Patience of patients

Bachelor Thesis: Reducing ultrasound access times and the workload for ultrasound technicians at the radiology department of SKB Winterswijk.

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Industrial Engineering and Management, BSc

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This report is destined for SKB Winterswijk and the examiners of the University of Twente

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PREFACE

Before you lies the bachelor thesis "Patience of patients: Reducing ultrasound access times and the workload for ultrasound technicians at the radiology department of *SKB Winterswijk*". The basis of which is the research of the strategic and online appointment planning methods at the radiology department of *Streekziekenhuis Koninging Beatrix Winterswijk* (SKB-W). It has been written to fulfill the graduation requirements of the undergraduate program Industrial Engineering and Management at the University of Twente. I was engaged in researching at SKB-W and writing this thesis from February to August 2017.

I would like to thank Wilco Kleine for giving me the opportunity to conduct my research at SKB-W. At SKB-W, it felt like everyone was very engaged with my research. I would also like to thank Suzanne Pothof, who ensured that I got in contact with the right people and was often available for questions or short discussions. Maurice Wienholts proved to be very helpful when I had data-related questions, as well as Wilco Teunissen, who is very well informed about every aspect the radiology department has to deal with. Wilco also helped me set the scope for my research, by informing me about all the problems that the radiology department was coping with. Furthermore, I would like to thank the whole team of radiologists, technicians, and secretaries at the radiology department of SKB-W. There was always someone available if I wanted to ask a question, which was, together with everyone's positive attitude, encouraging.

I also want to show my gratitude towards several people from the University of Twente. First of all, Erwin Hans, for bringing me into contact with Wilco Kleine. Second, Jeroen Staakman, my fellow student who helped me during the first part of the research. Third, Aron van Stiphout, whom I worked together with at SKB-W. And fourth, my supervisors Nardo Borgman and Ìpek Seyran Topan, who directed me very well throughout the whole period. Our feedback sessions were very valuable, and they were always available for more questions.

Lastly, I want to thank you, Jeroen, mom and dad, Laura and Michiel, my friends, and housemates. You were able to put things in perspective for me; whenever I needed it, you were able to put a smile on my face and encourage me to keep on going.

I hope you enjoy reading this report.

Wouter Veneklaas
Enschede, September 22nd, 2017

MANAGEMENT SUMMARY [EN]

Introduction and problem description

Streekziekenhuis Koningin Beatrix Winterswijk (SKB-W) is a regional hospital located in the east of the Netherlands and has the motto 'SKB, at home in *De Achterhoek*'. SKB-W is a modern hospital with 24 specialisms, 214 beds, and approximately 1100 employees. The catchment area of the hospital overlaps with the catchment area of another regional hospital: *Slingeland Ziekenhuis Doetinchem.* The two hospitals merged on January 1, 2017 (SKB Winterswijk, 2017).

Initially, the management team of SKB states that there are two main problems concerning ultrasounds. The first problem is high access times, which is the time between the moment that a patient requests an appointment and the moment that the appointment can take place. The second problem is the high workload perceived by technicians. We address the high fragmentation of resource capacity allocation as the core problem, as it is a root to both initial problems.

The aim of this project is to give a substantiated advice on balancing accessibility and utilization of ultrasounds at the RD to SKB-W. Eventually, we deliver a set of blueprint schedules or ideas for blueprint schedules that could be tested and assessed in more detail than we will do. Based on our findings, we will advise SKB-W which blueprint schedule should be assessed in more detail.

Analysis of the current situation

We identify three different groups of patients: outpatients, inpatients, and emergency patients. SKB-W discerns the following examination groups: regular, abdominal, biopsy, duplex, mammapoli, musculoskeletal, emergency, inpatient, and duplex carotids.

For the analysis of the access times for outpatient groups we conclude that the access times for abdominal and duplex patients are the highest. Other access times are too high as well, except for the examination group biopsy. Access times are higher when there is not sufficient capacity allocated to the specific examination group.

The analysis on utilization concludes that the measured utilization is too high, but also states that the measured utilization could be higher than the real situation because of assumptions for the data analysis. We conclude that an increase of capacity might be helpful to solve this problem, but not the real solution to the problem of a high workload. That would still

be defragmentation of the appointment schedule, by which the net time that rooms and technicians are available will increase. This sounds like an increase of capacity, but it is an increase of useable slots for outpatients.

Theoretical framework and literature review

Hans et al. (2012) state 'more capacity' is the universal panacea for many healthcare managers, and the challenge for improvement lies within tactical allocation and strategic organization of the available resources. To find such solutions, we use the hospital planning and control proposed by Hans et al. (2012) as our theoretical framework for the literature research.

We conclude the literature review with a choice for our analysis methodology. We choose simulation modeling over analytical approaches. We can use simulation modeling to test the effects of new blueprint schedules. For these new blueprint schedules, we also need new approaches towards appointment scheduling. The first approach for improvement is based on defragmentation of the schedule, by regrouping patients. The second approach considers a partial open access appointment system.

Simulation study

We make a discrete event simulation model of the appoint scheduling process for ultrasound rooms at the RD with the program Plant Simulation 13. After modeling the current situation, we experiment with a variety of alternative blueprint schedules and the use of open access policies. We assess our experiments on the KPIs 'average access time' or 'average waiting time', 'average capacity utilization', and 'average number of patients examined during overtime'. We experimented with a run length of 500 days, a warm-up period of 239 days, and 4 replications. The modeled performance of the current situation is very similar to the performance found in the data, with slight errors for the access times of the smaller examination groups. We use stepwise approach towards the creation of a new blueprint schedule that uses defragmentation and open access blocks as means to improve accessibility and lower the workload.

The best combination of defragmentation and open access yields an appointment schedule with scheduled outpatients of the regular, abdominal and musculoskeletal examination group which have an access time of 4,3 days, while the open access patients have no access time at all. The total average access time therefore amount 3,3 days, in comparison to the modeled 16,3 days in the current situation. The new scheduling policy also yields a lower average waiting time of 7,0 minutes, in comparison to 10,4 minutes in the current situation. There is a slight increase in the average number over overtime patients going from 9,7 in the current situation to 11,1 in the new situation, which is a result of the open access policy as well as the increased number of patients. Because of the improved accessibility, all patient requests can be accepted, which results in a 5% increase of number of examined outpatients.

Conclusions and recommendations

We conclude our research by saying whether we can solve the initial problems of high access times and high workload by solving the core problem 'high fragmentation of resource capacity allocation'. The answer is: partially.

