactical planning covers patient routing, capacity allocation, temporary capacity changes, admission control, and staff shift scheduling. Within the scope of this project, capacity allocation is the most relevant. The possibilities for adjustments depend on the planning horizon. On a tactical level it is for example possible to switch sessions between specialties, open or close additional OR sessions, lengthen or shorten operating hours, shift sessions between locations, spread and tune vacations, or change maintenance periods.

The division vital functions (DVF) is responsible for the operating rooms, OR-personnel, and materials. The Executive Board yearly discusses the available capacity with the DVF. Each specialty and division assesses the expected production for next year, in order to make arrangements with health insurance companies about the number and price for executed treatments (production agreements). Based on these production agreements the divisions calculate the estimated desired OR time. Based on the available OR capacity and the desired OR time from all specialties, the DVF assigns OR time to every specialty and reports this in a management contract with every division. Thereafter, this contract is translated to a monthly roster. The OR planning manager is the central person in this process. He creates the blueprint. The roster is finalized on a monthly basis, by creating a table that states in which operating room the specialties have their sessions. Appendix A shows an example of such a blueprint. Vital Functions releases the final schedule for every month two months ahead. Corresponding to the table, the sessions are released in the planning system. From that moment, the sessions can be filled by the planners of the corresponding specialties.

Since the renovation of the operating theatre, some sessions are planned as ‘white spot’ ORs. These are extended sessions from 8:00 to 20:00 to facilitate emergency surgeries. The emergency patients of the Cancer Center and DHS are clustered in one white spot OR. Besides the emergency patients, specialties can fill those sessions (partly) with elective surgeries. There are rules regarding the number and duration of sessions planned on the white spot ORs. According to the planning document of the DVF, sessions on the white spot of DHS/Cancer Center may be filled to a maximum of 360 minutes with elective surgeries. Only short elective surgeries on these sessions are allowed to ensure enough opportunities to interrupt the planned program for emergency patients.

2.2.3 Offline operational level – assigning surgeries to OR-days

Operational planning is the planning level with the shortest planning horizon. Hans *et al*. (2012) describe that there is limited flexibility on this level, since many decisions that mark the scope are made on higher levels. According to Hulshof *et al*. (2012), offline operational planning for the surgical care service includes: the staff-to-shift assignment, and surgical case scheduling. The latter includes determining the planned length of a surgical case, assigning dates and operating rooms to surgical cases, sequencing of surgical cases, and assigning starting times to surgical cases.

The division ‘vital functions’ takes care of the staff-to-shift assignment regarding anaesthesiology staff and operating room assistants. For surgeons this staff-to-shift assignment is dependent on the surgical case scheduling. The surgical case scheduling for the Cancer Center and DHS involves several planners at different locations.

Planning desks

The surgical planning desk plans the patients for CGO, QUR, CHI, ORT, VAAT, and URO with a rotation system. In this system, one of the four planners is responsible for the planning of a particular specialty. After six months, specialties are changed between planners to share and update knowledge of the planners and make the planning desk less vulnerable and dependent on specific people.

The planning desk at ward D5-West plans the QKN, QKA, KAA, and the KNO. This planning desk has two planners. One of them plans all KNO related patients, and one of them plans all QKA and KAA patients. This means they plan both cancer patients and patients with other diseases. Since the Cancer Center is a separate division there are separate sessions planned for the two patient groups.

For GON the coordinating surgeon performs the mayor part of operational planning. Currently GON has two surgery moments each week. Planning takes place based on the meeting that discusses patients with all GON surgeons, the coordinating surgeon makes a planning.

Planning methods

According to the planners, a good planning gives priority to the wishes of the patients, operates patients within the existing norm, and is also realistic and reliable. To create a schedule, they should match the sessions with the patients on the waiting list, the availability of anaesthesiology and operating room staff, and the availability of surgeons.

Surgery planning starts with an order from the surgeon with details from the patient and surgery. UMC Utrecht implemented treatment codes to support the estimation of surgery durations. These codes cluster specific interventions to enable better reporting and forecasting. When using a code, a pre-filled OR form is offered to the surgeon, which saves time in the administrative process. Currently treatment codes are not consistently used. Therefore the predicted surgery duration are best guesses of the surgeons and the treatment code system is not useful.

While creating the operating room programs the planners select the patients based on their order of entry date on the waiting list. Patients with the longest waiting time are planned first. In addition, the planners discuss with the coordinating surgeon whether there are other patients which have priority due to medical reasons.

Also all planning desks have their own planning document. Those documents provide guidelines and describe details and particularities to take into account while selecting and planning surgeries. For example, it describes surgery types that can or cannot be planned together and capabilities and preferences of surgeons. Also the DVF has a planning document. This is a document that describes the procedures and rules for planning surgeries produced by DVF. However, the document is not known by the planners from the different planning desks. Instead they have their own planning document.

The planning desks have their own rules to determine the order of patients on the day. They consider the medical reasons, the preferences from the OR (longest first), and what is convenient for the physician. Normally the longest surgeries are planned first to minimize the risk of long overtime, or a large gap in the program in case of cancellation. This is done unless there is a (medical) reason to keep to a different order (for example in case of diabetic patient that cannot be sober for too long). Within the Cancer Center many surgeries have a high duration. Therefore, in many cases, it is only possible to do one or two surgeries per OR-day. With only one surgery there is no choice regarding the order on the day, with two or more surgeries there are some options

The finished schedules are sent to the OR day coordinator. This coordinator checks whether everything is arranged and if the program is feasible, otherwise she calls the planners to discuss the desired changes. Most changes are regarding the order of patients on the day. If the day coordinator suspects the planned duration of a surgery is not realistic, the surgeon responsible for filling in the expected duration is contacted and may change the planned surgery duration.

Planning problems

There are several difficulties in surgery planning. First of all the separation of the oncological and non-oncological specialties rises challenges. Before the separation of the Cancer Center specialties from DHS into separate divisions, the benign and malign patients were on the same waiting list for the same OR sessions. This made it easier to react to fluctuations in the number of cancer patients, by giving priority to those patients. With the separation, this freedom is restricted and flexibility has decreased. Exchanging OR time with other specialties has become more complicated and bureaucratic.

Furthermore the planners see opportunities to improve the planning in switching time and the late start. Those gaps are not included in planning, but delay the programs. If those moments take long, time is wasted. It would contribute to the planning and use of capacity if there would be a summary of available time of the various divisions available for the planners. The planning could also be improved by reliable and completely filled out surgery orders, to prevent planners from checking and complementing order, and by starting the program at eight in the morning.

2.2.4 Online operational level – dealing with emergencies

Every day, a lot of choices have to be made to respond to the progress of the OR-program and to the arrival of emergency patients.

The central person in managing the daily (online operational) OR planning, is the OR day coordinator. This is a nurse anaesthetist that is the contact for all questions and changes to the OR program. The day coordinator monitors the list of the emergency patients, the progress of the OR programs, and is point of contact for the coordinating surgeon. When the process of the program deviates from the established program, the program coordinator informs and advises the planning coordinator, the medical floor manager, and the OR floor manager. If necessary, they can consult with the coordinating surgeons, then search for a proper modification to the program. Together with the floor managers, the day coordinator has the right and task to decide whether a surgery at the end of the day can take place.

The choice whether or not to start a new surgery at the end of the day is made based on several factors:

1. The time at the moment of decision: cancelling earlier on the day, results in a longer period of unused OR times
2. The number of other operating rooms with expected overwork: to find personnel for one overwork team is easier then to find extra teams for five overwork teams
3. Whether the patient comes from home or from the clinic
4. The reputation of the surgeon in providing accurate durations for surgeries
5. The amount of overwork in recent times for this specialty

To make the final decision there are no formal or written rules, the choice highly depends on the experience of the OR day coordinator, medical floor manager, and coordinating surgeon.

When the program of an OR finishes early, all personnel stays till 16:00. If the time left is long enough it can be used for another surgery. During the day it is not possible to call an additional patient, so if the program finishes early that time is mostly used for patients from the emergency list. It can also be used to switch with other ORs, or the operating room stays empty. Some specialties add a 'pm' patient to (over)fill their schedule. That patient is informed in advance that the surgery may, or may not take place that day. In case of overtime the teams mutually discus who is willing to do the overtime. In planning personnel for overwork, it is important to have OR assistants of several/the right specialties.

Another choice on online operational planning levels is how to accommodate emergency patients. There are various types of emergency patients depending on their urgency. The emergency type of the patient determines the choices. Figure 12 states the emergency categories and their implication for maximum waiting time. A- and B-emergency surgeries that cannot be performed during regular opening hours may be operated in the emergency program during the evening. C-emergencies stay on the waiting list for next day.

A-Emergencies

- Operate directly or as soon as possible, not longer than 2 hours after placement on the emergency list
- Operate on prolonged OR, break into program of first available OR, or operate on vacant OR

B-Emergencies

- Operate as soon as possible, not longer than 8 hours after placement on the emergency list
- Operate on prolonged OR of own division, break into program of regular OR of own division, or break into program of first available OR

C-Emergencies

- Operate as soon as possible, not longer than 24 hours after placement on the emergency list
- Operate (before 24:00) on prolonged OR of own division, or operate after completion of elective prorgam of own specilaty

Figure 12: Emergency types and definitions (Zakboek OK)

The restriction in the accommodation of the emergency patients are the surgeries that are already running, and cannot be interrupted. Another difficulty is that specialties plan their programs so full, that it is hard to accommodate B, and C emergencies within their own program.

The planners have little guidance from the planned durations in the choices they make throughout the day. It would help them, if the indicated durations would provide more insight in the actual filling of the program.

2.3 Operating room performance

This section provides facts and numbers regarding operating room planning performance. The aim of this section is show the OR performance and the areas with room for improvement. Section 2.3.1 introduces the performance indicators and Section 2.3.2 elaborates on the performance of 2015.

2.3.1 Performance indicators for OR and OR planning

There are many performance indicators for operating room planning. Demeulenmeester (2010) describes in his review that studies use one of more of the following performance indicators: waiting time, throughput, utilization, overtime levelling, makespan, patient refusal, financial criteria and other preferences. According to this literature review the majority of studies uses waiting time for patients, utilization, and overtime as performance indicators. Those are in line with the indicators that UMC Utrecht uses to monitor OR-production, we only add cancelled patients because those are the counterpart of overtime. Overtime can always be prevented by cancelling patients, and the other way around. This results in the following list of performance indicators:

$$Achievement\ of\ norm\ times\ for\ emergencies = \frac{emergency\ surgeries\ within\ norm\ time}{total\ number\ of\ emergency\ surgeries}$$

$$Overwork\ percentage = \frac{overtime\ for\ emergeny\ patients + overtime\ for\ elective\ patients}{regular\ capacity}$$

$$Cancelled\ patients = \frac{cancelled\ emergency\ patients + cancelled\ elective\ patients}{total\ number\ of\ cancelled\ patients + performec\ surgeries}$$

$$Utilization\ = \frac{session\ duration\ elective\ surgeries\ + emergency\ surgeries - overtime}{regular\ capacity}$$

2.3.2 Performance of 2015

This section describes the performance of 2015. It addresses the norm times for emergency patients, cancelled patients, overtime and utilization.

Norm times for emergency patients

Overall in 2015 92% of A-emergencies, 79% of B-emergencies, and 83% of C-emergencies were operated within the norm time for their category. The largest challenge is to provide timely surgery for B-emergencies. Table 6 shows that DHS has more emergencies than the Cancer Center. DHS performs better for the A-emergencies, for B- and C-emergencies the Cancer Center has a better performance. Overall 262 DHS and Cancer Center patients had to wait longer than their emergency norm for their surgery in 2015. Appendix D provides more detailed information for every specialty. Important to mention is that the results are dependent on the established emergency encryption, and that this can be influenced by individual assessments and registration choices. It is difficult to assess the purity of the distinction between these groups.

Division	Emergency Type	# Surgeries	Within norm	Outside norm	% within norm
DHS	A - Emergency	156	147	9	94%
	B - Emergency	511	391	120	77%
	C - Emergency	513	420	93	82%
Cancer Center	A - Emergency	36	30	6	83%
	B - Emergency	158	135	23	85%
	C - Emergency	92	81	11	88%

Table 6: Emergency patients within the norm per division (2015)

Cancelled patients

Elective surgeries that cannot be performed on their planned day are cancelled. The total number of cancelled patients within 24 hours before surgery, for UMC Utrecht in 2015 was 827, this is 5% of the planned surgeries (Appendix E). Table 7 provides an overview of the number of cancelled patients and the reason for cancellation for DHS and UCC in 2015.

Compared to UMC Utrecht average DHS performs slightly better with a relatively low cancellation rate. In 2015 there are 9641 realized surgeries, and 413 cancelled surgeries, this corresponds to a cancellation rate of 4.1%. 248 of those 413 cancelled patients (60%) are due to program reasons. The Cancer Center performs a bit better with an even lower cancellation rate. In 2015 there are 2273 realized surgery sessions, and 80 cancelled surgeries, this corresponds to a cancellation rate of 3.4%. 44 of those 80 cancelled patients (55%) are due to program reasons. Within the category 'program' the largest cause is 'exceeding planned duration'. This has to do with the predictability of surgeries and can be influenced by planning. The other major cause for cancelled patients are medical reasons. These cancelled patients cannot be directly influenced by planning. Appendix B shows the cancellations broken down to specialty and reason.

<table>
<tr><th>Division</th><th># Surgeries</th><th>Cancelled patients</th><th>% Cancelled patients</th><th colspan="2">Cancellation reason</th><th># Cancelled patients</th><th>% Cancelled patients per reason</th></tr>
<tr><td rowspan="13">DHS</td><td rowspan="13">9641</td><td rowspan="13">413</td><td rowspan="13">4%</td><td colspan="2">Material</td><td>4</td><td>1,0%</td></tr>
<tr><td colspan="2">Medical</td><td>127</td><td>30,8%</td></tr>
<tr><td colspan="2">Patient</td><td>31</td><td>7,5%</td></tr>
<tr><td colspan="2">Personnel</td><td>2</td><td>0,5%</td></tr>
<tr><td rowspan="8">Program</td><td>Decision of surgeon</td><td>10</td><td rowspan="8">60,0%</td></tr>
<tr><td>PM-patient</td><td>2</td></tr>
<tr><td>Regular OR: exceeding planned duration</td><td>130</td></tr>
<tr><td>Postponed emergency patient</td><td>9</td></tr>
<tr><td>Extended OR: exceeding planned duration</td><td>8</td></tr>
<tr><td>Priority for elective patient</td><td>1</td></tr>
<tr><td>Priority for emergency patient</td><td>82</td></tr>
<tr><td>Change of program within24 hours</td><td>6</td></tr>
<tr><td colspan="2">Unknown</td><td>1</td><td>0,2%</td></tr>
<tr><td rowspan="10">Cancer Center</td><td rowspan="10">2288</td><td rowspan="10">80</td><td rowspan="10">3%</td><td colspan="2">Material</td><td>1</td><td>1,3%</td></tr>
<tr><td colspan="2">Medical</td><td>26</td><td>32,5%</td></tr>
<tr><td colspan="2">Patient</td><td>3</td><td>3,8%</td></tr>
<tr><td colspan="2">Personnel</td><td>5</td><td>6,3%</td></tr>
<tr><td colspan="2">IC capacity</td><td>1</td><td>1,3%</td></tr>
<tr><td rowspan="5">Program</td><td>Decision of surgeon</td><td>1</td><td rowspan="5">55,0%</td></tr>
<tr><td>Regular OR: exceeding planned duration</td><td>32</td></tr>
<tr><td>Postponed emergency patient</td><td>2</td></tr>
<tr><td>Extended OR: exceeding planned duration</td><td>4</td></tr>
<tr><td>Priority for emergency patient</td><td>5</td></tr>
</table>

Table 7: Cancelled patients for DHS and Cancer Center 2015

Overtime

Overtime measures the number of surgery hours out of regular surgery sessions. Together the session time for DHS in 2015 was 15,695 hours. This divisions had 682 overtime hours. This is an overtime percentage of 4%. In 2015, the Cancer Center surgeries took 6188 hours, of which 386 were overtime hours. This is an overtime percentage of 6.2%, which is the highest of all divisions. Figure 13 shows the number, and spread of DHS and UCC for 2015. From DHS surgeries from ORT and VAT cause most overtime hours. For the Cancer Center QKA and CGO have the most overtime hours. Appendix C shows more detailed information.

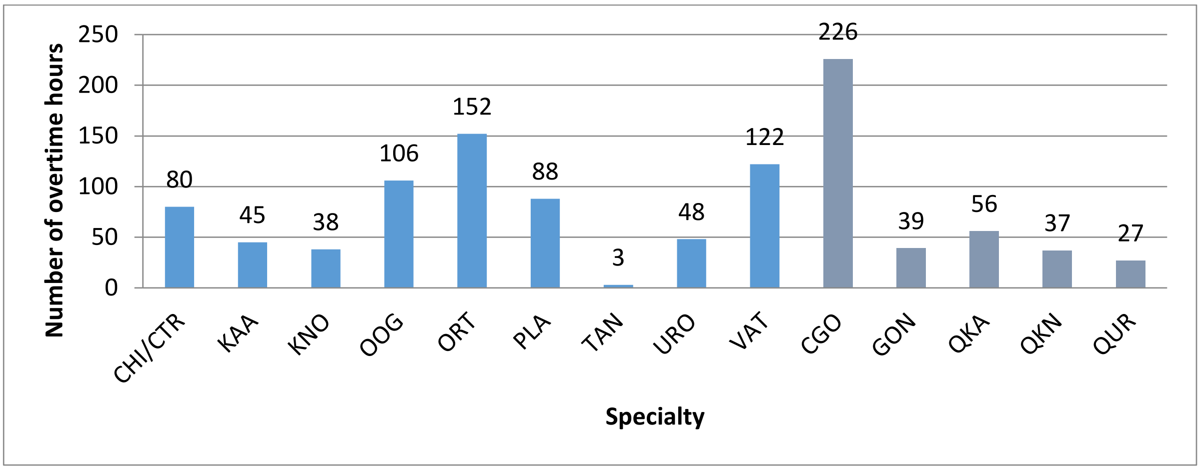


Figure 13: Overtime hours for the specialties of DHS and Cancer Center

Figure 14 shows that in most cases the overtime duration is short. Appendix C shows that long overtime sessions occur most frequently for CGO, PLA, VAT and QKA.

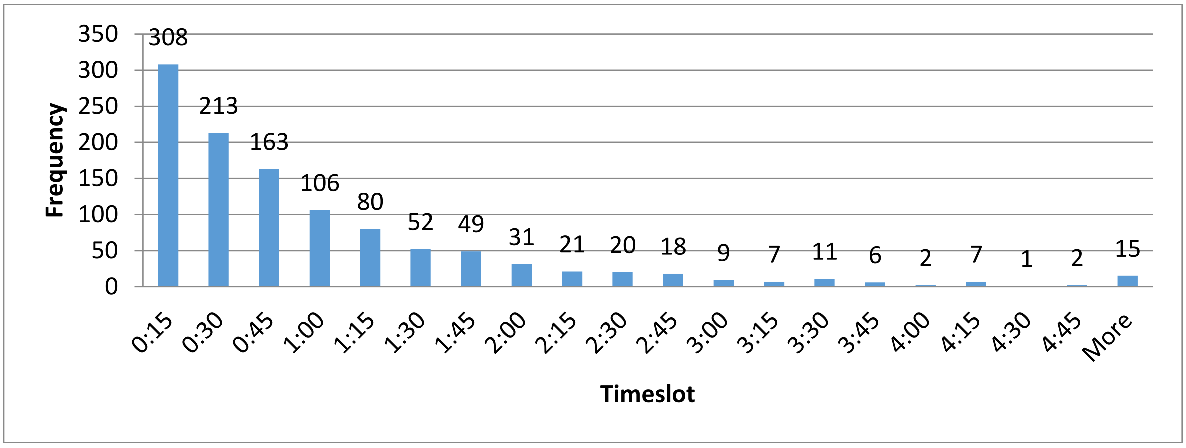


Figure 14: overtime frequencies per timeslot for DHS and Cancer Center in 2015

Utilization

The utilization of an operating room is below 100% because at several moments there are gaps with unused time in the OR-programs:

- At the beginning of the day – time for briefing and late start
- At the end of the day - early end
- During the day - changeover time

Table 8 shows that utilization of OR-time is between 68% (CHI) and 87% (QKA) when only using the actual surgery times. Cancer Center specialties have a higher utilization than DHS specialties. Another utilization definition includes also changeover time. According to this definition TAN has the lowest utilization (80%) and QKA the highest (92%). A third definition includes surgery time, changeover time, and the time for briefing. According to the last definition utilization for DHS and UCC specialties varies between 83% (TAN) and 94% (OOG, QKA). One factor influencing the utilization is the surgery duration. The surgery duration influences the utilization of the operating room time, because the duration of surgeries determines the number of patients in a program, and thus the number of changeovers. This means programs with many short surgeries also have many changeovers and thus relatively much changeover time, a high utilization excluding changeover time and briefing is then impossible.

	# OR-Days	Avg ut excl %	Avg ut incl change excl brf%	Avg ut incl change & brf%
CHI	383	68%	84%	87%
KAA	187	81%	88%	91%
KNO	3	78%	85%	88%
OOG	675	77%	91%	94%
ORT	446	78%	88%	91%
PLA	345	74%	87%	90%
TAN	68	71%	80%	83%
URO	228	74%	88%	91%
VAT	321	80%	88%	91%
CGO	526	82%	89%	92%
GON	178	80%	89%	92%
QKA	95	87%	92%	94%
QKN	164	81%	88%	91%
QUR	107	84%	89%	92%
Total	3726	77%	88%	91%

Table 8: Utilization per specialty for DHS and Cancer Center specialties in 2015

When the first surgery of an OR-day starts after the planned start of that OR-day, a 'late start' occurs. Figure 15 shows that only 5% of all first surgeries start within 10 minutes after the start of the surgery OR. Most surgery programs start within 30 minutes after start of the OR. The large peak for 10-20 minutes is caused by the start of the operating room teams at 8:00. One of the reasons for this is that one anaesthetist may be responsible for the anaesthesia of two operating rooms. One of the operating rooms then cannot start and has to wait for the anaesthesiologist to finish in the other room.

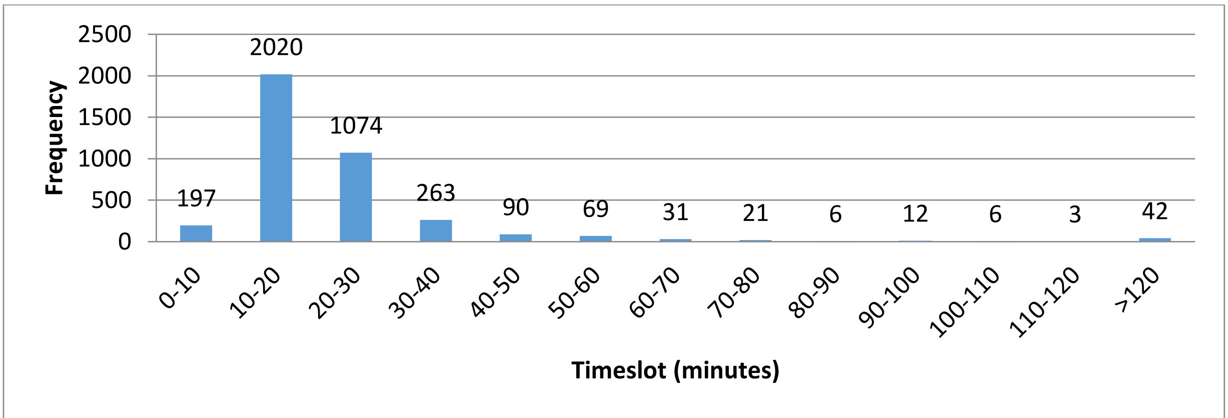


Figure 15: Late starts per timeslot for first surgeries of OR-days of DHS & CC

The changeover time is the period between the exit of one patient and the entrance of the next patient in the same operating room on the same day. While planning, planners calculate on default 15 minutes changeover time. Figure 16 shows that in practice a changeover time of 15 minutes most of the time too short. In 2015 there were 1,249 changeovers that took more than an hour, 318 changeovers of more than two hours, and 102 times of more than 3 hours. This indicates that the OR-time can be better used with improvements that prevent long changeover times. Changeovers may be longer than expected for example because a patient is last minute cancelled or did not show up, or because of delay in to process of calling and preparing the next patient. There is no registration or control on reasons for long changeovers.

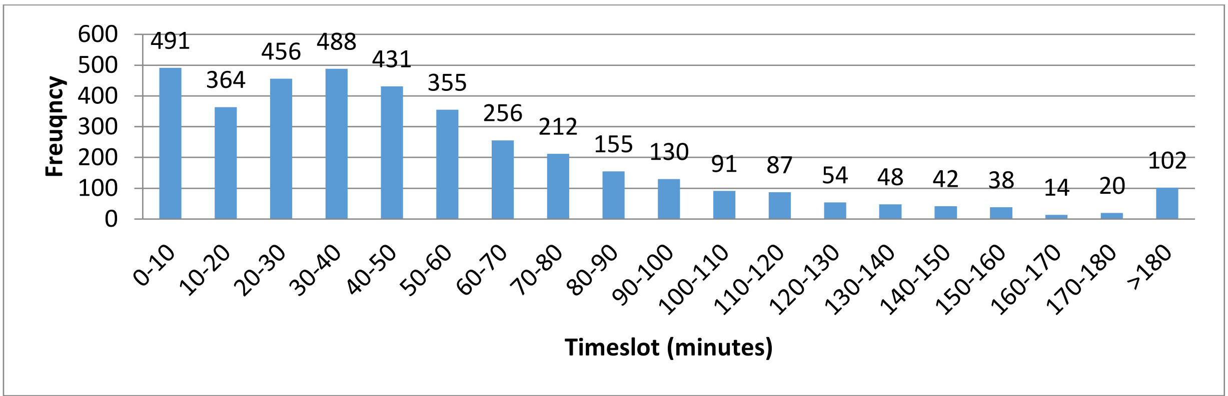


Figure 16: Histogram of number of changeovers per time slot for DHS & CC

Figure 17 shows that most OR-programs have some overtime or an 'early end' of less than ten minutes. In 2015 there were 320 times a gap at the end of the day of at least two hours. 190 OR-days ended with more than three hours unused OR-time. On average every day there is such a gap.

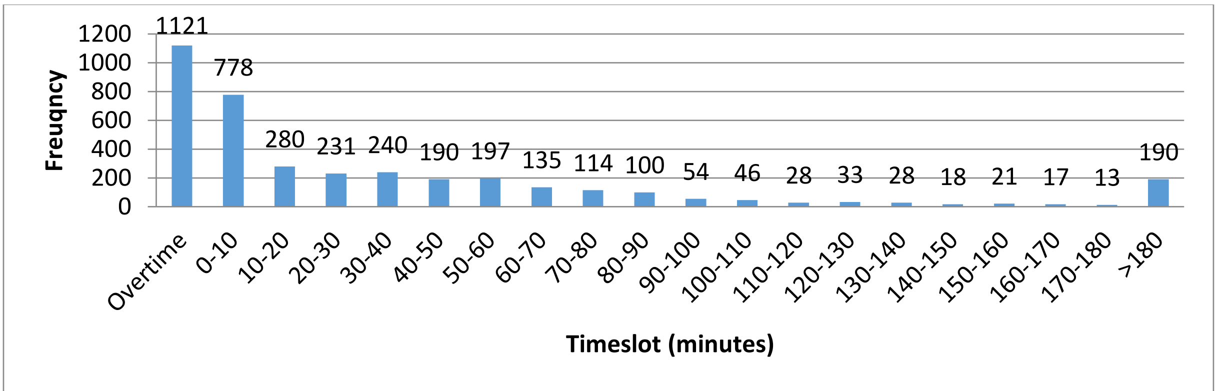


Figure 17: Early ends per timeslot for DHS & Cancer Center OR-days

2.4 Conclusion

This chapter showed that the planning of the UMC Utrecht is based on a blueprint that assigns capacity to the different surgical specialties. This blueprint is a scheme of four weeks that states which specialty can use which OR at which moments and is repeated every four weeks. The final month schedule is released two months in advance, after which patients can be scheduled in the sessions. To do so there are several planning desks and planners who plan surgeries for one of more specialties. The current schedule contains six hours per day to accommodate emergency surgeries. During the day the program is adapted based on deviations from planned surgery durations and the arrival of emergency patients. A-emergencies always interrupt the program of the first available OR, regardless the specialty of that OR. B-emergencies interrupt only the programs of their own specialty or the program with reserved capacity for emergencies. C-emergencies are performed at the end of the day.

DHS and Utrecht Cancer Center are the largest users of operating room capacity in UMC Utrecht. CHI, KNO, OOG, ORT, PLA, VAT, and CGO are the specialties using the largest part of capacity. The average surgery duration for both divisions together is 109 minutes. Some specialties (OOG, PLA, URO) mainly have short surgeries (<120 minutes), while other specialties have extremely long surgeries (CGO, QKA, QKN, VAT). The Cancer Center specialties have relatively long surgeries, with an average duration of more than 159 minutes, even 240 minutes for QKA. Those two specialties with long surgeries have the largest deviations from the planned duration.

We measured the performance for 2015 in cancellations, overtime, utilization, and emergencies within the norm. In 2015 the cancellation rate was 3.97%. Together the overtime for DHS and Cancer Center was 1068 hours. DHS had 682 overtime hours (4%). Cancer Center used 386 overtime hours (6.2%). The utilization based on session time without changeovers and briefing was 77%. In 2015 92% of A-emergencies, 79% of B-emergencies, and 83% of C-emergencies were operated within the norm time for their category. We want to improve the performance by increasing the number of patients within their norm, and decreasing the cancellations and overtime.

3. Interventions

Within UMC Utrecht the operating room management faces a trade-off between responsiveness to emergency surgeries and effective scheduling elective patients. This chapter describes different methods to reserve capacity to anticipate on arriving emergency patients. Section 3.1 describes the current approaches to deal with emergency patients as seen in literature. Section 3.2 translates these approaches to scenarios that we test for UMC Utrecht. Section 3.3. describes an overview our experiments.

3.1 Literature study

Cardoen, Demeulenmeester, and Belien (2010) provide us with a literature review of recent research on operating room planning and scheduling. According to their review the number of studies that focus on elective patient planning and scheduling is vast compared to the non-elective counterpart. The studies focussing on emergency patients may distinguish between emergencies patients and urgent patients. Whereas emergencies should be performed as soon as possible, urgent patients are sufficiently stable to postpone their surgery for a short period. Guerriero *et al.* (2011) provide a similar review about the application of operational research to surgical planning and scheduling. They grouped researches based on the hierarchical decision level and focussed on the mathematical methods used. One of their conclusions is that Operational Research approaches strive to increase patient throughput, improve satisfaction of patients and staff, maximize utilization of resources, reducing surgery cancellations, and reducing the time loss due to late starts and changeovers. Hulshof *et al.* (2012) provide an overview of typical decisions to be made in resource capacity planning, and an overview of articles relevant for those decisions.

The central question within our study is: How much capacity should be reserved for emergency patients, and when? To answer this question this section describes the state of the art concepts regarding the accommodation of emergency surgeries.

Within literature there are two major concepts to deal with emergency surgeries: reserve all capacity for emergencies on one (or more) dedicated urgency OR (dedicated policy), or by reserving capacity in the programs for elective surgeries (flexible policy) (Van Riet & Demeulenmeester, 2015). The advantage of the dedicated policy is that the first arriving emergency surgery can begin without waiting time. All further emergency surgeries may face delay. The flexible policy prescribes that all operating rooms should be filled with elective surgeries, but not to their full capacity. In this case, the elective program is interrupted after the arrival of emergency patients. Figure 18 provides a graphical representation of both methods.

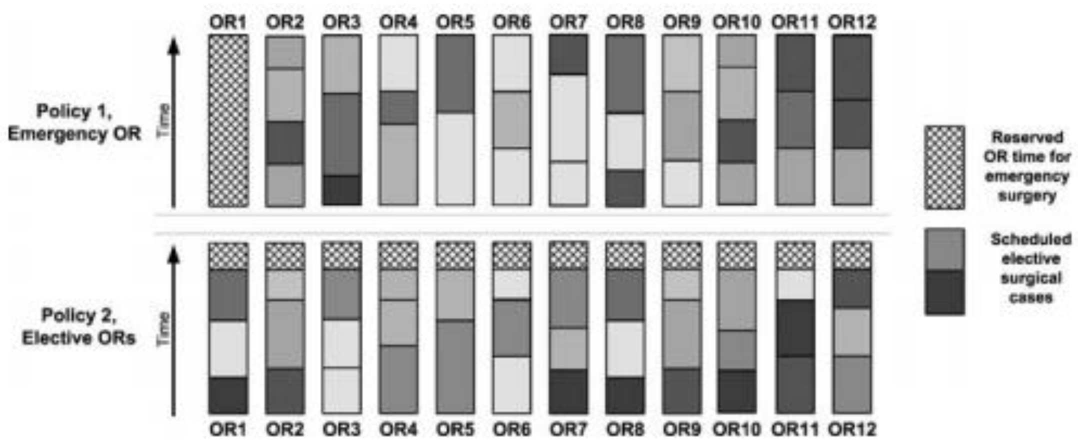


Figure 18: Visualization of the two studied policies for allocating reserved OR time, (Wullink *et al.,* 2007)

According to Wullink *et al.* (2007) the flexible policy is the best way to reserve capacity for emergency surgeries. This reduced the waiting time for emergency patients, as well as overtime. Overall OR utilization increases. Hans & Vanberkel (2012) describe that this flexible method schedules a certain amount of slack in order to fit emergency surgeries without causing excessive cancellations of elective surgeries. They state that this policy uses flexibility to react quickly on arriving emergency patients. The largest effect is for subsequent patients, their surgeries happen sooner than in a dedicated emergency operating room. The condition for this method, that enables flexibility, is that there are enough parallel operating rooms and that many (or all) of them must be equipped to deal with emergencies.

Lans *et al.(2006)* use simulation to evaluate planning to anticipate emergency surgeries. They use different scenarios with dedicated ORs, planned slack in some ORs, and planned slack in all ORs. For their study, they found planned slack in all ORs performs best.

Ferrand (2014) investigates whether a combination of flexible and dedicated rooms could be a preferable alternative. Within this study the central question is what the optimal combination of dedicated and flexible operating rooms is. They used a simulation model to evaluated different policies under various conditions and found that partial flexibility outperforms both the completely flexible and the completely dedicated policy for emergency as well as elective patients.

According to Van Riet and Demeulenmeester (2015) the flexible policy with non-electives inserted directly or through pre-scheduled buffer has received limited attention in literature so far, and is an opportunity for further research.

Most of the above studies are about one or a few departments and use data from (less than) one year. So those studies search for the best solution for a particular case. But different department have different characteristics (capacity, arrival pattern, duration patterns). Results from these studies therefore differ. There is no general consensus about the optimal method. According to Borgman *et al.* (2016) the size of the operating room complex and other case specific characteristics have a major influence on the results.