We could not solve the workload problem entirely. However, we do believe that the perceived workload becomes lower when there is a straightforward rule for handling emergency arrivals. This perceived workload cannot be expressed in figures, whereas the number of overtime patients can. There is no improvement for the number of overtime patients, because incorporating open access increases variability in demand.

Defragmentation of the appointment schedule by making big patient groups turned out to be very effective for decreasing access times. Table S1 shows the block schedule we propose.

Table S1 – Proposed new block schedule for the RD of SKB-W.

	E10 morning	**E10 afternoon**	**E4 morning**	**E4 afternoon**	**E3 morning**	**E3 afternoon**
Monday	Regular	MSU	Regular	Regular		Open access
Tuesday	Regular	MSU	Emergency	Regular	Regular	Open access
Wednesday	Regular	MSU	Regular	Regular	Regular	Open access
Thursday	Regular	MSU	Emergency	Regular	Regular	Open access
Friday		MSU	Regular	Regular	Regular	Open access

Our first recommendation is to consider grouping the regular and abdominal patients entirely. Our second recommendation is to consider using an open access policy for emergency patients from the emergency department. Our third recommendation is to let programs in the schedule be programs without scheduling any other examination groups through the program. Our fourth recommendation is to create clear protocols that eliminate the need for by-passing of the rules and restrictions of the blueprint schedule, as well as improve the handling of emergencies.

Managementsamenvatting [NL]

Introductie en probleembeschrijving

Streekziekenhuis Koningin Beatrix Winterswijk (SKB-W) is een regionaal ziekenhuis in het oosten van het land en heeft het motto 'SKB, thuis in de Achterhoek'. SKB-W is een modern ziekenhuid met 24 specialisaties, 214 bedden en ongeveer 1100 werknemers. Het verzorgingsgebied van het ziekenhuis overlapt met die van een ander regionaal ziekenhuis: Slingenland Ziekenhuis Doetinchem. De twee ziekenhuizen zijn in januari 2017 gefuseerd (SKB Winterswijk, 2017).

Het managementteam van SKB-W benaderde ons met twee problemen omtrent de echo-onderzoeken. Het eerste probleem is te hoge toegangstijden, wat de tijd is tussen het moment dat een patiënt een afspraak maakt en de tijd de afspraak plaatsvindt. Het tweede probleem is de hoge werkdruk die de echolaboranten ervaren. We beoordelen een hoge fragmentatiegraad van de capaciteitstoewijzingen als kernprobleem.

Het doel van dit onderzoek is om een advies op te stellen omtrent het balanceren van een acceptabele en verbeterde toegangstijd met een goede benuttingsgraad voor de echo-onderzoeken op de radiologie afdeling (RA) van het SKB-W.

Analyse van de huidige situatie

We identificeren drie verschillende patiënttypes: poliklinische patiënten, klinische patiënten van een van de andere klinieken in het ziekenhuis, en spoedpatiënten. Binnen deze patiënttypering, heeft SKB-W groeperingen gemaakt op basis van onderzoeks-type: regulier, bovenbuik, biopsie, duplex, mammapoli, musculoskeletaal, spoed, klinisch, en duplex carotiden.

Voor de analyse van de toegangstijden voor poliklinische groepen concluderen we dat de toegangstijden voor bovenbuik en duplex echo's het hoogst zijn. Overige toegangstijden vallen ook te hoog uit, op de onderzoeksgroep biopsie na. We zien dat toegangstijden hoger zijn voor de groepen waarvoor te weinig capaciteit toegewezen is in het afsprakenschema.

Bij de analyse van de capaciteitsbenutting concluderen we dat de gemeten benutting te hoog is, met de kanttekening dat de gemeten benutting hoger uit lijkt te vallen dan deze in de werkelijke situatie is. Dit komt door aannames die gedaan zijn in de data-analyse. De conclusie is dat een vergroting van de capaciteit behulpzaam kan zijn ter oplossing van de hoge benuttingsgraad, maar ook dat het niet *de* oplossing is voor het probleem dat met hoge werkdruk te maken heeft. Die oplossing ligt namelijk in de defragmentatie van het afsprakenschema, waarmee de netto tijd dat echokamers en -laboranten beschikbaar zijn hoger uit zal vallen. Dit klinkt misschien als een capaciteitsvergroting, maar dat is het niet. Het stelt meer tijdsloten beschikbaar voor het inplannen van de poliklinische patiënten, in plaats van dat er sloten geblokkeerd worden en mogelijk niet in gebruik worden genomen.

Theoretisch kader en literatuuronderzoek

Hans et al. (2012), beschrijven dat 'meer capaciteit' de universele magische oplossing lijkt te zijn voor vele zorgmanagers, echter de werkelijke uitdaging voor verbetering ligt in oplossingen door middel van tactische en strategische organisatie van de beschikbare middelen. Om zulke oplossingen te vinden, gebruiken we het raamwerk voor ziekenhuis planning en controle als theoretisch kader voor het literatuuronderzoek (Hans et al. 2012).

Uit het literatuuronderzoek blijkt dat discrete event simulatie de beste methode is voor ons verdere onderzoek. Door gebruik van simulatie kunnen we de effecten van nieuw geïmplementeerde afsprakenschema's relatief eenvoudig en snel testen. Om nieuwe afsprakenschema's te kunnen maken, is er ook gezocht naar nieuwe planningsmethoden. De eerste benadering is gebaseerd op defragmentatie van het afsprakenschema door middel van het hergroeperen van patiënten. De tweede benadering gaat over het werken op inloop.

Simulatiestudie

We maken een model voor discrete event simulatie. Het model representeert het zorgproces voor echopatiënten op de RA en is gemaakt in het programma Plant Simulation 13. Nadat de huidige situatie gemodelleerd is, experimenteren we met een aantal verschillende nieuwe rasters voor het afsprakenschema en maken we gebruik van een systeem dat deels op inloop werkt. De experimenten worden beoordeeld op de Kritieke Prestatie Indicatoren (KPI's) 'gemiddelde toegangstijd' of 'gemiddelde wachttijd', 'gemiddelde capaciteitsbenutting' en 'gemiddeld aantal patiënten dat in overtijd behandeld is'. De runlengte bedraagt 500 dagen, de warm-up periode 239 dagen, en er worden van elk experiment 4 observaties gedaan. De prestatie van het model komt sterk overeen met de resultaten uit de data-analyse en wordt valide verklaard. De nieuwe afsprakenschema's en planningsmethodes die worden getest zijn onder te verdelen in vijf categorieën, waarvan hieronder de aanpak en uitkomsten worden beschreven.