3.2 Planning policies

To deal with emergencies, all methods reserve time for emergency patients. They differ in the amount of, and the moments when time is reserved. Based on the literature review we decided to test two traditional methods, and one method that tries to improve the performance of the two traditional methods by combining the best of both. This results in the following three planning policies:

1. Dedicated policy
2. Flexible policy
3. Combination of flexible and dedicated policy

3.2.1 Dedicated policy

The first policy reserves capacity for emergencies in one operating room every day. We do not test the completely dedicated method because from a medical point of view this is inacceptable. If there is an A-emergency that needs surgery, this patient should be in the operating room as soon as possible, and never waits longer than necessary. Therefore, surgeries for emergency patients with priority 'A' that arrive when the emergency OR is busy, may interrupt the elective surgery programs on the operating rooms. According to the current plans of DHS and Cancer Center, those divisions will work according to this policy in 2017. This scenario addresses the expected impact of that choice on the operating room performance.

However, the blueprint describes that the complete program of twelve hours is reserved for emergency surgeries, and we also like to test the effect of ten or eight hours reserved for emergencies. This means that there may be elective surgeries planned on the emergency OR for two, respectively four hours. We make this elective capacity 'general' which means all specialities of DHS and Cancer Center may plan surgeries within this capacity. The restriction to surgeries planned on these emergency programmes is that they may not take longer than two hours per surgery. Within this policy, all A-emergencies go to the next available operating room, independent of the specialty. B- and C-emergencies may be operated in the emergency OR, or on operating rooms of their own specialty. A-emergencies that have not been performed on their arrival day are performed during the night. B- and C-emergencies stay on the emergency list for next day.

The expected effects of this policy are:

- Quick responses to first arriving emergency patient
- Few interruptions to the elective program causing delay, overtime and cancelled patients

- High utilization of elective programs
- Possibly low utilization of emergency OR, depending on the number of emergencies and reserved amount of time

3.2.2 Flexible policy

The second policy has no emergency OR, but instead reserves time at the end of all elective OR programs to accommodate emergency surgeries. When an A- or B emergency patient arrives, one of the elective programs is interrupted. C-emergencies wait till the end of elective programs.

In this scenario (and policy 3) we take into account that the patients of the specialties are not always easily interchangeable. For A-emergencies, the planning rules remain the same: perform the surgery on the first available OR, regardless of the specialty of that OR. For B- and C-emergencies we use clusters to determine interchangeability. Based on consultation with a surgeon, we chose to make the following groups of specialties:

- CHI, CGO, URO, QUR, GON, CTR, ORT
- QKA, QKN, KAA, KNO
- VAT

This means for example that B- and C-emergencies of CHI may be performed in surgery programs of CGO, GON, URO, QUR, CTR, and ORT, but not in programs of QKA, QKN, KAA, KNO, or VAT.

The expected effects of this policy are:

- High utilization of all OR capacity
- Less cancelled surgeries
- Quick response to all (also second, third etc. arriving) emergencies

3.2.3 Combination of dedicated and flexible policy

The first two scenarios are well known and used in hospitals. The third scenario extends the conventional options with a hybrid form that reserves time during day for emergency patients to ensure quick reaction to arriving emergencies, but spreads this time across several elective programmes. There is no emergency OR. At moments with a long time till the next possibility to interrupt another program one of the ORs becomes emergency OR for a period. During this period, the OR stays empty to be able to react quickly to arriving emergency patients. When one of the other operating rooms (nearly) finishes, the temporary emergency room may continue its elective program.

The division of OR capacity and rules for emergency patients of this scenario is the same as in scenario 2. This method is different because it considers the next opportunity to break into the elective program when starting an elective surgery. If a long surgery is running in all other operating rooms, this method waits in the empty OR until one of the other ORs nearly finished.

Basically this policy has similar expected effects as the flexible policy: a high utilization of all OR capacity and a high response to all (also second, third etc. arriving) emergencies compared to policy one.

Compared to the flexible policy we expect that:

- With the same amount of emergency slack, the reaction time to emergencies decreases
- Or, that with less time reserved for emergencies, we can reach the same level of emergencies within the norm
- The waiting time delays elective programs, this might result in cancellations or overtime

The expectations for this policy depend on several factors:

- Surgery duration: this determines the amount of interruption moments in the elective programs. If there are many small surgeries scheduled, which corresponds with many interruption moments, there will probably be less waiting moments, and the increase in emergency reaction is small. For schedules with many long surgeries we expect a larger effect.
- Amount of operating rooms: the more operating rooms, the more interruption moments. More interruption moments decreases the need for saving time for emergencies during the day.

3.2.4 Summary of expected effects of planning policies

Table 8 provide a summary of the expected pros and cons for the different planning methods.

Planning policy	Pros (+) and cons (-)
Dedicated	(+) Quick responses to first arriving emergency patient
	(+) Few interruptions to the elective program causing delay, overtime and cancelled patients
	(+) High utilization of elective programs
	(-) Possibly low utilization of emergency OR, depending on the number of emergencies and reserved amount of time
Flexible	(+) High utilization of all OR capacity
	(+) Quick response to all (also second, third etc. arriving) emergencies
Combination	(+) High utilization of all OR capacity compared to a dedicated policy
	(+) High response to all (also second, third etc. arriving) emergencies compared to a dedicated policy
	(+) With the same amount of reserved capacity, a better reaction time for emergencies / less reserved capacity needed to perform the same number of emergencies within their norm compared to a flexible policy
	(-) More waiting time that delays elective programs causing more cancelled patients and/or overtime compared to the flexible policy

3.3 Experimental design

This section provides an overview of all experiments. We test the aforementioned dedicated, flexible, and combinational policy. We test all policies for eight, ten, and twelve hours reserved for emergencies. We then test all combinations for the number of patients from 2015, in case of 5% growth, and in case of 10% growth of the patient population. The gaps used for the combinational policy are 60 and 120 minutes. Finally we perform some extra experiments to test the effects of different scheduling methods for the combinational policy.

Table 9 provides a list of experiments. The first column of this table states the planning policy. We test the dedicated, flexible, and combination policy described in paragraph 3.2. The second column states the amount of reserved time for emergencies per day. We test for eight, ten, and twelve hours reserved for emergencies. The third column states the number of patients. We distinguish experiments with the same number of patients as in 2015, with 5% more (elective and emergency) patients, and with 10% more patients. The dedicated and flexible policy each have 9 experiments (3 capacity variants x 3 growth scenarios), all with a scheduling policy that plans based on descending duration and level fit. We allow to plan the surgeries with overtime, because then the number of surgeries in the different experiments are best comparable.

The experiments with the combination policy have an extra variable, the maximal allowed time till next BIM. We perform experiments for an allowed gap of 60 and 120 minutes. Furthermore we expect that the scheduling policy has an important role for this planning policy, we therefore add some extra experiments to test the effect of other scheduling policies than descending duration, level fit. We test the effect of BIM, and random selection.

Nr.	Planning method	Emergency Capacity	Number of patients	Max time till next gap	Scheduling policy
1	Dedicated policy	8 hours	2015	∞	Descending duration + level fit
2	Dedicated policy	10 hours	2015	∞	Descending duration + level fit
3	Dedicated policy	12 hours	2015	∞	Descending duration + level fit
4	Dedicated policy	8 hours	2015 + 5%	∞	Descending duration + level fit
5	Dedicated policy	10 hours	2015 + 5%	∞	Descending duration + level fit
6	Dedicated policy	12 hours	2015 + 5%	∞	Descending duration + level fit
7	Dedicated policy	8 hours	2015 + 10%	∞	Descending duration + level fit
8	Dedicated policy	10 hours	2015 + 10%	∞	Descending duration + level fit
9	Dedicated policy	12 hours	2015 + 10%	∞	Descending duration + level fit
10	Flexible policy	8 hours	2015	∞	Descending duration + level fit
11	Flexible policy	10 hours	2015	∞	Descending duration + level fit
12	Flexible policy	12 hours	2015	∞	Descending duration + level fit
13	Flexible policy	8 hours	2015 + 5%	∞	Descending duration + level fit
14	Flexible policy	10 hours	2015 + 5%	∞	Descending duration + level fit
15	Flexible policy	12 hours	2015 + 5%	∞	Descending duration + level fit
16	Flexible policy	8 hours	2015 + 10%	∞	Descending duration + level fit
17	Flexible policy	10 hours	2015 + 10%	∞	Descending duration + level fit
18	Flexible policy	12 hours	2015 + 10%	∞	Descending duration + level fit
19	Combination policy	8 hours	2015	60	Descending duration + level fit
20	Combination policy	8 hours	2015	120	Descending duration + level fit
21	Combination policy	10 hours	2015	60	Descending duration + level fit
22	Combination policy	10 hours	2015	120	Descending duration + level fit
23	Combination policy	12 hours	2015	60	Descending duration + level fit
24	Combination policy	12 hours	2015	120	Descending duration + level fit
25	Combination policy	8 hours	2015 + 5%	120	Descending duration + level fit
26	Combination policy	10 hours	2015 + 5%	120	Descending duration + level fit
27	Combination policy	12 hours	2015 + 5%	120	Descending duration + level fit
28	Combination policy	8 hours	2015 + 10%	120	Descending duration + level fit
29	Combination policy	10 hours	2015 + 10%	120	Descending duration + level fit
30	Combination policy	12 hours	2015 + 10%	120	Descending duration + level fit
31	Combination policy	8 hours	2015	120	Descending duration + level fit + BIM
32	Combination policy	10 hours	2015	120	Descending duration + level fit + BIM
33	Combination policy	12 hours	2015	120	Descending duration + level fit + BIM
34	Combination policy	8 hours	2015	120	Random + level fit
35	Combination policy	10 hours	2015	120	Random + level fit
36	Combination policy	12 hours	2015	120	Random + level fit

Table 9: Overview of experiments

We use 36 experiment, different in planning method, reserved capacity for emergency surgeries, maximal allowed gap, and scheduling policy, to find the best settings for DHS and Cancer Center.

4. Model construction and simulation of the current situation

In Chapter 4 we select and build a model to test the effect of the proposed interventions. Section 4.1 addresses the selection of the right type of model. Section 4.2 describes the details of the model by giving the problem formulation, modelling assumptions, input data, and concludes with verification and validation of the model.

4.1 Model Selection

There are several possible model types to analyse the proposed interventions. Law (2007) describes that it is possible to experiment with the actual system, or with a model of the system (Figure 19). We perform this research to support the decisions beforehand, so we do not want to experiment with the real systems. This might be costly, time consuming, and hard to control the experiments.

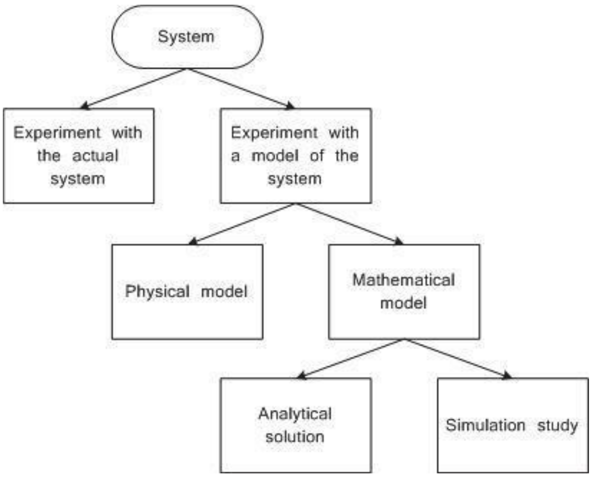


Figure 19: Methods to analyze a system (Law 2007)

Then there is a choice between physical models, and mathematical models. It is difficult to create a physical model with the size and complexity of an operating room complex, so we will use a mathematical model. We can use an analytical model, or perform a simulation study.

Van Riet and Demeulenmeester (2015) describe that simulation is a suitable method to model operating rooms for two main reasons. First, simulation is suitable to incorporate stochastic elements in the model, and thus to study complex environments. Second, simulation is suitable for scenario analysis. Cadoen et al. (2010) support this by stating that the majority of operating room planning studies uses discrete event simulation.

We want to test the effect of different types of interventions (scenarios) in a complex environment. Riet and Demeulenmeester (2015) describe several reasons to simulation modelling is suitable if there are too many influencing factors to solve the problem analytical. Also Law (2008) mentions that a reason to use simulation is that most problems are too complex to solve analytically, and that simulation then is the only possible method. Law states that simulation is a suitable method to test different scenarios because simulation allows to estimate the performance of existing systems under different conditions. The main argument against simulation models are the barriers to implement the findings in practice. However, this argument is also true for other methods.

According to Law (2008) a sound simulation study consists of seven steps as shown in Figure 20. Following sections will describe those different steps for our simulation study.

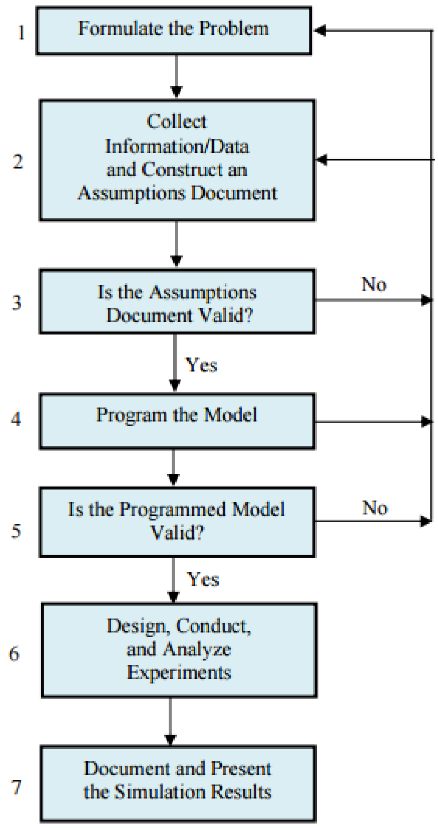


Figure 20: A seven-step approach for conducting a successful simulation study (Law, 2008)

The simulation model used for this project is an adapted version of a program developed at the University of Twente. This program is specifically designed to model operating theaters. (Hans & Nieberg, 2007)

The program is able to model all operating rooms with their opening hours, the case mix of patients and a statistical distribution per surgery type. The model consists of several building blocks with different functions: 1. Initialization, 2: Strategic management, 3: Tactical management, 4. Operational management, and 5: Simulation (Figure 21).

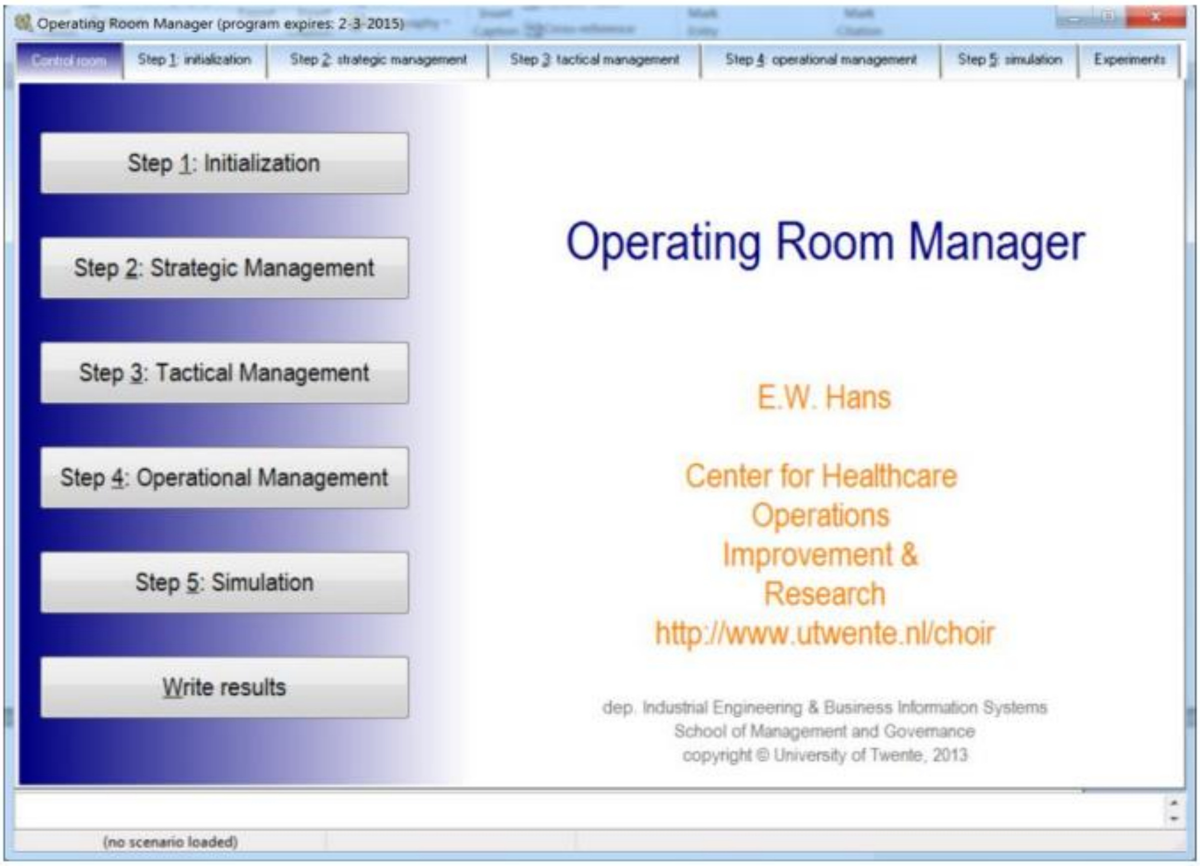


Figure 21: Simulation interface

In the initialization phase we load all basic settings into the program. This includes a definition of the specialties, their case mix, and surgery types per specialty. Every surgery type has a name, number, specialty, duration (distribution), case mix share, and patient type. Also the distributions for the operating duration per surgery type and the distribution for cleaning time are entered here.

The next step sets the strategic settings. For this model this means setting the number of operating rooms. The third tactical step is linked to this, because the third step assigns the available operating rooms to specialties. This tab represents the Block Schedule as shown in Appendix A. In this tab for every week a specific schedule can be loaded, or the same schedule can be repeated every week.

On the operational level, step four determines the scheduling approach. The tab contains decisions regarding the number of patients to generate, the allowance of overtime, and the operating room selection criteria.

In the final simulation tab we can define the number of warm-up periods, the rules for cancelling patients, and the availability of patients. Also this tab contains the settings regarding the rescheduling of surgeries, for example due to a delay of a previous surgery.

4.2 Model building

The existing model has been adapted in several ways. This section describes the problem formulation, modelling assumptions, data collection and model validation and verification.

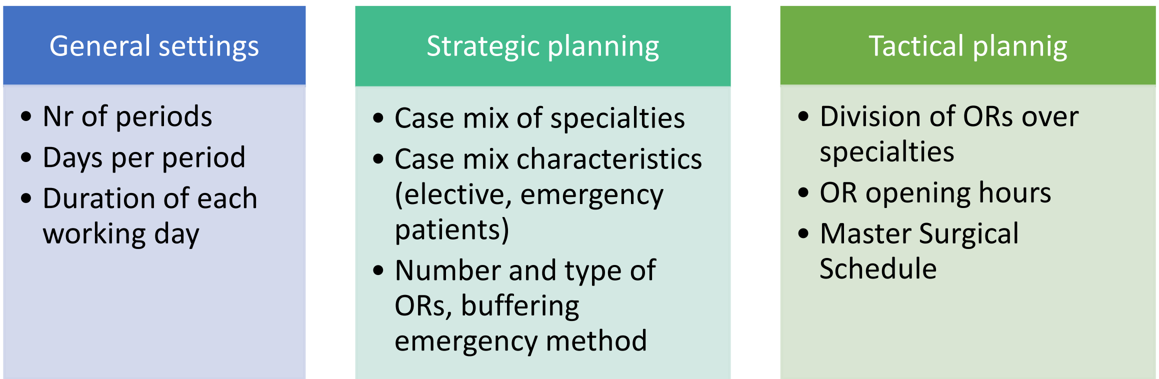
4.2.1 Problem formulation

The goal of our simulation is to provide insight into the effects of several scenarios of accommodating emergency surgeries for the Cancer Center and DHS patients and to support this with numerical insights. This means we want to know the performance of the OR planning in different scenarios. Performance is expressed as number of cancellations, overtime, utilization and percentage of emergency patients treated within the norm time.

4.2.2 Data and information collection

In our model we include all surgeries from the Cancer Center and DHS that were done in 2015. The available OR capacity in our baseline scenario is based on the session information for 2015: all operating time available to Cancer Center and DHS, for emergency as well as planned surgeries. In 2015, every working day there was one operating room available from 08.00 to 20:00 hours to accommodate emergencies. However, emergencies were also scheduled in other ORs if the emergency OR was occupied.

According to Law (2003) we need information and data to specify the probability distributions and modelling parameters. This section presents the collection of data and corresponding distributions and parameters. Figure 22 provides an overview of the needed information.



Operational management

- Initilization options
- Method to handle resource conflicts
- Limits to schedule in outpatient ORs
- Plan duraton according to expected duration or appointment slot
- Do/don't plan lunch breaks
- Scheduling, selection and priority rules

Online planning settings

- Availability of patients
- Allow/Forbid surgeries to start before planned start
- Options for moving surgeries between ORs
- Cancellation settings
- Surgery sequence if OR becomes available

Figure 22: Overview of simulation model input

We analyzed all surgery data from the year 2015 to deduct the modeling parameters. The specialties and their case mix share are based on the production information reports of the DVF (Table 10). We exclude the specialty OOG from our simulation because although this specialty belongs to DHS, is has own emergency time, because of the needed equipment. It is therefore not interchangeable with the other specialties.

Specialty	CGO	GON	QKA	QKN	QUR	CHI	KAA	KNO	URO	ORT	VAT	TAN	PLA
# surgeries (2015)	1,103	296	166	498	209	1,171	487	837	883	1,297	806	158	1,189
Percentage	12%	3%	2%	5%	2%	13%	5%	9%	10%	14%	9%	2%	13%

Table 10: Specialties

Data analysis showed that it is hard to cluster surgeries into similar surgery types. There are several reasons for this: available parameters such as treatment codes, specialty, surgeon and diagnosis do not create homogeneous groups and also data is often incomplete. Our research involves too many specialties and surgeries (9,100 surgeries) to cluster them all by hand. Therefore we decided to create eight surgery types for every specialty: 1: long clinical surgeries, 2: middle long clinical surgeries, 3: short clinical surgeries, 4: long daycare surgeries, 5: short daycare surgeries, 6: A-emergencies, 7: B-emergencies, 8: C-emergencies. This approach leaves out many details, but is the best alternative available. With this method, the case mix share per type is easy to determine because the registration for emergencies and hospital location is available. Based on their specialty, priority (A/B/C-emergency), their location (D: day-care, K: clinical), and their planned duration surgeries are clustered in the different categories.

The planned duration for every category of patients is the average duration of the surgeries from that category in 2015. Furthermore, for every different surgery type we need a different distribution function to determine the actual surgery duration in the model. Previous research has shown that a 3-

parameter lognormal distribution is the best method to model surgery durations (Stephaniak *et al.*, 2009). The best alternative is to use a normal distribution. That is why we fitted both the normal and 3-parameter lognormal distribution to the data of every surgery type. We model the distributions for the surgery types that had at least ten surgeries in 2015, types with less than 10 surgeries are left out of further analysis. We selected the best distribution based on the Mean Squared Error (MSE), for all distributions we found a MSE smaller than 0.007. A small MSE means a good fit between distribution and data.

Furthermore we need distributions for the arrivals of emergency patients. According to Van Riet, and Demeulenmeester (2015) 'variability in duration and arrivals are main causes for scheduling difficulties. The assumptions determine the analytical possibilities and determine the models reflection of reality'. Arrival processes are generally modelled as a Poisson process (although this assumption is far from truth in certain settings). This is because the Poisson distribution is suitable to represent a big population, with small chances of events and independent arrivals. The implication for our result is that the arrival rate stays the same during the day. In practice the arrival curve of emergencies looks more like a 'whale' (an increasing number of patients during the morning, decreasing amount in the afternoon and a peak at the start of the evening). This spread over the day is easier to model with a distribution than the realistic pattern, this probably has a positive effect on the results.

The rebuilding of the OR complex will be finished in 2017. OR capacity is then reallocated and increased. The surgery capacity for 2017 is described in a new blueprint with the capacity allocation per period of four weeks. (Appendix A). Within this blueprint every four weeks the surgical capacity is 1,945 hours (approximately 240 OR-days). The four week scheme of the blueprint is repeated throughout the whole year, thus 13 times.

Because both divisions have no explicit growth perspective we base our simulation on the amount of patients in 2015. To provide insights in the effect of growth we increase the number of patients with 5% and 10%. The case mix that determines the type of surgeries per specialty is equal to the 2015 scenario (Section 2.3, Appendix F).

In practice, the operating theatre is not always running on full capacity due to ten weeks of holiday period and some days off for public holidays or anaesthesia education days. Historical data from UMC Utrecht shows that this results in approximately five weeks of lost capacity. Normally this would mean that one (or all) operating rooms are closed for one (or more) consecutive days. Since we do not exactly know when these days will take place and therefore do not know how to spread the loss off capacity over the specialties, we evenly distribute the lost time over the specialties by taking away full periods at the end of the year. In our model we only take the surgery programs during the weekdays into account. This means we simulate 47 (=52-5) weeks of five days. A consequence of this correction is that there are slightly fewer emergency patients. The emergency patients arrive every day according to the probability distributions for inter arrival times. If we simulate fewer days, fewer emergency patients will arrive. To correct for this we use a multiplication factor of (53/47=) 1.13 for the number of emergencies. With this multiplication factor the model generates the emergency arrivals of 53 weeks, in the simulation period of 47 weeks. By doing so we simulated all elective and emergency patients from the complete year, and the capacity for the complete year. We only artificially modified the number of periods to correct for deviations from the blueprint. Those deviations are caused by holidays, maintenance and other events resulting in extra closed OR's during the year.

During this period there is an average daily capacity of twelve OR programs per day. The exact allocation of capacity slightly differs from the blueprint since the blueprint is based on twelve hours emergency capacity on one OR each day. In scenario 2 and 3 the time that was used as an emergency OR, is used as generic OR capacity: all specialties may plan elective surgeries on this OR. We test every planning policy with eight, ten, and twelve hours of emergency slack, because DHS and Cancer Center want to improve their performance compared to the current six hours emergency slack, and because 2015 data analysis shows that twelve hours is in approximately 90% of the days enough. In scenario 2 and 3 the amount of reserved time for emergencies is spread evenly over all available ORs. This means for a scenario with twelve hours of emergency slack and twelve operating rooms, every operating room has to reserve one hour for emergencies. Total capacity is the same for all variants. Table 11 provides the details for every scenario.

	8 hours for emergencies	10 hours for emergencies	12 hours for emergencies
1	Four hours of the emergency capacity from the blueprint becomes generic capacity for elective surgeries	Two hours of the emergency capacity from the blueprint becomes generic capacity for short elective surgeries	Capacity according to the blueprint
2 & 3	Emergency OR becomes generic OR form emergencies. All ORs have to reserve (8/Nr of ORs) hours for emergencies.	Emergency OR becomes generic OR form emergencies. All ORs have to reserve (10/Nr of ORs) hours for emergencies.	Emergency OR becomes generic OR form emergencies. All ORs have to reserve (12/Nr of ORs) hours for emergencies.

Table 11: Division of OR capacity per policy

The historic information together with some interviews provided sufficient information to fill all model settings for the planning process (Appendix A).

A lot of information is collected and registered in the electronic hospital information system HIX. This makes data regarding patient type, cancellation reasons, and surgery duration easily available. Furthermore there is a 'production information' document that states the number of sessions, their total time, overtime, etcetera. The difficult part is to determine the used planning methods, and involved exceptions to those rules. We modelled those rules based on interviews with the planners of the different planning desks. To create the initial schedule for elective patients we choose to use a descending, level-fit planning method. This means surgeries are planned in descending order of duration. The longest surgeries are planned first, at the beginning of the day. We do this because the planners describe that the planning coordinator from OR prefers this. A descending order of duration results in schedules with most uncertainty in the surgeries at the beginning of the day. Shorter and better predictable surgeries at the end of the day prevent overtime or unnecessary cancellations. Furthermore we use level-fit. This means that the model levels the workload of OR's.

4.2.3 Model settings

To align the model with practice we need the proper model settings. Table 1 12 provides the common settings for all experiments.

After the correction for the weeks with lower OR capacity, we created input data for 47 periods (weeks). Every period has 5 days, since we only simulated the working days. Surgeries programs start from 8.00 a.m. and last for 480 or 720 minutes. Based on our analysis in Chapter 2 the number of elective patients is 7579. All ORs can handle (A-) emergencies. The model uses a fixed amount of start-up time and cleaning time, equal to the target times for practice: both 15 minutes. Surgeries are planned for a pre-set duration, using appointment slots. We allow overtime in planning to make sure every experiment plans all patients, the amount of patients are then best comparable. The programs may be filled to their full capacity (100%). The amount and type of patients is generated based on the case mix, their arrival is also based on capacity. This means the model determines the arrivals for every individual week. The total capacity differs between the weeks of the blue print. The number of patients generated per period is dependent of the capacity of that period compared to the total capacity. By rounding the number of surgeries per week, the total number of patients deviates among experiments, although the input value for number of surgeries is the same. The due date for all elective surgeries is the end of the year. Because of this rule patients are not operated on order of arrival, this causes some patients waiting very long.

During the simulation we assume all patients are available at the beginning of the day. This means surgeries can start before their planned start on the same day. To prevent that simulation results are influenced by chance, instead of by the settings and choices, we performed a replication-deletion analysis to determine the necessary number of simulation runs for our simulation. This method determines based on the variation in results the amount of replications needed for reliable statistics. We performed this method for cancellations, utilization, overtime, and emergencies within their norm time. Appendix H provides calculations and results for every performance indicator. This analysis shows that the variation in results is small, and that performing four replications is enough to obtain a 95% confidence interval for these indicators. Since the model is very fast and we did not test for all indicators, we use more replications and perform 10 simulation runs per experiment. The amount and division of OR capacity, and the initial schedule are the same for every replication, but the actual duration of surgeries and arrival of emergencies differ per experiment because they are determined based on statistical distributions.

In line with practice, delayed surgeries may move to another (suitable) OR. Elective surgeries that have not been performed on their planned day are cancelled. The model does not plan those patients again. Elective surgeries with more than 90% of time in overtime are cancelled.

Emergencies that have not been performed on their arrival day, stay on the emergency list for next day. However, as a result of our emergency handling rules this hardly happens in the model. This rule states that all emergency surgeries that can start during working hours are completed on their arrival day. We chose this rule because it is desirable from a medical point of view, and because there is no other good indication available. We know that practice is different, and some emergency patients stay on the waiting list overnight but there is no clear decision rule for this. The amount of no-shows in UMC Utrecht is low enough to assume that there are no no-shows. We assume that the emergency list is empty on Monday morning, this makes our system stable from the beginning. Therefore it is not necessary to use a warm up period.

General settings	Number of periods	47 (53 for validation)
	Number of days per period	5
	Start of working day	8:00
	Length of working day (minutes)	480
	Expected number of patients per year	7,579
	Number of ORs that can deal with emergencies	All
	Default surgery start-up time	0:15
	Default surgery cleaning time	0:15
	Use appointment slots	True
	Allow overtime	True
	Capacity target	100 %
	Number of generated patients	case mix & capacity
	Due date of generated surgeries is end of horizon	Yes

Simulation options	Elective surgeries may start before planned start	True
	Number of simulation runs	10
	Elective surgeries may move to another available and suitable OR	True
	Cancel elective surgeries that have not been performed on their planned day	True
	Cancel emergency surgeries that have not been performed on their arrival day	False
	All patients are available at the start of the day	True
	Use no-show	False
	Do not start elective surgeries if more than x% is outside working hrs	90%
	Do not start (semi) emergency surgeries if more than x% is outside working hrs	99%
	Number of warm-up periods	0

Table 12: General simulation settings

4.2.4 Assumptions

In the simulation model we make the following assumptions:

- Every operating room program starts at 8:00.
- The arrival patterns does not include seasonal trends, the arrival rate is the same during the whole year.
- We use theoretical distributions to model the surgery times. All surgery types for one type of surgery are drawn from the same probability distribution. In contrast to reality, there is no structural difference between the speeds of surgeons.
- All elective patients arrive at the beginning of their planned day for surgery.
- There are no personnel restrictions, if there is an operating room program planned, then there is a surgeon, anaesthetist and surgery assistants.
- Elective surgeries are performed in the programs of their own specialty.
- There are no patient 'no-shows'.
- No other resources are considered then surgery assistants: there are sufficient beds and personnel at the recovery, holding, and wards.

4.2.5 Verification and validation

The verification phase takes place while programming of the model. This concerns "debugging" the model, to make sure that the conceptual model is works and is well represented. According to Law (2008) 'validation is the process of determining whether a simulation model is accurate representation of the system, for the particular objectives of the study'.

Verification

To show that the model represents our planning policies, this section shows examples of the different policies and describes how we adapted the existing simulation model to represent the operating room complex of UMC Utrecht.

We adapted the model to make B- and C- emergencies limited exchangeable. It differs among planning policies which emergency patients may be treated in operating rooms from what specialties. Only A-emergencies may go to all operating rooms, regardless the specialty. B- and C- emergencies may only be operated in the emergency OR, or on elective programs of their own specialties. For the policies without an emergency room we created clusters with interchangeable specialties: CHI, CGO, URO, QUR, GON, CTR, PLA, and ORT emergency surgeries may be performed on each other's programs. QKA, QKN, KAA, KNO are exchangeable. And VAT emergencies should be performed on VAT programs.

We adapted to model to this by adding an extra input section that states which surgeries may take place in which programs. We added the restriction that every B- or C- emergency may only start in an operating room of a certain specialty if allowed by the new input section.

Another model adaption guarantees that on the emergency ORs that are partially filled with elective surgeries, only elective surgeries with a maximal expected duration may be planned. UMC Utrecht uses this rule to prevent that the time till next possibility to interrupt the program in an emergency OR is too long, resulting in more interruptions in the elective programs. We adapted the model to this by creating a restriction that limits surgeries on generic operating programs (all emergency ORs are suitable for all DHS and Cancer Center specialties, and thus generic) to two hours. If checking the surgery duration gives a duration of more than 120 minutes, the surgeries may not be planned on that generic operating room.

Figure 23 shows an example of a dedicated schedule and simulation results. All specialties have their own OR programs, filled with surgeries from their own specialty. Within the figure, surgeries with the same specialty have the same colour. One of the OR's is completely reserved for emergencies. After running the simulation model we get a similar chart, shown at the right part of Figure 23. In this figure we not only see elective surgeries, but also the emergency surgeries (in red). In this example all emergencies are B-emergencies. These are only allowed to interrupt the elective programs of their own specialty or otherwise they should wait for the emergency OR. Only one CGO emergency interrupts the CGO program on the fifth OR, all others are performed in the emergency OR since no other OR of their own specialty becomes available.