De beste combinatie van defragmentatie en een inloopsysteem, zoals in categorie 5, lever teen afsprakenschema op waarin alleen afspraken voor de onderzoeks-types regulier, bovenbuik, en musculoskeletaal worden gemaakt. De overige groepen komen op inloop in vastgestelde tijdsintervallen. De toegangstijd voor patiënten met een afspraak bedraagt 4,3 dagen, in vergelijking tot de 16,8 dagen uit het model voor de huidige situatie. Het gaat hierbij om weekdagen, dus het verschil bedraagt 2 weken. De nieuwe methode levert ook lagere wachttijden op; gemiddeld 7,0 minuten in vergelijking tot een gemiddelde van 10,4 minuten in de oude situatie. Voor het gemiddeld aantal patiënten dat gedurende de overtijd behandeld wordt is er een kleine toename waarneembaar. Die gaat van 9,7 naar 11,1. Dit valt met name te verklaren door het feit dat er op inloop gewerkt wordt, waardoor de kans groter is dat een patiënt voor de pauze aankomt.

Conclusies en aanbevelingen

Uiteindelijk concluderen we of we de initiële problemen 'hoge toegangstijden' en 'hoge werkdruk' kunnen oplossen door het kernprobleem 'hoge fragmentatiegraad van de capaciteitstoewijzingen' op te lossen. Het antwoord is: gedeeltelijk.

We kunnen het probleem van de werkdruk niet goed oplossen met onze aanpak. Echter, we geloven wel dat de waargenomen werkdruk afneemt doordat we in ons systeem gebruik maken van een duidelijke regel omtrent het omgaan met spoedpatiënten. Deze waargenomen werkdruk kan niet uitgedrukt worden in cijfers, in tegenstelling tot het aantal patiënten dat gedurende overtijd geholpen wordt. We zien geen verbetering voor dat aantal patiënten, vanwege het gebruik van het systeem op inloop waarbij de variatie in vraag toeneemt.

Defragmentatie van het afspraken schema door het maken van grote patiëntgroepen blijkt zeer effectief te zijn voor het verlagen van de toegangstijden. Tabel S2 weergeeft het nieuwe blokkenschema dat we voorstellen.

Table S2 – Het nieuwe voorgestelde blokkenschema uit categorie 5 van de simulatiestudie.

	E10 ochtend	**E10 middag**	**E4 ochtend**	**E4 middag**	**E3 ochtend**	**E3 middag**
Maandag	Regulier	MSU	Regulier	Regulier		Op inloop
Dinsdag	Regulier	MSU	Spoed	Regulier	Regulier	Op inloop
Woensdg	Regulier	MSU	Regulier	Regulier	Regulier	Op inloop
Donderdag	Regulier	MSU	Spoed	Regulier	Regulier	Op inloop
Vrijdag		MSU	Regulier	Regulier	Regulier	Op inloop

We raden ten eerste aan om te overwegen om de groepen regulier en bovenbuik volledig samen te voegen. Ten tweede raden we aan om het gebruik van een inloopsysteem voor spoedpatiënten van de spoedafdeling in te voeren. Ten derde wordt aangeraden om programma's daadwerkelijk programma's te laten zijn, zonder dat er andersoortige onderzoeken tussendoor gepland kunnen worden. Als vierde raden we aan om een duidelijke planningsprotocollen op te stellen die ervoor zorgen dat de regels en restricties van het raster niet meer overschreden hoeven worden en er dus ook beter met spoed omgegaan kan worden.

TABLE OF CONTENTS

1. INTRODUCTION

Streekziekenhuis Koningin Beatrix Winterswijk (SKB-W) is a regional hospital located in the east of the Netherlands, a region better known as *De Achterhoek.* The management team of the Radiology Department (RD) stated that there are two problems related to ultrasounds: high access times and a high workload for technicians. High access times result in a loss of patients because they choose to go to another hospital where they can be helped earlier, and a high workload directly affects personnel.

First, we give a context description in Section 1.1. Second, we give the problem description in Section 1.2. Third, we describe the research objectives in Section 1.3. Fourth and finally, the research questions are given in Section 1.4. The approach that we used for our problem identification is phase 1 of the Managerial Problem-Solving Method (Heerkens and Van Winden, 2012).

1.1. Context description

SKB-W has the motto ‘SKB, at home in *De Achterhoek*’. The hospital operates with respect to its core values: ‘good’, ‘safe’ and ‘hospitable’. The catchment area of SKB-W contains 150.000 inhabitants. SKB-W is a modern hospital with 24 specialisms, 214 beds, and approximately 1100 employees. The catchment area of the hospital overlaps with the catchment area of another regional hospital: *Slingeland Ziekenhuis Doetinchem.* The two hospitals merged on January 1, 2017 (SKB Winterswijk, 2017).

The RD conducts examinations that use techniques such as X-ray scans, Computerized Axial Tomography (CAT), Magnetic Resonance Imaging (MRI), and ultrasound scans. There are three ultrasound rooms: ‘E10’, ‘E4’ and ‘E3’. Ultrasounds are conducted by ultrasound technicians. The technicians report their findings to a radiologist. Some technicians are specialized to do a certain type of scan, for example, musculoskeletal scans (scans of joints such as the shoulders and knees). Similarly, radiologists are specialized in examining and assessing certain diagnostics. Specialistic diagnostic are mostly carried out in a specifically appointed room (for example one specialism always operates in room E10 while another operates in E3). Since the radiologists and technicians are not located in the same room, the hospital strives to minimize walking distances from the ultrasound rooms to a radiologist’s office. Therefore, the allocation of certain specialisms within the ultrasound rooms is a result of the pairing of specialisms of technicians and radiologists.

1.2. Problem description

Initially, the management team of SKB states that there are two main problems concerning ultrasounds. The first problem is high access times, which is the time between the moment that a patient requests an appointment and the moment that the appointment can take place. The access time at the RD of SKB-W averages three to four weeks, while four weeks is the 'passed standard'. The passed standard is a rule that obligates the hospital to refer patients to another hospital when an appointment cannot take place within four weeks. The second problem is the high workload perceived by technicians. Starting from the initial problems we create a problem cluster (Figure 1) and define the underlying core problems. First, we discuss the relevance of the initial problems (1.2.1. and 1.2.2). Second, we elaborate on the underlying problems that affect the initial problems (1.2.3).

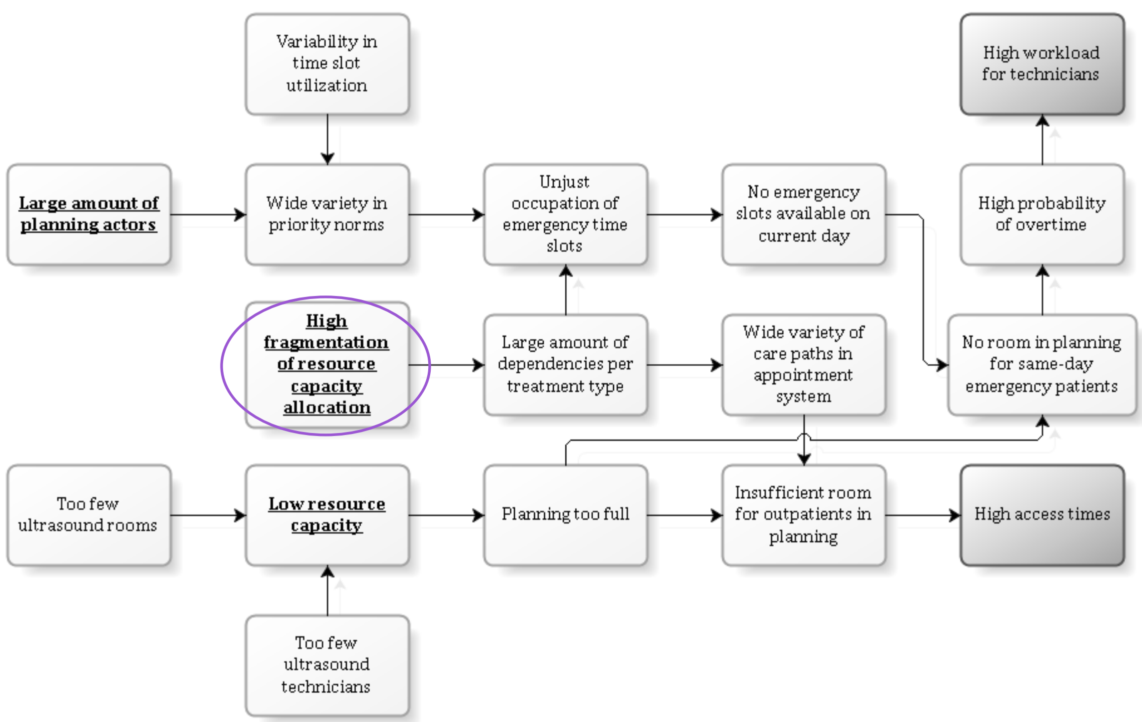


Figure 1 - The problem cluster of SKB-W, with initial problems in darker boxes and the most important underlying causes to the initial problems, are underlined. 'High fragmentation of resource capacity allocation' is the core problem.

1.2.1. High access times

The overly crowded appointment planning for ultrasounds at SKB-W affects the expected access times for outpatients. Outpatients are patients that come to the hospital via a general practitioner and who go home after their examination. Inpatients are patients who come to the

RD via other departments of the hospital and will go back to that department after the examination is finished. Access time is the time it takes before an outpatient has access to the needed examination. Experts at the RD say this expected access time amounts three to four weeks, while the RD would like to see an access time of one to two weeks.

High access times could lead to patients not receiving medical care in time or, to patients choosing to go to another hospital. *Slingeland Ziekenhuis Doetinchem*, for example, has an access time for ultrasounds of one week. Due to this lower access time, it does happen that potential SKB-W patients go to the hospital in Doetinchem, which is undesirable for SKB-W as a company. Fortunately, SKB-W and the hospital in Doetinchem have merged, which makes the adverse effects of losing patients less harming for the hospital's finances. However, it does harm the image of SKB-W, considering the hospital might be known for its high access times.

1.2.2. High workload for technicians

As stated earlier, the high access times for ultrasounds go hand in hand with a high workload on technicians. In addition to a fully booked appointment schedule, unforeseen emergency arrivals occur as well. Even though the RD reserves time for emergency patients, that reserved time is often appointed to semi-urgent inpatients from other departments who arrived one or two days before the "current" day.

Based on the urgency of an emergency patient, technicians serve emergency patients before they continue with their scheduled program, with the risk of working overtime or skipping a break. If the urgency of a patient is not very high, the patient may need to wait an hour on the same day, or the patient may get an appointment on the next day or the day after. The last two situations occur too often, states the SKB-W management team. However, those situations occur because it is also undesired that technicians skip breaks and work overtime, which both result in a high workload.

1.2.3. Causes of the initial problem

Here, we identify the core problem. Heerkens and Van Winden (2012) state that a core problem: 1) is certainly a problem; 2) has no clear cause; 3) can be influenced by the researcher, and 4) will have a great influence towards solving the initial action problem, once solved. Figure 1 shows that there are three underlying problems that cause the initial problems of a high workload and high access times. The first problem is 'high fragmentation of resource capacity allocation'. Resource capacity allocation is the way an organization uses its resource capacity to meet demand. Fragmentation of the resource capacity allocation at the RD refers to the way that the department has categorized different types of examinations in the appointment schedules.

Categorization of patients is a useful tool to accommodate a technician that is specialized in a certain type of examination that the patient needs. However, when there are too many categories or when the different categories seem to be appointed randomly in the appointment schedule, it leads to undesirable dependencies within the appointment schedule. For example, for patients that need a *'duplex carotiden'* examination, there are only four moments per week where the RD can plan an appointment in the schedule because of the availability of specialized technicians and radiologists at that time. Because a '*duplex carotiden-patient'* must be helped within 24 hours, it might happen that the appointment is planned on a moment that is reserved for emergency patients. We call this unjust occupation of emergency time slots (Figure 1). Ultimately the high fragmentation causes a lack of room for both emergency patients and outpatients. The first leads to a high workload and the second leads to high access times. We can identify the problem of high fragmentation of resource capacity allocation as a core problem.

The second cause of the initial problems is the large amount of planning actors. Secretaries, technicians, radiologists and the coordinator of the RD can all decide whether and when a patient is scheduled. These different planners all set their priorities differently and therefore make different decisions regarding patient scheduling. This also leads to the unjust occupation of emergency slots, like the previous problem. Ultimately it affects the high workload on technicians. Since the problem involves online decision making of a big number of individuals, it is difficult to influence as a researcher in the timespan we have available. Therefore, it falls outside of the scope of this research.