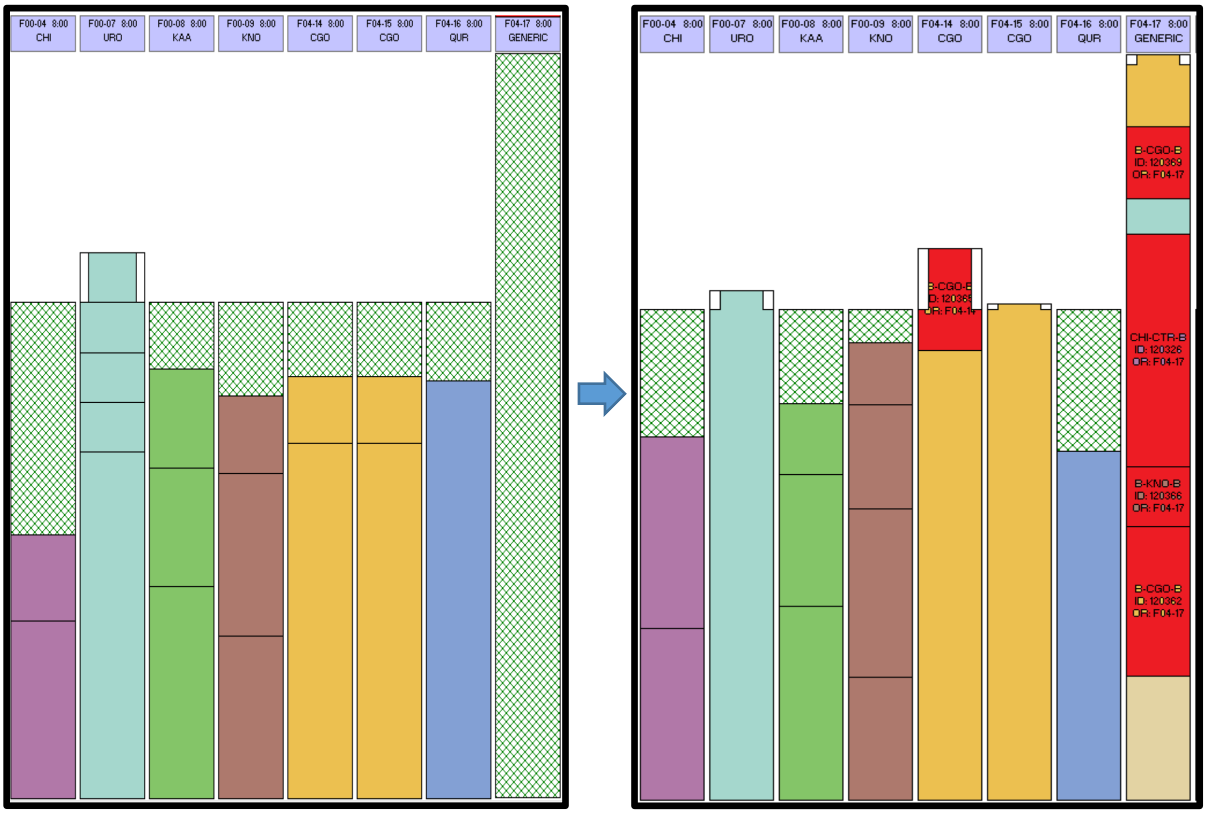


Figure 23: Example of an initial schedule and simulation result for the dedicated policy

Figure 24 shows an example of a schedule according to the flexible policy, and an example of corresponding simulation output. The left side of figure 24 shows that all programs are filled with surgeries from their own specialties. There is no (completely) reserved emergency room, instead all elective programs have some emergency slack that prevents them planning the complete program. When emergencies arrive they are allowed to break into other programs according to the formed cluster. In this specific example there is first one CGO B-emergency that interrupts the CGO program. Then a KAA A-emergency arrives which is performed in the first available OR. Then a KNO B-emergency arrives. According to the clustering rules this surgery may be performed in operating rooms from QKA, QKN, KAA, KNO.

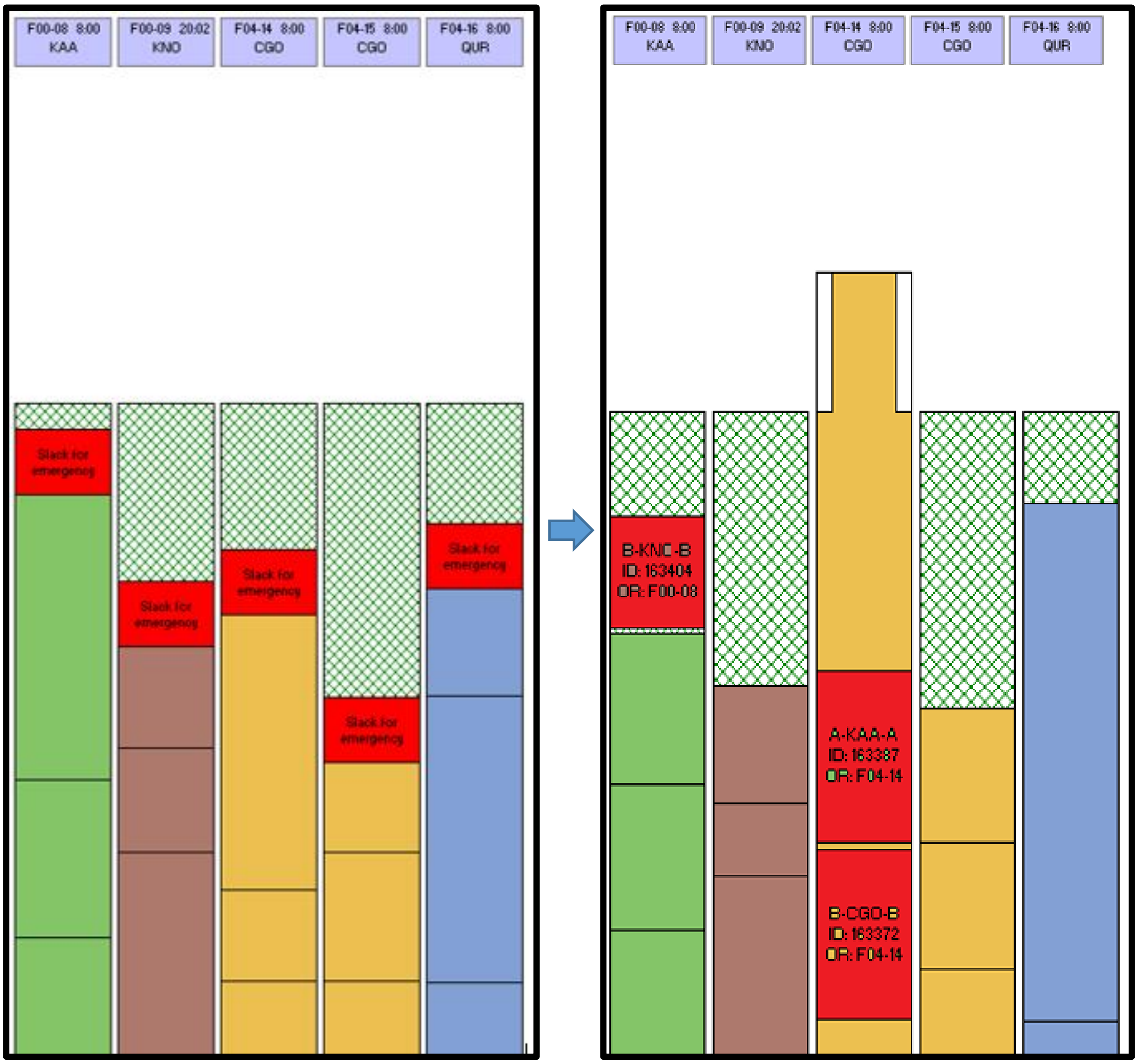


Figure 24: Example of an initial schedule and simulation result for the flexible policy

The combination policy is executed in the model with is by the steps shown in Figure 25.

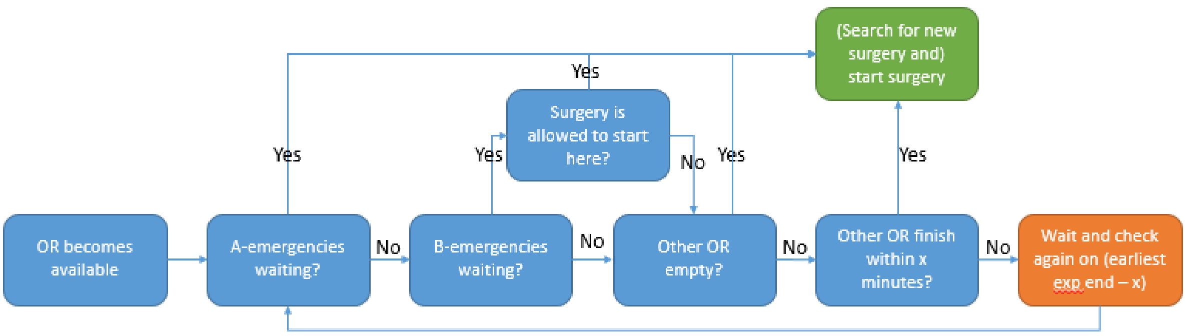


Figure 25: Flowchart describing the combination policy

Figure 26 gives an example of a schedule and simulation results for the combination policy. In this example we used a maximal allowed period till next break in possibility of two hours. Since four OR's start with a surgery for longer than two hours, one OR stays empty, waiting for emergencies to arrive to ensure quick response. Then a KNO A-emergency arrives which can start right away. In this specific example most surgeries took longer than planned.

This method enables quick response to emergency surgeries, without reserving capacity on one emergency OR.

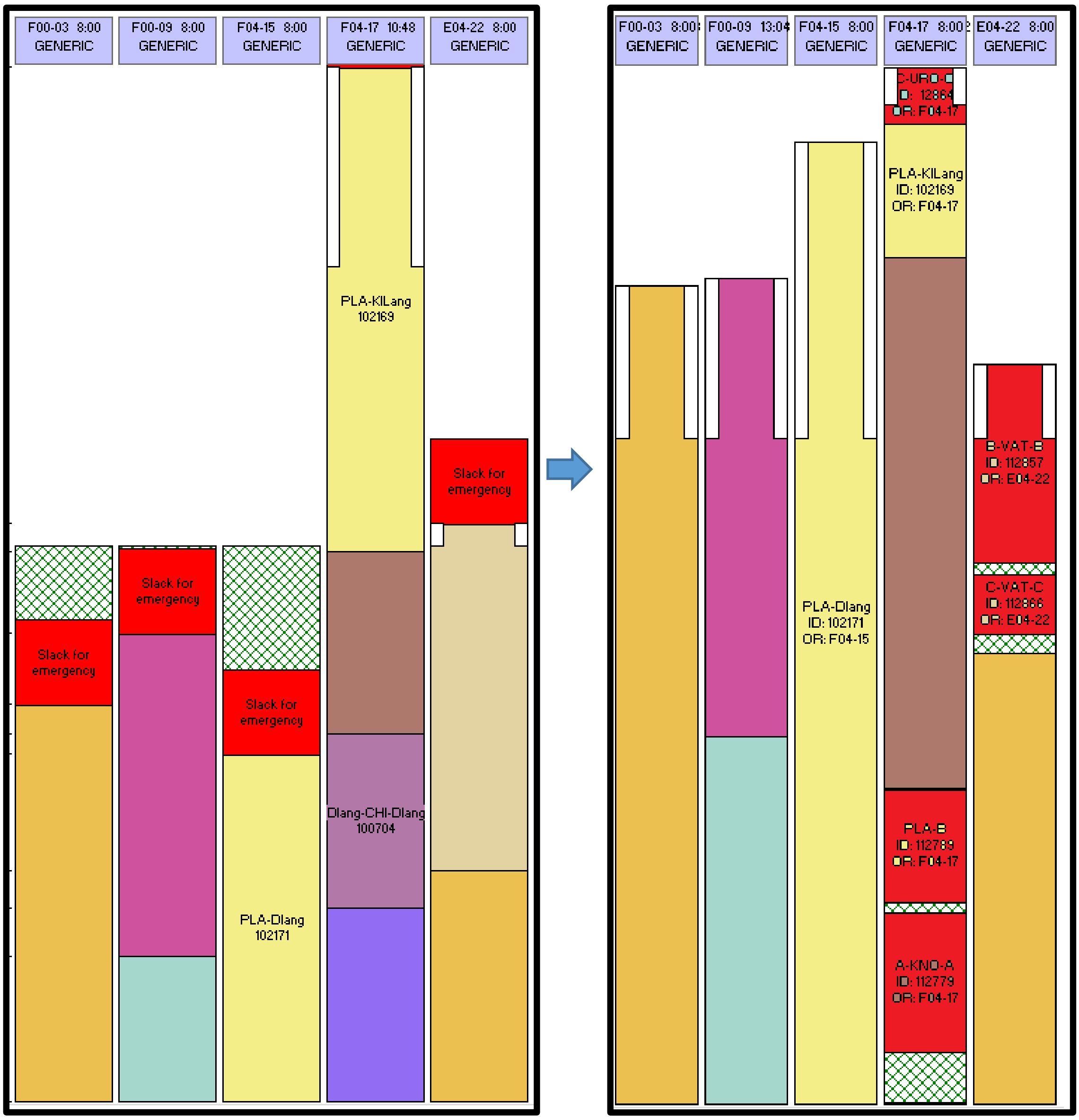


Figure 26: Example of an initial schedule and simulation result for the combinational policy

Validation

To validate our model and check whether our model corresponds to reality, we compare the performance following from the simulation model with the actual performance of 2015. One part of the analysis concerns the input, therefore we compare:

- Number of surgeries
- Operating room capacity

The analysis of the current situation already defined the key performance indicators. We will assess the results of the model on the same performance indicators:

- Cancelled patients
- Overtime
- Utilization
- % of emergency patients within the norm

Table 13 gives the actual performance and results from the model for ten replications. The left column of Table 13 summarizes the actual performance of the operating room in 2015 according to reports of UMC Utrecht. The third column of the table summarizes the performance following from the simulation model. The last column shows how much our simulation model deviates from reality. Although there are still differences, we can explain them. This means the model is still valuable for comparing different scenarios, although we do have to remind that simulation results will not only give an indication of the effects of the alternatives.

The available surgical capacity is equal to the capacity of 2015 since the model input for every individual OR for every individual day is derived from the list of actual OR programs and their specialties.

The number of patients slightly differs from reality for both elective and emergency patients. The model generated 1% more patients. The elective patients are generated based on a probabilities from a case mix. This allows the model to deviate from the input number of patients. Although there are more elective patients than in 2015, the number of elective surgeries is a bit lower because the model cancelled more patients. Also for the emergencies the model generated 59 more patients, due to the 32 different used distributions for all emergency types. We consider the differences in patient numbers small enough to accept this model.

The average elective surgeries duration is one minute shorter than in practice, it corresponds to the number from 2015. The emergencies took longer than in 2015. Again this is related to the 32 individual distributions that we fitted to the emergency surgeries. Some categories only had a small number of surgeries, then chance can play a role and have a large effect on the results. The extra time needed for emergencies is 171 hours, and is partly compensated by the 123 hours shorter duration of the elective surgeries. The overall difference is small enough to assume that the surgeries represent the patient population from 2015.

Both the cancelled patients and the overtime are caused by the planning methods of the model and our clustering method. The model uses strict planning rules that allow elective surgeries only in operating rooms of their own specialty, and sends A- and B- emergencies directly to the first available operating room. In practice another room may be available one minute later, resulting in a better continuation of the program, the model does not considers this. Therefore we see a decrease in utilization of regular capacity. The other reason for both more cancelled patients and more overtime is related to our surgery clustering method. We clustered historic data based on the specialty of the planed surgeon, hospital location (day-care surgery, or clinical), and duration (short < 2 hours, average >2 and < 4 hours, long >4 hours). This results in clusters that may cover a lot of medically different surgeries, and variety in duration. For every surgery cluster we fitted a distribution to determine the expected and real duration. Because of the large differences within each group the gap between planned and actual surgery duration increases, which impedes planning. Unfortunately there currently is no method available to cluster such a large number of surgeries to medical comparable groups. We know that the planned and actual durations from the model for individual surgeries do not always correspond to reality, but on average the duration per specialty is equal, and at the moment with the current registration this was the best available method.

To compensate the otherwise very high cancellation rate, we tuned the rules to balance the number of cancelled patients and overtime, resulting in a very smooth rule for elective surgeries to continue at the end of the day: elective surgeries may start if only 5% is during regular time, resulting in extra overtime. After tuning the rules for balancing the number of cancelled patients and overtime, the model results in 50 extra cancelled patients.

The real planners are more flexible and consider many more aspects. By doing so they can better balance the surgery programs. This causes a part of the high amount of overtime.

The other part is related to the high emergency within the norm rate. In consultation with the involved people we decided to send A- and B- emergencies always to the first available (suitable) OR, and allow to complete all emergency surgeries that can start during working hours. This results in overtime. Normally, those surgeries would be either performed in the night or they have to wait till next day. Since our model does not consider capacity at night, all patients then should wait till next day, and C-emergencies even till the end of next day. Because this is medically not responsible we decided to use the above rule.

Parameter	Actual performance	Model performance	Difference
Available surgery capacity	19916 hours	19916	0
Number of elective surgeries	7438	7403	-35
Number of emergency surgeries	1428	1467	49
Cancellations (program)	185	235	50
Cancellations (%)	2.0%	2.5%	0,5%
Total number of surgeries (em + el + canc)	9051	9105	54
Average elective surgery duration	123 min	122 min	-1 min
Average emergency surgery duration	106 min	113 min	7 min
Overtime	961 hours	1468 hours	507
Overtime (%)	4.8%	7.3%	2.5%
Utilization	85%	82%	-3%
% emergencies within norm	82%	92%	10%

Table 13: Validation model performance for 2015

Although there are differences between model and reality, we can explain them and they are logical. Therefore we consider the model to be valid for answering our research questions. The model with the settings used for validation is the basis for our further analysis.