The last cause to the initial problem is a low resource capacity. As Hans et al. (2012) state, the universal panacea for many healthcare managers is 'more capacity'. Increasing resource capacity for ultrasounds would consist of hiring an extra technician, opening an extra ultrasound room (and purchasing another ultrasound machine), and maybe even hiring an extra radiologist. It would be a very expensive solution to the problems that the RD struggles with. Therefore, we do not treat this as a core problem.

1.3. Research objective

In this section, we take a closer look at the core problem 'high fragmentation of resource capacity allocation' and what the research deliverables are.

1.3.1. Relevance

The problem 'high fragmentation of resource capacity allocation' is a root to both initial problems (see Figure 1). A time slot is a time interval in the appointment planning system, where an appointment can take place. The starting time and ending time of appointment slots are pre-determined. Additionally, appointment slots are labeled as different types or specialisms (e.g., slots for mammapoli patients are marked as *'mammapoli'* and slots for musculoskeletal patients are marked as *'MSU'*). The different time slot types are a result and cause, of block planning and restrictions in the appointment system, which implies that there is a reinforcing loop that affects the situation negatively. Figure 2 displays this reinforcing loop, and the next paragraph gives an explanation.

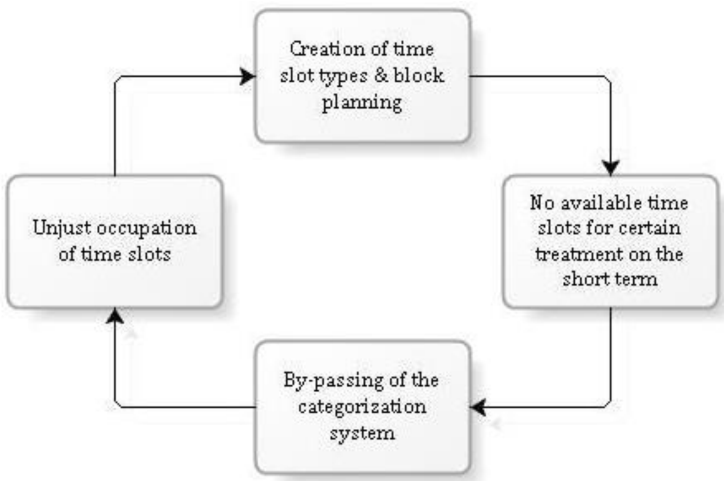


Figure 2 – The reinforcing loop of block planning and by-passing at SKB-W.

There are many different time slot types with different lengths and restrictions. There are time slots for different patient types and different examination groups. Because of this, planners purposely appoint patients to the wrong time slots sometimes, so that an appointment fits within the appointment schedule. When that happens, the appointment system gets by-passed. By-passing happens as follows: a planner who wants to appoint an inpatient, notices that there is e.g. a free emergency slot for the next day; the department where the inpatient in question is situated wants that the inpatient is helped as soon as possible; the planner appoints the inpatient to the emergency slot by changing the patient's status to 'emergency'. The result is an unjust occupation of time slots.

Through by-passing, the initial categorization of time slot types and the use of block planning becomes obsolete. However, SKB-B reinforced those methods over the course of the years: more and more time slot types and care paths to conduct specialized examinations were added to the appointment schedule. Breaking this reinforcing would ultimately help with creating an appointment schedule that will lower the access times for outpatients and the workload for technicians, while effectively utilizing the resources of SKB-W. Further explanation on the process of making an appointment and the healthcare process at the RD is given in Chapter 2.

1.3.2. Research deliverables

The aim of this project is to give a substantiated advice on balancing accessibility and utilization of ultrasounds at the RD to SKB-W. We can make new patient groups and assess multiple variants of resource capacity allocation that could help with finding the right balance between accessibility and utilization. We want to examine what effects new blueprint schedules and appointment scheduling policies could have on these two factors.

Because there are many restrictions that determine whether a blueprint schedule is valid or not, we are looking at the problem from an operations researcher's perspective. Hence, we do not consider all (medical) restrictions. These medical restrictions might imply that a proposed blueprint is invalid, while the outputs might show that the proposed blueprint has a very positive effect on the access times and workload. This way, we encourage ourselves to generate creative ideas.

Eventually, we deliver a set of blueprint schedules or ideas for blueprint schedules that could be tested and assessed in more detail than we will do. Based on our findings, we will advise SKB-W which blueprint schedule should be assessed in more detail. With the model that we use for this thesis, the hospital, or another student could test further to what extent the final blueprint schedule could be implemented.

1.4. Research questions

We expect that solving the core problem 'high fragmentation of resource capacity allocation' will lead to both lower access times for outpatients and a lower workload for technicians. The research questions below give a structured approach towards solving the core problem. The main question of this research is: *'How can SKB-W apply defragmentation of resource capacity allocation in order to solve the initial problems 'high access times for outpatients' and 'high workload for technicians'?'*

1. *How does SKB-W organize their healthcare processes and categorize their patients, and what resources, appointment scheduling methods, and resource capacity planning does SKB-W use for their healthcare delivery process?*

In Chapter 2 we describe how SKB-W organizes their healthcare processes. We also explain what different types of patients, and what different patient groupings SKB-W uses in their appointment schedule. We also elaborate on the resources that SKB-W uses to deliver their healthcare services at the RD, and how those resources are used for their healthcare delivery process and resource capacity planning.

2. *What is, as result of the current appointment scheduling policies and resource capacity planning, the current performance of the appointment schedule?*

In Section 2.4. we conduct an analysis on the number of patients that receives an ultrasound examination at the RD. We also look how the RD has created several patient groupings and how this affects the access times of certain patient groups. Additionally, we assess the performance of the appointment schedule on the basis of utilization of the appointment rooms and average utilization of resource capacity per day.

3. *What analysis methodology is most suitable for testing new patient categorizations as well as different ways of capacity allocation, according to the literature?*

In Chapter 3 we use the theoretical framework for healthcare planning and control proposed by Hans, et al. (2012). With this framework, we set a scope for our literature review. In the beginning of the literature review, we explain why simulation will be the best analysis methodology for this research because of its advantages over analytical models.

4. *What are the different types of patient categorization and capacity allocation we can assess, according to the literature?*

In the literature, we look for approaches towards the improvement of the current capacity allocation. In Chapter 4, we, therefore, aim to find approaches that cause defragmentation of the resources capacity allocation, as well as a new approach towards appointment scheduling.

5. *What is the modeled performance of the current appointment scheduling policies and resource capacity planning?*

To test whether the analytical model from Chapter 3 represents the real situation, we have to assess whether the modeled performance is comparable to the performance in 2016. We answer this question by validating our analytical model.

6. *What is the modeled performance of the new categorization and scheduling approaches in question 4 and what configuration has the best performance?*

In Chapter 4 we test the proposed approaches in different scenarios. For each scenario, we conduct experiments. These experiments are then judged on the basis of the way they score on certain performance measures.

Following from these questions, we draw conclusions and give recommendations for SKB-W in Chapter 5.

2. CURRENT SITUATION AND PERFORMANCE ANALYSIS

This chapter concerns the first two research questions: 1) 'What appointment scheduling methods and resource capacity planning uses SKB-W for their healthcare delivery process and what requirements for new proposed solutions must be met?'; and 2) What is, as result of the current appointment scheduling policies and resource capacity planning, the current performance of the appointment schedule?

Section 2.1. elaborates on the way that patients are categorized, what examination groups SKB-W has, and how the healthcare process is organized. Section 2.2 discusses the available resources. Section 2.3. explains how the appointment scheduling processes are executed. Section 2.4. gives an analysis of the current performance. Section 2.5. ends the chapter with conclusions and findings.

2.1. Patient categorization, examination groups and healthcare delivery process

In this section, we first describe how the core processes are organized (healthcare process in 2.1.1 and appointment scheduling in 2.1.2.) and what relevant data is stored in which database during those processes. Second, we define what the relevant databases are (2.1.3). And third, we describe the categorization of patients that the RD uses (2.1.4).

2.1.1. Patient categorization

In this subsection, we introduce the different types of patients and examinations before we discuss the different processes that are relevant for this research.

Patient types

SKB-W identifies three different patient types: outpatients, inpatients, and emergency patients. Outpatients make an appointment via their GP or doctor, come to the hospital when their appointment is scheduled, and leave the hospital after their examination. The time between the appointment request and the appointment is always more than one day and the patient waits at home until the appointment day and time. There is a disclosed time frame in which an inpatient must be helped, which is the passed standard of four weeks. The access time for outpatients mostly varies from one to four weeks.

Inpatients make an appointment via their specialist in one of the other outpatient clinics of SKB-W. These patients wait in their bed at the outpatient clinic until the examination takes place at the appointment time that both the RD and the specialist of the patient have agreed on.

Inpatients typically have a higher urgency than outpatients since they stay in a bed at the hospital. SKB-W aims to help inpatients within three working days.

The third patient type is emergency patients. These patients arrive through the ED or through one of the outpatient clinics. Emergency patients have the highest urgency since their need for care is the most urgent, and because the ED must meet certain service level agreements. Emergency patients typically need to be helped within a time span of two hours or one day.

Inpatients and patients from the ED share the characteristic that they need urgent care and that their appointments are not scheduled far in advance. Even though SKB-W identifies these patients as separate types, the processes concerning both ED patients and inpatients are organized similarly in practice. Therefore, when we mention the type 'emergency patient' it concerns the ED patients, inpatients and another urgent group of patients that we introduce in Section 2.1.2.

2.1.2. Examination groups

In addition to the categorization of patients based on their patient type, SKB-W categorizes patients based on examination group as well. Each examination group has a treatment code. In Appendix A, we give a list of all the treatment codes for every examination group. The treatment codes are used to identify to which examination group a patient belongs. SKB-W discerns the following examination groups with different time slot lengths:

Outpatients

- *Regular:* standard procedure examinations that can be executed by all ultrasound technicians (25 minutes).
- *Abdominal:* ultrasounds of the abdominal region. Patients in this group need to be sober (have an empty stomach) before examination (25 minutes).
- *Biopsy*: a radiologist or technician needs ultrasound equipment to retrieve tissue from a body part (50 minutes).
- *Duplex*: regular vascular examinations (15 minutes).
- *Mammapoli*: a pathological program for ultrasounds of the breasts (15 to 30 minutes).
- *Musculoskeletal*: an examination of the joints, designed as a pathological program (20 minutes in 2016, adjusted to 25 minutes in 2017).

Emergency patients

- *ED patient*: any type of examination for ED patients with high urgency (25 minutes).

- *Inpatient*: any type of examination for an inpatient from another clinic (25 minutes).
- *Duplex carotids*: the same as a duplex, except the radiologist examines the carotids, and the patients have a high urgency that demands help within 24 hours (45 minutes). *Note:* SKB-W addresses this group as outpatients, but treats it as an emergency patient.

The categorization above is a first example of the degree of fragmentation in the appointment schedule. Besides the earlier mentioned fragmentation by patient type and examination group, there is also fragmentation by time slot length. SKB-W already interprets these groupings loosely by surpassing certain rules on the suitability of a specific time slot by, for example, scheduling two regular patients in a biopsy slot, or scheduling regular patients in abdominal patient slots.