5. Simulation results

This chapter presents the computational results from the simulation model. Section 5.1 presents the results for the dedicated policy. This section is more comprehensive than for the other policies, because it represents the future plans of DHS and Cancer Center. Section 5.2 presents the results for the flexible policy. Section 5.3 presents the results for the combinational policy. Section 5.4 makes the comparison between all policies. Finally, Section 5.5 presents the results for some extra experiments regarding the theoretical value of the combinational policy.

5.1 Results for dedicated policy

Table 14 shows the simulation results for the dedicated policy with the number of patients of 2015. Since the capacity is fixed input this is the same for all variants. The number of patients is generated according to case mix probabilities and therefore slightly differs. The differences in number of performed elective patients are the biggest, but when comparing them we have to consider the cancelled patients too. The dedicated policy with eight hours slack performed 25 more elective surgeries then the policy with 12 hours. In the policy with 12 hours those surgeries are cancelled.

When the amount of emergency slack decreases, the number of cancelled patients decreases as well. Since total capacity is equal for all variants, when more capacity is reserved for emergencies, there is fewer capacity for elective surgeries. With a tight planning for elective surgeries and the variation in surgery durations, the deviations from the planned program will cause more cancellations compared to programs which are less tightly scheduled. Although this could be compensated by a lower number of emergencies that interrupt the elective programs, the results show that with a more spacious planning the number of elective patients that moves between OR's is smaller, and thus that there apparently is space to accommodate those emergencies. The cancellation percentages are closely related to the number of cancelled patients since the total number of surgeries is comparable.

Overtime differs for both elective and emergency patients. We recognise that the variants with more emergency slack and less time for elective surgeries cause more overtime for elective patients. The overtime caused by emergency surgeries there is no clear trend. For A- and B-emergencies the amount of overtime should be comparable because they break into the elective program when the emergency OR is occupied, no matter how much time is reserved. For C-emergencies there could be differences between the policies, because those have to wait till the end of the elective program. With more spacious elective planning (less time reserved for emergencies) there will be more time for C-emergencies at the end of programs, but meanwhile this also means that there will be less time left in the emergency OR. Furthermore the deviations could be caused by the initial schedules. Although we perform ten replications per experiment, the replications for every experiment are based on the same elective schedule. If the schedule for the policy with ten hours slack is favourable it may result in less overtime. The overtime percentage shows that the differences are small, and is the same for all policies. The number of OR's with overtime corresponds to the amount of overtime, policies with more overtime have also more operating rooms with overtime.

All policies result in a utilization of 81%. This could be expected since the capacity is equal and the number of patients and amount of overtime is comparable.

The emergency performance for all variants is high, 97 or 98% of emergency surgeries is performed within their norm time. The results disaggregated to the different emergency categories show that all A- and C-emergencies are performed within their norm time for all variants. This has to do with our emergency handling rules. A-emergencies have their surgery as soon as possible on any OR. Apparently the amount of operating rooms is large enough so that there always was an OR available within two hours after an emergency arrival. In practice there are also organizational aspects involved, changeovers delay the start of emergencies, and it is not always the case that the first available OR-is interrupted. B-emergencies are allowed to break into programs of their own specialty, or otherwise they are performed on the emergency OR. Since not every specialty has an elective program every day, some surgeries are dependent on the time reserved for emergencies. Apparently there is always time at the end of the elective program to start all C-emergencies.

Name	(1) DE 8	(2) DE 10	(3) DE 12
Capacity (hours)	22,848	22,848	22,848
Number of elective surgeries	7,598	7,598	7,573
Number of emergency surgeries	1,407	1,412	1,419
Cancelled patients (#)	32	42	50
Total number of patients	9,037	9,052	9,042
Cancelled patients (%)	0.4%	0.5%	0.6%
Overtime (hours)	985	965	1,012
Overtime (hours) elective	535	546	576
Overtime (hours) emergency	450	418	437
Overtime (%)	4%	4%	4%
Number of OR days in overtime	693	706	737
Interruptions elective program	275	213	218
Elective patients moved to another OR	634	794	883
Utilization	81%	81%	81%
Emergencies within norm	97%	98%	97%
A within 2 hours (%)	100%	100%	100%
B within 8 hours (%)	96%	96%	96%
C within 24 hours (%)	100%	100%	100%

Table 14: Simulation results dedicated policy

The differences between the experiments are small, the utilization is even the same for all experiments, but the most important conclusion from this table is that more time reserved for emergencies results in more cancelled patients and more interruptions in the elective program. If the UMC Utrecht chooses for an emergency OR, we would, based on the largest deviations in the number of cancelled patients, recommend to reserve 8 hours for emergencies.

As mentioned earlier we provide some more detailed information for this scenario on specialty level, because these policies represent the future plans of UMC Utrecht. Table 15 shows that CGO, CHI, ORT, PLA, and QKA are the specialties with most cancelled patients, regardless of the amount of time reserved for emergencies. This could be expected because those specialties also have the largest number or surgeries and OR programs. When considering the cancel percentages also GON has with 8 hours for emergencies a relatively high cancellation percentage. Furthermore Table 16 shows that that for (almost) every specialty the amount of cancelled surgeries increases when less time is reserved for emergency surgeries. This is not true for every individual specialty, because the cancellations depend on the arriving emergencies. Within this planning policy B- and C-emergencies are only allowed in the emergency OR and operating rooms of their own specialty. The arrival order of emergencies determine which emergencies are performed on the emergency OR, and which emergencies break into the elective programs. -

	Number of cancelled elective surgeries per specialty											
	CGO	CHI	GON	KAA	KNO	ORT	PLA	QKA	QKN	QUR	URO	VAT	Total
12 hrs	4 0.4%	5 0.5%	1 0.1%	1 0.1%	1 0.1%	5 0.5%	4 0.4%	4 0.4%	2 0.2%	2 0.2%	4 0.4%	2 0.2%	32
10 hrs	6 0.5%	3 0.3%	2 0.2%	2 0.2%	1 0.1%	7 0.6%	9 0.8%	4 0.4%	2 0.2%	1 0.1%	5 0.5%	1 0.1%	42
8 hrs	6 0.5%	5 0.5%	5 0.5%	4 0.4%	1 0.1%	8 0.7%	6 0.5%	7 0.6%	2 0.2%	2 0.2%	4 0.4%	0 0%	50

Table 15: Expected cancelled patients per specialty, number and percentage of total number of surgeries

Table 16 shows that CGO and PLA not only have most cancelled patients, but also have the highest amount of overtime. Again this may be explained by the number of surgeries and OR programs of these specialties. The VAT also has a relative large amount of overtime. There again is a correlation: less time for emergencies, means more overtime, but the correlation is smaller than for the cancelled patients. This can be explained by the fact that the rules determining the allowed overtime are a fixed percentage and do not change for the different amounts of reserved time for emergencies.

Emergency surgeries cause a large part of the overtime. This is due to our simulation choices: all emergency patients that can start during opening hours will be operated, also when 99% of the surgery duration is outside working hours.

	Overtime duration for elective surgeries per specialty (hours)												Emergency
	CGO	CHI	GON	KAA	KNO	ORT	PLA	QKA	QKN	QUR	URO	VAT	
12 hrs	109	20	47	18	10	29	122	65	7	42	16	51	450
10 hrs	98	18	57	31	9	33	135	67	5	32	15	46	418
8 hrs	117	19	84	35	8	26	131	64	11	25	23	33	437

Table 16: Simulation results for overtime duration in hours

We tested growth scenarios with five, and with ten percent more patients. Table 17 shows that for all policies the number of cancelled patients and overtime goes up, as the number of patients increases. This is a logical effect because capacity stays the same. In line with this, the effect on utilization of the OR time is that more patients result in a slightly higher utilization. Furthermore we see the same differences between the scenarios: more time reserved for emergencies causes more cancelled patients and interruptions in the elective programs. There is hardly any effect on the number of emergencies within the norm. This is due to our emergency handling rules, which are equal for all policies, regardless of the amount of reserved time.

If the number of patients grows compared to 2015, this results in slightly worse results. This can be explained because the capacity growth compared to 2015 is approximately 15%. In the tested growth scenarios, the growth in number of patients is smaller than the capacity growth since we want to improve the current performance, and not match it. That explains why the results are still better than the results from 2015.

Name	(4) DE 8 + 5%	(5) DE 10 + 5%	(6) DE 12 + 5%	(7) DE 8 + 10%	(8) DE 10 + 10%	(9) DE 12 + 10%
Capacity (hours)	22,848	22,848	22,848	22,848	22,848	22,848
Number of elective surgeries	7,935	7,943	7,907	8,271	8,262	8,215
Number of emergency surgeries	1,463	1,484	1,499	1,559	1,537	1,558
Cancelled patients (#)	59	68	97	118	136	166
Total number of patients	9,457	9,495	9,503	9,948	9,934	9,939
Cancelled patients (%)	0.6%	0.7%	1.0%	1.2%	1.3%	1.6%
Overtime (hours)	1,088	1,146	1,147	1,365	1,376	1,328
Overtime (hours) elective	618	679	681	864	873	829
Overtime (hours) emergency	470	468	466	500	503	498
Overtime (%)	5%	5%	5%	6%	6%	6%
Number of OR days in overtime	789	825	846	998	996	1,019
Interruptions elective program	322	245	252	396	306	296

Elective patients moved to another OR	642	797	898	625	783	898
Utilization	84%	85%	84%	90%	90%	89%
Emergencies within norm	98%	97%	97%	97%	97%	97%
A within 2 hours (%)	100%	100%	100%	100%	100%	100%
B within 8 hours (%)	96%	95%	95%	95%	95%	95%
C within 24 hours (%)	100%	100%	100%	100%	100%	100%

Table 17: Results for growth dedicated policy

5.2 Results for flexible policy

Table 18 shows the simulation results for the experiments with a flexible emergency scheduling policy. Just as in the previous scenarios, the capacity for all variants is equal. The variation in the number of patients is caused by the generation of patients from a case mix.

This planning policy has for all variant a similar number of cancelled patients. This is logical because this scenario reserves only capacity for emergencies at the end of the day. The original planning therefore differs between the variants. During the day for all variants the same emergency rules apply. The amount of reserved time does not influence the number of elective and emergency patients generated by the model. The variants have equivalent variations in surgery durations and arrivals of emergencies and although the initial planning differs, the course of the day will be equivalent.

The variant with eight hours slack has more overtime for both emergencies and electives, partly because of the higher number of surgeries. In overtime percentage terms, all variants have (rounded) 5% overtime.

The utilization is approximately equal, the variant with twelve hours reserved for emergencies is slightly lower. This is related to the fact that this variant performed the least elective surgeries. This difference is caused by the surgery generation of the model, it generates a slightly different number of elective and emergency patients for every experiment, and by the differences in number of cancelled patients.

For the emergencies there are again difficulties in realizing surgeries of B-emergency patients within their norm time. All A- and C- emergencies took place within their norm time. This can again be explained by the fact that A-emergencies are allowed to interrupt any program. Thus although they have to be operated as soon as possible, maximum two hours after arrival, there is always an operating room available in time. For the C-emergencies the time period is 24 hours so that leaves enough space to find a suitable OR. The B-emergencies are the largest group of emergency patients and have a smaller time window.

Name	(10) BI 8	(11) BI 10	(12) BI 12
Capacity (hours)	22,848	22,848	22,848
Number of elective surgeries	7,548	7,530	7,529
Number of emergency surgeries	1,394	1,397	1,389
Cancelled patients (#)	72	82	71
Total number of patients	9,014	9,009	8,988
Cancelled patients (%)	0.8%	0.9%	0.8%
Overtime (hours)	1,110	1,069	1,037
Overtime (hours) elective	657	644	606
Overtime (hours) emergency	452	425	432
Overtime (%)	5%	5%	5%
Number of OR days in overtime	772	753	741
Interruptions elective program	403	419,9	403,2
Elective patients moved to other OR	845	834	847
Utilization	81%	81%	80%
Emergencies within norm	98%	97%	97%
A within 2 hours (%)	100%	100%	100%
B within 8 hours (%)	96%	95%	95%
C within 24 hours (%)	100%	100%	100%

Table 18: Simulation results for Flexible policy

Again the differences in Table 18 are relatively small, for cancellation rate, as well as overtime, utilization, and emergencies within the norm. The differences are this small because in the model we allow to plan overtime if necessary to make sure all surgeries are planned to make the results the best comparable. This means although we should reserve twelve hours for emergencies in variant 3, our scheduling rules allow to fill some programmes a bit more to be able to plan all surgeries. By doing so the number and duration of elective patients determine the capacity that is left for emergencies. Because all variants have a similar number of surgeries there is hardly any difference between the variants. The results do not provide us with an unambiguous advice.

Table 19 shows that when the number of patients increases, the cancellation, overtime, and utilization rate increases as well. The cancellations nearly doubles, the overtime increases with 150 hours, and the utilization increases from 81 to 85% in a scenario with 5% growth. It does not seem to influence the percentage of emergencies within the norm time. This is due to our emergency scheduling rules that prioritize A- and B-emergencies and always compete C-emergencies if they can start within opening hours.

Name	(13) BI 8 + 5%	(14) BI 10 + 5%	(15) BI 12 + 5%	(16) BI 8 +10%	(17) BI 10 + 10%	(18) BI 12 + 10%
Capacity (hours)	22,848	22,848	22,848	22,848	22,848	22,848
Number of elective surgeries	7,893	7,867	7,870	8,196	8,207	8,178
Number of emergency surgeries	1,485	1,476	1,463	1,567	1,546	1,561
Cancelled patients (#)	132	136	132	206	199	201
Total number of patients	9,510	9,479	9,465	9,969	9,952	9,940
Cancelled patients (%)	1.4%	1.4%	1.4%	2.0%	2.0%	2.0%
Overtime (hours)	1,273	1,230	1,226	1,390	1,424	1,406
Overtime (hours) elective	802	751	756	887	910	903
Overtime (hours) emergency	472	479	470	502	515	503
Overtime (%)	6%	5%	5%	6%	6%	6%
Number of OR days in overtime	925	890	869	1,018	1,042	1,034
Interruptions elective program	484	485	469	552	546	544
Elective patients moved to other OR	843	850	871	852	851	854
Utilization	86%	85%	85%	88%	89%	89%
Emergencies within norm	97%	98%	97%	97%	97%	97%
A within 2 hours (%)	100%	100%	100%	100%	100%	100%
B within 8 hours (%)	95%	96%	95%	94%	95%	95%
C within 24 hours (%)	100%	100%	100%	100%	100%	100%

Table 19: Growth results for flexible policy

5.3 Results for combinatorial planning method

The combinatorial panning method results are shown in Table 20. We tested the method for allowed gaps of 60 and 120 minutes.

Just as in the previous scenarios, the capacity for all variants is equal. The variation in the number of patients is caused by the generation of patients from a case mix.

With a smaller maximal allowed gap (60 minutes) we see more cancelled patients than with the larger (120 minutes) allowed gap. This is because with a smaller allowed gap the number of waiting periods, and also the duration of those periods increases. With an allowed gap of 10 hours, there will be no waiting moments, and with an allowed gap of one minute, approximately the complete day one operating room will be waiting unless an emergency arrived. Waiting time delays the elective programs, end may result at the end of the day in cancellations.

The differences in overtime are again small, all variants have an overtime percentage of 5%. This has a similar reason as in previous policies. Although the initial schedule differs, the course of the day is similar.

The emergency performance is again high, due to a similar reasons as in previous policies: the reasons that give priority to emergencies and allow a lot of overtime to complete them on their day of arrival.

Name	(19) CO 8 -60	(20) CO 8 -120	(21) CO 10 - 60	(22) CO 10 - 120	(23) CO 12 - 60	(24) CO 12 - 120
Capacity (hours)	22,848	22,848	22,848	22,848	22,848	22,848
Number of elective surgeries	7,521	7537	7,523	7,534	7,510	7,530
Number of emergency surgeries	1,406	1,423	1,394	1,384	1,414	1,398
Cancelled patients (#)	98	90	97	92	108	95
Total number of patients	9,025	9,050	9,014	9,010	9,032	9,023
Cancelled patients (%)	1.1%	1.0%	1.1%	1.0%	1.2%	1.0%
Overtime (hours)	1,064	1,126	1,073	1,077	1,125	1,061
Overtime (hours) elective	617	656	623	637	689	620
Overtime (hours) emergency	446	470	450	440	436	440
Overtime (%)	5%	5%	5%	5%	5%	5%
Number of OR days in overtime	756	783	756	778	797	790
Interruptions elective program	416	417	411	407	439	422
Elective patients moved to other OR	875	847	865	820	864	845
Utilization	81%	81%	80%	81%	81%	81%
Emergencies within norm	97%	98%	97%	97%	97%	98%
A within 2 hours (%)	100%	100%	100%	100%	100%	100%
B within 8 hours (%)	95%	96%	95%	95%	95%	96%
C within 24 hours (%)	100%	100%	100%	100%	100%	100%

Table 20: Simulation results combinatorial planning policy

When comparing the results from the combination policy with the results from the flexible policy, which has the same settings only does not consider the allowed gap we see that there is hardly any difference. The gaps do not have the expected influences described in Section 3.2.3.