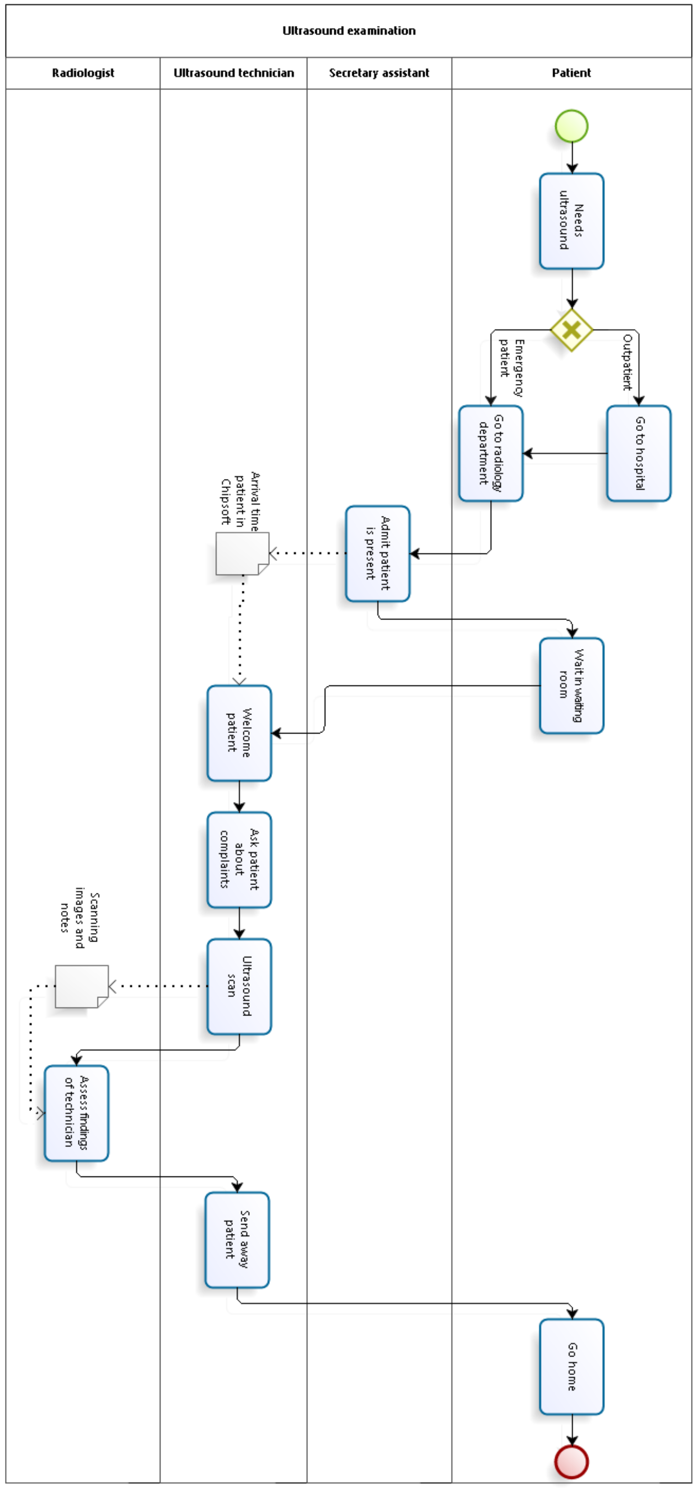
2.1.3. Healthcare process

Most of the ultrasound examinations take place as described in , the figure displays a process model for outpatients and emergency patients. The step of 'making an appointment' is left out of this process model because it is not a part of the examination process. The process model makes use of swim lanes that indicate who executes the task described in the box. The file icons represent relevant information flows.

A technician is aware that a patient is at the RD as soon as the secretary assistant has admitted the patient as 'present' because that will be visible in Chipsoft (SKB-W's program for, e.g., appointment scheduling and storing patient information). When the technician is ready for the patient, he or she will go to the waiting room to take the patient to the ultrasound room. Before a patient enters the ultrasound room, he or she will enter a dressing room where he or she can undress if that is necessary. From the dressing room, the patient can directly enter the ultrasound room for examination.

Before scanning the patient, the technician asks the patient about his or her medical complaints. During the scan, the technician makes images of the researched body parts, which can be done with the ultrasound machine. The images and additional notes about the examination are stored in the electronic patient record (EPR). The technician also fills out a form on which the most interesting findings from the examination can be written. At that moment, the ultrasound is "finished" (the time that the technician finishes the scan and saves the finding in the EPR is also stored), and the technician will ask the patient for a moment to consult with the radiologist.

Figure 3 - Care process of an ultrasound examination at the Radiology Department of SKB-W. The process model counts for outpatients with an appointment, as well as emergency patients and inpatients without an appointment.



While the patient waits in the ultrasound room, the technician walks from the ultrasound room to the radiologist's office. When the technician arrives at the radiologist's office it might be the case that the radiologist is already having a consult with another technician or that he or she is busy looking at other scans. If that is the case, the technician has to wait at the office until the radiologist has time for their consult. During the consultation, the technician and radiologist discuss the findings of the technician, the images and notes stored in the EPR which are also accessible for the radiologist, and the form that the technician filled out. If the technician's scans, notes, and file are inconclusive the technician might have to make extra images or the radiologist might do it him- or herself. When the radiologist has a clear understanding of the patient's situation, the technician leaves the form at the radiologist's office and goes back to the patient. The radiologist will take a more critical look at the images and report of the technician to make an official diagnosis. This does not happen directly, since radiologists execute this task for multiple diagnostics and also carry out other activities.

Back in the ultrasound room, the technician informs the patient that there has been a consultation with the radiologist and that the results of the examination will be given by the one who referred the patient to the RD, within a given timeframe (most of the time 5 to 10 working days). The patient can dress again in the changing room and can go away.

2.2. Available resources

In this section, we discuss the available resources of the RD of SKB-W. We distinguish five resource types that are relevant for this research: ultrasound rooms, human resources, medical equipment, the electronic patient record Chipsoft, and the appointment blueprint application within Chipsoft.

2.2.1. Ultrasound rooms

There are three different ultrasound rooms available at the RD: 'E10', 'E4' and 'E3'. The RD uses these rooms to conduct examinations of planned patients as well as emergency patients. Specialisms are allocated to certain rooms to ensure that the walking distances from the ultrasound room to the radiologist's offices are minimized. E4 is the biggest ultrasound room and offers space for both a technician and a radiologist, which can be very useful for the execution of several programs. E10 and E3 are comparable in size and offer room for one technician (see Appendix B for the floor plan).

2.2.2. Human resources

The staff at the RD that is involved with ultrasounds consists of secretary assistants, technicians, radiologists, and coordinators.

Secretary assistants

The secretary assistants at the RD answer calls with appointment requests from secretary assistants at other departments in SKB-W, general practitioners (GPs), and patients that received an official referral from their GP. Secretary assistants can appoint most requests within the appointment schedule. If not, they report the request to the department coordinator.

Technicians

The ultrasound technicians at the RD are nurses who are trained to carry out ultrasound diagnostics. Some of the technicians are specialized to do certain types of examinations. Most days there are three ultrasound technicians available during office hours. Every day, the RD has at least one 'all round' technician available who can conduct most of the ultrasound examinations. In order to accommodate a specialized technician for a certain program, the RD must take into account that the technicians are scheduled during the program of their specialty. Technicians report their findings on the examination to their appointed radiologist.

Radiologists

The radiologists at SKB-W analyze the different scans that are made at the RD. During office hours, there are three radiologists available in most cases. Out of these three radiologists, two are responsible for examining ultrasound scans (among other scans). When a technician reports his or her findings to a radiologist, that radiologist stores the information and will examine the given information as soon as possible. The findings are then reported to either the patient's GP or to specialists from other departments in the hospital through a phone call or the electronic patient record.

Coordinators

There is a coordinating 'senior nurse' available every day. When it comes to appointment scheduling, he schedules appointments that do not fit within the appointment schedule. Thus, the coordinator is able to by-pass the rules of the appointment grid. Additionally, the coordinator makes decisions regarding emergency patients. On busy days, the coordinator is constantly answering questions from secretary assistants, technicians, and radiologists. The high fragmentation of resource capacity allocation affects the coordinator the most of all the above human resources.