The emergency performance does not increase compared to scenario 2. This may have to do with the already very high performance in scenario 2. Another reason is that the number of surgeries and 'Break-in moments' is sufficiently large to handle emergency surgeries very quick without gaps. We recognise this from previous results showing a 100% score for A-emergencies, this means also without waiting there always was an empty room within two hours after an A-emergency arrival. Finally we use specialty restrictions for B-emergencies. Not every B-emergency may start in any type of OR, this means an OR can be empty and waiting, and an arriving emergency still cannot start there. This decreases the effect even further.

We also do not see a decrease in utilization, because we leave some capacity open that might not be used for emergencies. Probably the waiting periods are too short to recognise the effect in utilization.

We see a small increase in the number of cancelled patients that could be caused by the delay of elective surgeries. This might be the case because the waiting periods delay the elective programs, but there are only few waiting moments with a short waiting time for UMC Utrecht case.

Also for this scenario we want to test the effect of an increased number of patients. Because the tightest interval for emergencies is two hours, and a smaller interval does not contribute to better performance for norm times, we choose to continue next simulations with a maximal allowed gap of 120 minutes. Table 21 shows the results of the experiments with scenario 3 and an increase number of patients with five percent and ten percent.

Name	(25) CO 8 +5%	(26) CO 10 +5%	(27) CO 12 +5%	(28) CO 8 +10%	(29) CO 10 +10%	(30) CO 12 +10%
Capacity (hours)	22,848	22,848	22,848	22,848	22,848	22,848
Number of elective surgeries	7,861	7,885	7,870	8,176	8,182	8,186
Number of emergency surgeries	1,467	1,480	1,478	1,534	1,529	1559
Cancelled patients (#)	128	142	129	210	191	208
Total number of patients	9,456	9,507	9,477	9,920	9,902	9,953
Cancelled patients (%)	1.3%	1.5%	1.3%	2.1%	1.9%	2.0%
Overtime (hours)	1,202	1,255	1,198	1,408	1,284	1,449
Overtime (hours) elective	748	788	719	916	789	943
Overtime (hours) emergency	454	466	479	492	495	506
Overtime (%)	5%	5%	5%	6%	6%	6%
Number of OR days in overtime	877	908	880	1,015	979	1,052
Interruptions elective program	465	499	469	540	524	545
Elective patients moved to other OR	842	871	891	873	895	874
Utilization	84%	85%	84%	88%	87%	88%
Emergencies within norm	97%	97%	98%	97%	97%	97%
A within 2 hours (%)	100%	100%	100%	100%	100%	100%
B within 8 hours (%)	96%	95%	95%	95%	95%	94%
C within 24 hours (%)	100%	100%	100%	100%	100%	100%

Table 21: Simulation results for growth with combinational policy

When the number of patient increases, the number of cancelled patients increases as well. For an increased number of patients the method hardly makes any difference as well. Still there is hardly any difference between the results of scenario 2.

Within this policy the initial schedule determines a large part of the effect because the spread of BIM's influences the number of waiting moments. To test those influences we compare our planning method that plans surgeries from longest to shortest with two other planning methods. The first uses BIM optimization to spread the BIM's over the day by interchanging surgeries in the initial schedule in order to minimize the largest gap between two BIM's. The other method plans the surgeries in a random order. Table 22 shows the overall results. To compare then with the descending planning method, Table 23 provides an overview for our main performance indicators.

Name	(31) CO 8 - 120 – BIM	(32) CO 8 - 120 - Rand	(33) CO 10 - 120 - BIM	(34) CO 10 - 120 - Rand	(35) CO 12 - 120 - BIM	(36) CO 12 - 120 - Rand
Capacity (hours)	22,848	22,848	22,848	22,848	22,848	22,848
Number of elective surgeries	7,538	7,545	7,532	7,530	7,521	7,552
Number of emergency surgeries	1,388	1,389	1,401	1,415	1,424	1,396
Cancelled patients (#)	89	82	94	96	111	80
Total number of patients	9,015	9,016	9,027	9,041	9,056	9,028
Cancelled patients (%)	1.0%	0.9%	1.0%	1.1%	1.2%	0.9%
Overtime (hours)	1,089	1,276	1,106	1,313	1,091	1,273
Overtime (hours) elective	659	846	672	890	640	858
Overtime (hours) emergency	430	431	434	423	451	415
Overtime (%)	5%	6%	5%	6%	5%	6%
Interruptions elective program	408	391	413	415	442	401
Utilization	81%	81%	82%	82%	82%	81%
Emergencies within norm	97%	98%	98%	97%	98%	98%
A within 2 hours (%)	100%	100%	100%	100%	100%	100%
B within 8 hours (%)	95%	96%	96%	95%	96%	96%
C within 24 hours (%)	100%	100%	100%	100%	100%	100%
Elective patients moved to other OR	825	740	832	753	831	773
Number of OR days in overtime	763	772	784	788	804	780

Table 22: Simulation results for combinational policy when using BIM and random planning

Table 23 shows that the order of patients within a program influences the performance. With both BIM and a random order the performance for emergencies increases. We can explain this because both methods create more spread of the BIM in methods than planning all programs with descending duration. As seen before the difficulties in reaching the emergency norms only exist for B-emergencies. With a better spread of BIM's those emergencies can probably earlier interrupt a program and performance increases.

There is no obvious negative effect on the other indicators. With eight hours and a random planning method we see a slight decrease in cancellations and increase in overtime. Those two indicators compensate each other. For ten hours we see a slightly higher utilization. This might come because the spread of BIM's decreased the number of moments that an OR starts waiting for emergencies because the next BIM is further away than the maximal allowed time till next gap. For twelve hours we see minor differences in the cancelled patients and overtime which mutually compensate, with the same emergency percentage within the norm.

	(20) CO 8 -120	(31) CO 8 - 120 BIM	(32) CO 8 - 120 Rand
Cancelled patients (%)	1.0%	1.0%	0.9%
Overtime (%)	5%	5%	6%
Utilization	81%	81%	81%
Emergencies within norm	96%	97%	98%
	(22) CO 10 -120	(33) CO 10 - 120 BIM	(34) CO 10 - 120 Rand
Cancelled patients (%)	1.0%	1.0%	1.1%
Overtime (%)	5%	5%	6%
Utilization	81%	82%	82%
Emergencies within norm	95%	98%	97%
	(24) CO 12 -120	(35) CO 12 - 120 BIM	(36) CO 12 - 120 Rand
Cancelled patients (%)	1.0%	1.2%	0.9%
Overtime (%)	5%	5%	6%
Utilization	81%	82%	81%
Emergencies within norm	98%	98%	98%

Table 23: Comparison of simulation results for descending policy with BIM and a random planning order

Based on the results from Table 23 we conclude it would be beneficial to consider the spread of BIM's by either a BIM optimization method, or just by planning a random order of surgeries in the surgery schedules.

5.4 Comparison of results

This section presents and compares the simulation results for the different experiments. Furthermore we elaborate on the findings and discuss what we learn from these results.

Previous sections provided more detail regarding the simulation results, here we will focus on the main performance indicators: cancelled patients, overwork, utilization, and emergencies performed within their norm time. The formulas used for calculations are according to the definitions of Section 2.3.1.

Table 24 presents an overviews of the simulation results. The colours indicate the attractiveness of the scenarios. The variants coloured with red are unattractive, since other variants (green) score better on all performance indicators:

- Policy 1 with eight hours slack outperforms, policy 2 with ten hours slack, policy 2 with twelve hours slack, and policy 3 with ten hours slack. Those policies all have an emergency rate of 97% and score worse on one of the other performance indicators.
- Policy 1 with ten hours slack outperforms policy 2 with eight hours slack, policy 3 with eight and twelve hours emergency slack. Those policies all have an emergency rate of 98% and score worse on one of the other three performance indicators.

2017	8 hours emergency slack	10 hours emergency slack	12 hours emergency slack
Dedicated	C: 0.4% O: 4% U: 81% Emergencies within norm: 97% # elective surgeries: 7,598 # emergency surgeries: 1,407 # Interruptions in elective pr: 275 # ORS with overtime: 693	C: 0.5% O: 4% U: 81% Emergencies within norm: 98% # elective surgeries: 7,598 # emergency surgeries:1,412 # Interruptions in elective pr: 213 # ORS with overtime: 706	C: 0.6% O: 4% U: 81% Emergencies within norm: 97% # elective surgeries:7,573 # emergency surgeries: 1,419 # Interruptions in elective pr: 218 # ORS with overtime:737
Flexible	C: 0.8% O: 5% U: 81% Emergencies within norm: 98% # elective surgeries: 7,548 # emergency surgeries: 1,394 # Interruptions in elective pr: 403 # ORS with overtime: 772	C: 0.9% O: 5% U: 81% Emergencies within norm: 97% # elective surgeries: 7,530 # emergency surgeries:1,397 # Interruptions in elective pr: 420 # ORS with overtime: 753	C: 0.8% O: 5% U: 80% Emergencies within norm: 97% # elective surgeries: 7,529 # emergency surgeries: 1,389 # Interruptions in elective pr: 403 # ORS with overtime: 741
Combination	C: 1.0% O:5% U:81% Emergencies within norm: 98% # elective surgeries: 7,537 # emergency surgeries: 1,423 # Interruptions in elective pr:417 # ORS with overtime: 783	C: 1.0% O: 5% U: 81% Emergencies within norm: 97% # elective surgeries: 7,534 # emergency surgeries: 1,384 # Interruptions in elective pr: 407 # ORS with overtime: 778	C: 1% O: 5% U:81% Emergencies within norm: 98% # elective surgeries: 7,530 # emergency surgeries: 1,398 # Interruptions in elective pr: 422 # ORS with overtime:790

Table 24: Overview of simulation results

There are two variants which may be the best, dependent on the value and weight assigned to the different performance indicators. When focussing on cancellations reserving eight hours with a dedicated policy would be best. When focussing on emergency performance, twelve hours reserved for emergencies performs best. They both have 4% overtime and 81% utilizations.

It is important to mention that the differences between the policies are very small. Within this decision also other aspects should be considered, such as medical and or organizational aspects.

Policy 2 has similar scores for overtime, utilization, and emergencies. The main difference is the cancellation rate. The higher cancellation rate for this policy could be explained by the fact that this method spreads emergency capacity over all the operating rooms and by doing so creates many small gaps. At the end of the day there may be some time left if no emergency interrupted the program, that is not enough to perform another elective surgery, or an emergency took longer than the planned reserved capacity which delayed the elective program to much to start with a new surgery.

Table 25 provides an overview of the results with 5% growth of the patient population. For all variants, the number of cancelled patients, overtime, and utilization increase because capacity remains the same. The table shows that when the number of patients increases with 5% we see differences in the optimal policy, also the flexible policy becomes attractive. The flexible policy has a higher utilization. The dedicated policy has the lowest cancellation rate.

5%	8 hours emergency slack	10 hours emergency slack	12 hours emergency slack
1	C: 0.6% O: 5% U: 84% Emergencies within norm: 98% # elective surgeries: 7,935 # emergency surgeries: 1,463 # Interruptions in elective pr:322 # ORS with overtime: 789	C: 0.7% O: 5% U: 84% Emergencies within norm: 97% # elective surgeries: 7,943 # emergency surgeries: 1,484 # Interruptions in elective pr: 245 # ORS with overtime: 825	C: 1% O: 5% U: 84% Emergencies within norm: 97% # elective surgeries: 7,907 # emergency surgeries: 1,499 # Interruptions in elective pr: 252 # ORS with overtime:846
2	C: 1.4% O: 6% U: 86% Emergencies within norm: 97% # elective surgeries: 7,893 # emergency surgeries: 1,485 # Interruptions in elective pr: 484 # ORS with overtime:925	C: 1.4% O: 5% U: 85% Emergencies within norm: 98% # elective surgeries: 7,867 # emergency surgeries: 1,476 # Interruptions in elective pr: 485 # ORS with overtime: 890	C: 1.4% O: 5% U: 85% Emergencies within norm: 97% # elective surgeries: 7,870 # emergency surgeries:1,463 # Interruptions in elective pr: 469 # ORS with overtime: 869
3	C: 1.3% O: 5% U: 84% Emergencies within norm: 97% # elective surgeries: 7,861 # emergency surgeries: 1,467 # Interruptions in elective pr: 465 # ORS with overtime: 877	C: 1.5% O: 5% U: 85% Emergencies within norm: 97% # elective surgeries: 7,885 # emergency surgeries: 1,480 # Interruptions in elective pr: 499 # ORS with overtime: 908	C: 1.3% O: 5% U: 84% Emergencies within norm: 98% # elective surgeries: 7,870 # emergency surgeries: 1,478 # Interruptions in elective pr: 469 # ORS with overtime: 880

Table 25: Overview of simulation results with 5% growth

When the number of patients increases with 10% we again find the same optimal policy. The number of cancelled patients, overtime, and utilization increase because capacity remains the same. The dedicated policy is outperformed by the combination scenario and seems a future proof policy.

10%	8 hours emergency slack	10 hours emergency slack	12 hours emergency slack
1	C: 1.2% O: 6% U: 90% Emergencies within norm: 97% # elective surgeries: 8,271 # emergency surgeries: 1,559 # Interruptions in elective pr: 396 # ORS with overtime: 998	C: 1.3% O: 6% U: 90% Emergencies within norm: 97% # elective surgeries: 8,262 # emergency surgeries: 1,537 # Interruptions in elective pr: 306 # ORS with overtime: 996	C: 1,6% O: 6% U: 89% Emergencies within norm: 97% # elective surgeries: 8,215 # emergency surgeries: 1,558 # Interruptions in elective pr: 296 # ORS with overtime: 1019
2	C: 2% O: 6% U: 88% Emergencies within norm: 97% # elective surgeries: 8,196 # emergency surgeries: 1,567 # Interruptions in elective pr: 552 # ORS with overtime: 1018	C: 2% O: 6% U: 89% Emergencies within norm: 97% # elective surgeries: 8,207 # emergency surgeries: 1,546 # Interruptions in elective pr: 546 # ORS with overtime: 1042	C: 2% O: 6% U: 89% Emergencies within norm: 97% # elective surgeries: 8,178 # emergency surgeries: 1,561 # Interruptions in elective pr: 544 # ORS with overtime: 1034
3	C: 2.1% O: 6% U: 88% Emergencies within norm: 97% # elective surgeries: 8,176 # emergency surgeries: 1,534 # Interruptions in elective pr: 540 # ORS with overtime: 1015	C: 1.9% O: 6% U: 87% Emergencies within norm: 97% # elective surgeries: 8,182 # emergency surgeries: 1,529 # Interruptions in elective pr: 524 # ORS with overtime: 979	C: 2% O: 6% U: 88% Emergencies within norm: 97% # elective surgeries: 8,186 # emergency surgeries: 1,559 # Interruptions in elective pr: 545 # ORS with overtime: 1052

Table 26: Overview of simulation results with 10% growth

5.5 Extra experiments for flexible and dedicated policy

To show the influence of the amount of reserved capacity for the flexible policy we adapt the planning rules. Within the experiments in this section it is not allowed to over plan the available capacity. This may result in unplanned surgeries. The more reserved capacity for emergency patients, the more unplanned elective surgeries we expect. When the number of elective patients increases, we expect bigger differences in the number of unplanned surgeries. We compare only the extreme situations with eight and twelve hours for emergencies. We perform experiments with a similar number of elective surgeries as in 2015, and increase this to 8,000, 8,500, and 9,000. After performing the experiments with the flexible policy, we also perform them with the dedicated policy, to compare the effect of our new planning rules.

Table 27 shows the results for the flexible policy. These results show that with more time reserved for emergencies, there are more unplanned surgeries. It is striking that it does not seem to influence the performance indicators. The cancellation rate, overtime percentage, utilization, and emergencies within the norm are similar. With a similar cancellation rate, and more unplanned patients, the twelve hour variants perform fewer elective surgeries. The exception to this is the variant with 8,500 elective patients. The model there generated more elective patients, resulting in more elective patients despite there are more unplanned surgeries. Based on these results, reserving eight hours seems best.

Name	BI 8	BI 12	BI 8 8000	BI 12 8000	BI 8 8500	BI 12 8500	BI 8 9000	BI 12 9000
Capacity (hours)	22,848	22,848	22,848	22,848	22,848	22,848	22,848	22,848
Nr of elective surgeries	7,555	7,546	7,896	7,887	8,351	8,367	8,731	8,703
Nr of emergency surgeries	1,151	1,146	1,150	1,124	1,153	1,149	1,168	1,155
Cancelled patients (#)	38	45	63	61	88	107	176	156
Total number of patients	8,744	8,737	9,109	9,072	9,592	9,622	10,075	10,014
Cancelled patients (%)	0.4%	0.5%	0.7%	0.7%	0.9%	1.1%	1.7%	1.5%
Overtime (hours)	913	907	1,045	1,024	1,133	1,137	1,402	1,362
Overtime (%)	4%	4%	5%	4%	5%	5%	6%	6%
Nr of OR days in overtime	648	644	753	741	853	864	1060	1061
Interruptions elective program	246	250	254	250	277	270	293	296
Elective patients moved to other OR	833	849	837	836	869	848	840	885
Utilization	75%	74%	77%	77%	80%	80%	83%	84%
Emergencies within norm	95%	95%	95%	95%	95%	95%	94%	95%
Nr of unplanned surgeries	24	45	40	52	48	50	96	151

Table 27: Overview of simulation results extra experiments flexible policy, planning overtime is not allowed

Table 28 shows the results for the dedicated policy when it is not allowed to plan surgeries in overtime. Here we recognise the same effect: with more time reserved for emergencies, there is fewer capacity for elective surgeries, resulting in more unplanned patients. The overtime, utilization and emergency rate are equal. For this policy the differences in cancellations between eight and ten hours are larger, the variant with twelve hours has more cancelled patients. The larger the number of patients, the bigger the difference between the number of unplanned patients with eight, and twelve hours. Based on the number of elective surgeries performed and the cancellations reserving eight hours would be best with the dedicated policy.

Name	DE 8 (no ot)	DE 12 (no ot)	DE 8 (no ot 8000)	DE 12 (no ot 8000)	DE 8 (no ot 8500)	DE 12 (no ot 8500)	DE 8 (no ot 9000)	DE 12 (no ot 9000)
Capacity (hours)	22840	22848	22840	22848	22840	22848	22840	22848
Nr of elective surgeries	7569	7506	7903	7837	8343	8209	8749	8570
Nr of emergency surgeries	1154	1154	1152	1162	1142	1150	1139	1155
Cancelled patients (#) em	37	63	66	82	111	152	169	197
Total number of patients	8785	8777	9156	9169	9642	9649	10146	10157
Cancelled patients (%)	0,4%	0,7%	0,7%	0,9%	1,1%	1,6%	1,6%	1,9%
Overtime (hours)	812	863	917	925	1070	1106	1192	1183
Overtime (%)	4%	4%	4%	4%	5%	5%	5%	5%
Nr of OR days in overtime	626	689	712	735	857	917	981	991
Interruptions elective program	194	151	246	166	274	186	289	187
Nr of elective patients moved to another OR	598	846	589	878	598	911	611	926
Utilization	75%	75%	78%	77%	81%	81%	84%	83%
Emergencies within norm	97%	97%	97%	97%	96%	96%	96%	96%
Nr of unplanned surgeries	25	55	35	88	46	138	90	236

Table 28: Overview of simulation results extra experiments dedicated policy, planning overtime is not allowed

For the variants with the 2015 patient number the differences between dedicated and flexible policy are small. When the number of patients increases, the results with eight hours stay similar. But the flexible policy with twelve hours starts to outperform the dedicated policy with twelve hours.

5.6 Additional experiments for the combination policy

For the current a-mount of patients in UMC Utrecht, the planning method of policy 3 is not very promising. This is probably because of the large number of operating rooms and short surgeries. The differences in performance are too small to compensate for the practical difficulties in organizing and coordinating such a policy in practice.

To test whether the results are mainly dependent on the specific case of UMC Utrecht, we perform extra theoretical experiments. The goal of these experiments is to check the added value of the combination policy for other settings. The extra experiments have settings that will probably show the positive expected effects of this policy. For these experiments we decrease the number of operating rooms with 50%, and remove the short surgeries (< 2 hours) to limit the BIM's the programs. When we use a normal flexible policy there may be long times between the interruption moments, which delay emergency surgeries outside their norm. Furthermore we consider generic operating rooms that may perform surgeries of all specialties to prevent that waiting OR's are not allowed to perform arriving emergencies because of their specialty.

Nr.	Planning method	Emergency Capacity	Max time till next gap	Growth	Extra
37	Combination policy	10 hours	120 minutes	½ * 2015	50% of capacity
38	Flexible policy	10 hours	∞	½ * 2015	50% of capacity

Table 29: Settings for additional experiments of simulation results

To compensate for the decrease in capacity and longer surgery duration we use 2500 surgeries as input parameter.

Table 30 shows the results of experiment 37 and 38. We recognise the expected effect of more cancelled patients, and a lower utilization because of the waiting time that the OR stays empty. Furthermore we recognise the effect of more A-emergencies within their norm time, also for the B emergencies we see an improvement. Since the C-emergencies have to wait for the completion of elective programs and are not allowed to use the reserved gaps, the delay due to waiting time decreases the results for C-emergencies.

Name	(37) COM 10 - 120	(38) BI 10
Capacity (hours)	11,524	11,524
Number of elective surgeries	2,452	2,470
Number of emergency surgeries	1,167	1,171
Cancelled patients (#)	64	46
Total number of patients	3,683	3,687
Cancelled patients (%)	1,7%	1,2%
Overtime (hours)	2,019	1,954
Overtime (hours) elective	1,659	1,589
Overtime (hours) emergency	360	365

Overtime (%)	18%	17%
Number of OR days in overtime	813	805
Interruptions elective program	352	287
Elective patients moved to other OR	352	359
Utilization	89%	90%
Emergencies within norm	97%	97%
A within 2 hours (%)	95.21%	91.84%
B within 8 hours (%)	99.15%	98.8%
C within 24 hours (%)	95.3%	96.8%

Table 30: Simulation results extra experiments with combinational policy

This small experiment shows that our expectations are correct for specific cases. For those cases this policy is possibly valuable. The differences between those experiments on cancellations, utilization and emergencies that can start without delay poses a trade-off that is interesting for further research. Therefore it would be interesting to determine the characteristics of these cases, and estimate the potential benefit of this policy.

Other interesting research questions would be if the combinational policy is effective when there are many A-emergencies with a small allowed interval, or what whether we see the same effect with non-generic speciality bounded operating rooms.

6. Conclusions and recommendations

From the analysis in previous chapters, we draw conclusions and make recommendations concerning the operating room planning of emergency surgeries for DHS and Cancer Center of UMC Utrecht. Section 6.1 returns to the research questions by answering them based on the information from previous chapters. Section 6.2 discusses the limitations and suggestions for further research following from this project. Section 6.3 describes our recommendations and the implications for practice.

6.1 Conclusions

The central goal of this study, was the following:

UMC Utrecht promises patients to deliver 'top care', which among other things means complying with the target times for emergency patients. The goal of this research is to evaluate the way OR planning can contribute to the promise of 'Top care' for DHS and Cancer Center.

To reach this objective, we analysed how surgeries are currently planned and evaluated which planning methods are efficient and effective for DHS and Cancer Center. We answered these question by means of several sub questions:

1. *What is the current operating room planning process in UMC Utrecht?*

UMC Utrecht uses a blueprint to allocate and assign capacity to the different surgical specialties. The blueprint is prepared based on the available OR capacity and desired surgery time of the various divisions. This blueprint is a scheme of four weeks that states which specialty can use which OR at which moments and is repeated every four weeks. The final month schedule is released two months in advance, after which patients can be scheduled in the sessions. To do so there are several planning desks and planners who plan surgeries for one of more specialties. The current schedule contains six hours per day to accommodate emergency surgeries. During the day the program is adapted based on deviations from planned surgery durations and the arrival of emergency patients. A-emergencies always interrupt the program of the first available OR, regardless the specialty of that OR. B-emergencies interrupt only the programs of their own specialty or the program with reserved capacity for emergencies. C-emergencies are performed at the end of the day.

2. *What are the characteristics of the patients of DHS and Cancer Center?*

DHS and Utrecht Cancer Center are the largest users of operating room capacity in UMC Utrecht. CHI, KNO, OOG, ORT, PLA, VAT, and CGO all used more than 1500 hours of surgery capacity in 2015 (approximately thirty hours per week). The average surgery duration for both divisions together is 109 minutes. Some specialties (OOG, PLA, URO) mainly have short surgeries (<120 minutes), while other specialties have extremely long surgeries (CGO, QKA, QKN, VAT). The Cancer Center specialties have relatively long surgeries, with an average duration of more than 159 minutes, even 240 minutes for QKA. Those two specialties with long surgeries have the largest deviations from the planned duration.

3. *What is the current OR-planning performance?*

In 2015, 413 DHS patients, and 80 Cancer Center patients were cancelled on the planned day of surgery. The majority of them was cancelled due to program related reasons. In the same period DHS had an overtime percentage of 4% (682 hours), for the Cancer Center this was 6.2% (386 hours), the highest of all divisions. The utilization of OR time for DHS and Cancer Center was 77% (excluding changeover and briefing). 92% of A-emergencies, 79% of B-emergencies, and 83% of C-emergencies is operated within the applicable norm time for their category. Resulting in an overall emergency within norm time rate of 82%.

4. *What are suitable planning methods to improve the operating room performance?*

Based on a literature review and interviews with the stakeholders of the operating theatre, we developed the following interventions:

> Scenario 1 - Dedicated policy: Emergency OR + break-in in the elective programme for A-emergencies. The expected benefits of this policy are short waiting times for emergencies because the first emergency surgery can start without delay, and few interruptions in the elective programs.
>
> Scenario 2 - Flexible policy: no emergency OR, white spots at the end of every OR-day to accommodate emergency patients. The expected benefits of this policy are a high utilization, low overtime and still a quick response to arriving emergency surgeries.
>
> Scenario 3 - Combination of flexible and dedicated policy: No emergency OR, white spots spread over the day to accommodate emergency patients. The expected benefits of this policy are similar to the benefits of scenario 2. By extending the policy with extra rules that leave an OR empty if the next possibility to break into an elective program is too far away, the reaction time for emergencies should improve.

We test all scenarios for eight, ten, and twelve hours emergency slack per day.

5. *What is a suitable model to test the effect of the proposed planning methods?*

We used the ‘Operating Room Manager’ developed at the University of Twente to test our interventions. This is a discrete event simulation model that models the specific settings of a hospital based on the operating room capacity, case mix of patients, distributions for surgery durations and patient arrivals, and planning and scheduling rules. Simulation is a suitable method to test the different planning methods because it enables to model complex environments and uncertainty, and is very suitable for testing scenarios.

6. *What is the effect of the suggested planning methods?*

Table 31 shows the results for the different scenarios following from the simulation model.

2017	8 hours emergency slack	10 hours emergency slack	12 hours emergency slack
1	C: 0.4% O: 4% U: 81% Emergencies within norm: 97% # elective surgeries: 7,598 # emergency surgeries: 1,407 # Interruptions in elective pr: 275 # ORS with overtime: 693	C: 0.5% O: 4% U: 81% Emergencies within norm: 98% # elective surgeries: 7,598 # emergency surgeries:1,412 # Interruptions in elective pr: 213 # ORS with overtime: 706	C: 0.6% O: 4% U: 81% Emergencies within norm: 97% # elective surgeries:7,573 # emergency surgeries: 1,419 # Interruptions in elective pr: 218 # ORS with overtime:737
2	C: 0.8% O: 5% U: 81% Emergencies within norm: 98% # elective surgeries: 7,548 # emergency surgeries: 1,394 # Interruptions in elective pr: 403 # ORS with overtime: 772	C: 0.9% O: 5% U: 81% Emergencies within norm: 97% # elective surgeries: 7,530 # emergency surgeries:1,397 # Interruptions in elective pr: 420 # ORS with overtime: 753	C: 0.8% O: 5% U: 80% Emergencies within norm: 97% # elective surgeries: 7,529 # emergency surgeries: 1,389 # Interruptions in elective pr: 403 # ORS with overtime: 741
3	C: 1.0% O:5% U:81% Emergencies within norm: 98% # elective surgeries: 7,537 # emergency surgeries: 1,423 # Interruptions in elective pr:417 # ORS with overtime: 783	C: 1.0% O: 5% U: 81% Emergencies within norm: 97% # elective surgeries: 7,534 # emergency surgeries: 1,384 # Interruptions in elective pr: 407 # ORS with overtime: 778	C: 1% O: 5% U:81% Emergencies within norm: 98% # elective surgeries: 7,530 # emergency surgeries: 1,398 # Interruptions in elective pr: 422 # ORS with overtime:790

Table 31: Overview of simulation results

This results in the following conclusions:

1. *Amount of reserved capacity for emergencies:*

The differences in performance are small. Based on our simulation results reserving eight hours will be the best alternative for elective patients because of the low number of cancelled patients. For the emergency patients reserving ten hours will be beneficial because of the higher emergency rate.

2. *Emergency operating room or not*

   From a theoretical point of view the number of operating rooms is on the tipping point between what is optimal: a dedicated or flexible policy. We recognise this in our results by the very small differences between both policies. A dedicated policy seems to be the best alternative. For all growth scenarios this policy could be optimal, and also the number of interruptions in elective programs is smaller. Furthermore the dedicated policy is the easiest to understand and work with in practice, so is therefore preferable as well. We prefer having an emergency OR above breaking into the elective program for emergencies.

3. *Growth scenarios*

   To see which policies are future proof we tested for an increased number of patients. With 5% growth of elective patients both the dedicated and flexible policy could be optimal. In case of 10% growth the dedicated policy performs best again. We prefer this policy above the combinational policy because of the difference in overtime and cancelled patients.

4. *Overall conclusion*

   Both the capacity for emergencies as well as the capacity for elective surgeries increases. The model shows that the expected effect of the extra capacity increases the performance for cancellations, overtime, and emergencies. Only the utilization decreases. In practice in the beginning this will be compensated by the current waiting list that allows planning extra patients, later on when there is no waiting list anymore we will see the expected effects on the performance. Based on the simulation results we would recommend Cancer Center and DHS to use a dedicated policy with eight or ten hours reserved for emergencies. The differences between both variants are too small to distinguish only based on the simulation results. The choice between those two should depend on the other factors such as organizational and medical aspects.

6.2 Discussion & further research

This section discusses the weaknesses and areas of further research for this project. The first and one of the most important limitations is our method to determine surgery types. We decided to create clusters based on historic data. The clusters are based on speciality of the planned surgeon, hospital location (day-care surgery, or clinical), and duration (short < 2 hours, average >2 and < 4 hours, long >4 hours). This results in clusters that may cover a lot of medically different surgeries, and variety in duration. For every surgery cluster we fitted a distribution to determine the expected and real duration. Because of the large differences within each group the gap between planned and actual surgery duration increases, which impedes planning. Unfortunately there currently is no method available to cluster such a large number of surgeries to medical comparable groups. UMC Utrecht has a treatment codes system, but this is not consequently used. Furthermore every patient has a diagnosis, but this does automatically say something about the surgery and surgery duration. We know that the planned and actual durations from the model for individual surgeries do not always correspond to reality, but on overage the duration per specialty is equal, and at the moment with the current registration this was the best available method. This influences our results because the initial planning in worse, and therefor may cause extra cancelled patients, lower utilization, and/or overtime.

- ➔ Further research: The model could be improved by testing other clustering methods that create clusters with surgeries with similar characteristics.
- ➔ Practical: Implement a surgery clustering method, for example proper treatment code system in the UMC Utrecht.

A second limitation is the small degree of flexibility in the model. The model uses strict planning rules, but those were hard to find in practice. This makes the model very suitable for theory, but the connection to practice is difficult. Since there are many people involved in creating schedules and coordination, in practice the rules differ from person to person and from case to case. With those rules the model is not able to check to possibilities for each individual case, like the operating room coordinators do. This applies specially for emergency planning. Not every A-emergency is equally urgent, and the same is true for B- and C-emergencies. Furthermore not every surgeon is equally fast and experienced in every type of surgery and also the specific conditions of the patients may influence the surgery. However, the model does provide insights into the expected effects of the various options and therefore supports a reasoned choice and creates expectations for the potential impact in the various performance indicators.

- ➔ Further research: There are several adaptations to the current model that make the model more realistic and answer other related questions. It would be interesting to test the effect of realistic cancellations rules, and of detailed rules for handling B- and C-emergencies. The cancellation rules for the UMC Utrecht should take into account the unused time when a patient is cancelled: a surgery of 5 hours is not cancelled if it causes thirty minutes overtime, but a surgery of one hour that causes 15 minutes probably will be cancelled. The current rule that uses only a percentage is too simple.

Third, we did not look at the other parts in the care chain, we did not think about the influence on the wards, the outpatient clinic, or preoperative screening, while UMC Utrecht currently works on the alignment of the different steps in the care chain. It is important align OR-planning with capacity at other departments and to check the effects before deciding on those important decisions.

A fourth limitation is that there are many more performance indicators to take into account. Our final advices are based on cancelations, overwork, utilization and emergencies within their norm time, but we do not consider the norms for elective patients. Within our simulation the restriction for these patients is the end of horizon, so they should have their surgery within the year. Also for these patients there are norms that should be taken into account. We also do not consider the number of patients moved between OR programs. This may result in unrest and a lot of communication. These other performance indicators might influence the result.

During the project, we discovered various other subjects that where related to operating room planning, but out of the scope of this project because of data or time limitations, which could be interesting topics for further research

- ➔ Although scenario 3 was not interesting for UMC Utrecht, it would be interesting to test from a theoretical point of view whether this would be a good planning method for other cases, and what the characteristics of such cases are. We performed a small test which seems promising.
- ➔ The different planning desks have little mutual communication and all have their own planning methods. It would be interesting to see if the planning desks could learn from each other's methods and what would be the benefit of more cooperating in filling OR programs and sharing capacity. Some adaptations to this simulation could help to test the effects of these kind of interventions.

6.3 Recommendations

Based on the conclusions, we recommend DHS and Utrecht Cancer Center for the capacity according to the blueprint of 2017 and the number of patients equal to the amount in 2015, to stay with their plans to use an emergency OR to accommodate arriving emergency patients. There are two possible variants: reserve eight hours for emergencies on a dedicated OR, or reserve ten hours for emergencies and plan elective surgeries for maximal two hours on a dedicated OR. The number of cancelled patients is based on the simulation model expected to increase when reserving only ten hours for emergencies. However, in practice the difference might be smaller, because it takes time and coordination to arrange emergency surgeries. The coordinators start their shift only a short period before the start of the OR programs. Therefore it might be more efficient to start with a short elective surgery which does not need any special coordination early in the morning.

During our project several other things came across that were not directly related to our simulation study, but could help to improve OR (planning) performance:

- The planned surgery duration is structurally shorter than the actual surgery duration. This hinders making a good planning and results in many program changes during the day, cancelled patients, and overwork. To fully benefit from the planning methods UMC Utrecht should prevent planning structurally too short by planning careful and realistic.
- To support the planning of surgery durations one uniform clustering method would provide insight in surgery durations per patient type. This enables using historical data to plan surgery durations and make them more reliable.

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