2.2.3. Medical equipment

Most ultrasound scans can be made with one type of ultrasound machine, which is available in every room. For some examinations, however, technicians and radiologists might need specialized equipment. Most ultrasound machines are mobile and can be transported from one room to another if necessary.

2.2.4. Chipsoft

SKB-W records a lot of information concerning appointment times, waiting times, access times, and other measurements. Chipsoft, the software application of SKB-W, contains tools such as an appointment planning environment and an electronic patient record. The hospital stores the earlier mentioned information through the use of these tools.

2.2.5. Blueprint schedule

The blueprint schedule is an appointment schedule without appointments, but with rules attached to the appointment slots. The appointment blueprint is mostly the same for every week and over time, management makes some slight adjustments to the blueprint if necessary. However, the blueprint does not change significantly throughout the year. The blueprint schedule is constructed bottom-up, as follows:

- Each examination group has its own treatment code.
- There are treatment codes attached to each appointment slot.
- The treatment code inherently says something about the patient class (inpatient, emergency, or uncategorized), the length of the required time slot (15, 20, 25, 45, or 50 minutes), and the program it belongs to.
- With this treatment code, the appointment planning application within Chipsoft can look for the first suitable appointment slot within the appointment schedule. An appointment slot is suitable when the treatment code belongs to the set of treatment codes that are appointed to an appointment slot.
- When multiple slots with the same sets of treatment codes are placed after each other, it is called a program. Programs are the biggest building blocks of the blueprint schedule. SKB-W uses programs to increase efficiency: technicians can perform similar examinations in a row.

Figure 4 gives a schematic overview of the appointment blueprint. It discerns the three different ultrasound rooms (E10, E4, and E3) and divides the schedule for each room per day.

In our figure, we use the MSU block (the musculoskeletal pathological program) as an example to illustrate fragmentation within programs. Within the MSU block, the blueprint defines separate appointment slots. Those appointment slots are marked as a certain type of slot (by using the examination groups we mentioned in Section 2.1.2.). Within the MSU program, there may be a distinction between different examinations that are part of the MSU program. Figure 4 illustrates this by showing slots for 'Shoulders' and 'All MSU'. Management makes these distinctions to, e.g., ensure that people with shoulder problems can be helped on a short notice. Even within the separate appointment slot, there might be a distinction of which patient type can be accommodated to the appointment slot. It could be reserved for either outpatients, inpatients, or emergency patients.

Because the appointment blueprint is designed in so much detail, it can be very difficult to find a suitable appointment slot for certain patients. However, it also makes very clear when which examination can take place. Appendix C shows the blueprints for the ultrasound rooms.

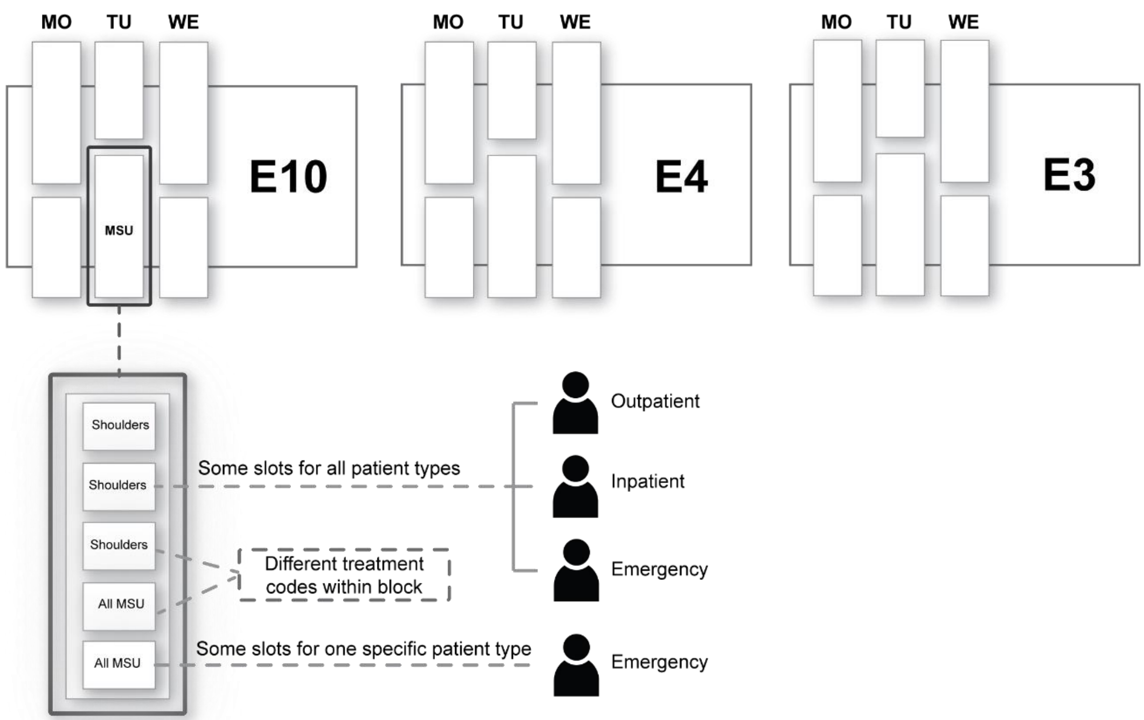


Figure 4 - Schematic overview of the different levels within the appointment schedule of the radiology department of SKB-W. E10, E4, and E3 are the names of the ultrasound rooms. For each room, there is a blueprint for every day, consisting of a block planning that is dictated by the division of pathological programs (here, MSU).

Emergency slots in the blueprint have a special feature: a blocking option. The appointment schedule puts blockades on emergency slots so that they cannot be appointed to any other examination groups. Those blockades may disappear two days in advance, or the rule can be surpassed by the coordinator of the RD to ensure that other patients can be helped within one or two days.

2.3. Appointment scheduling process

In this section, we describe the appointment scheduling process at the RD of SKB-W.

2.3.1. Scheduling outpatients

Most patients go to the RD with an appointment. Appointment scheduling is a process that may be different per patient type (inpatient, outpatient, or emergency). Figure 5 shows the process for making an appointment.

A secretary assistant receives appointment requests via phone. A phone call may come from a GP, a patient with a referral from their GP, or secretary assistants from other departments within the hospital. The requesting party says what examination is needed and the secretary assistant will select the correct treatment code accordingly.

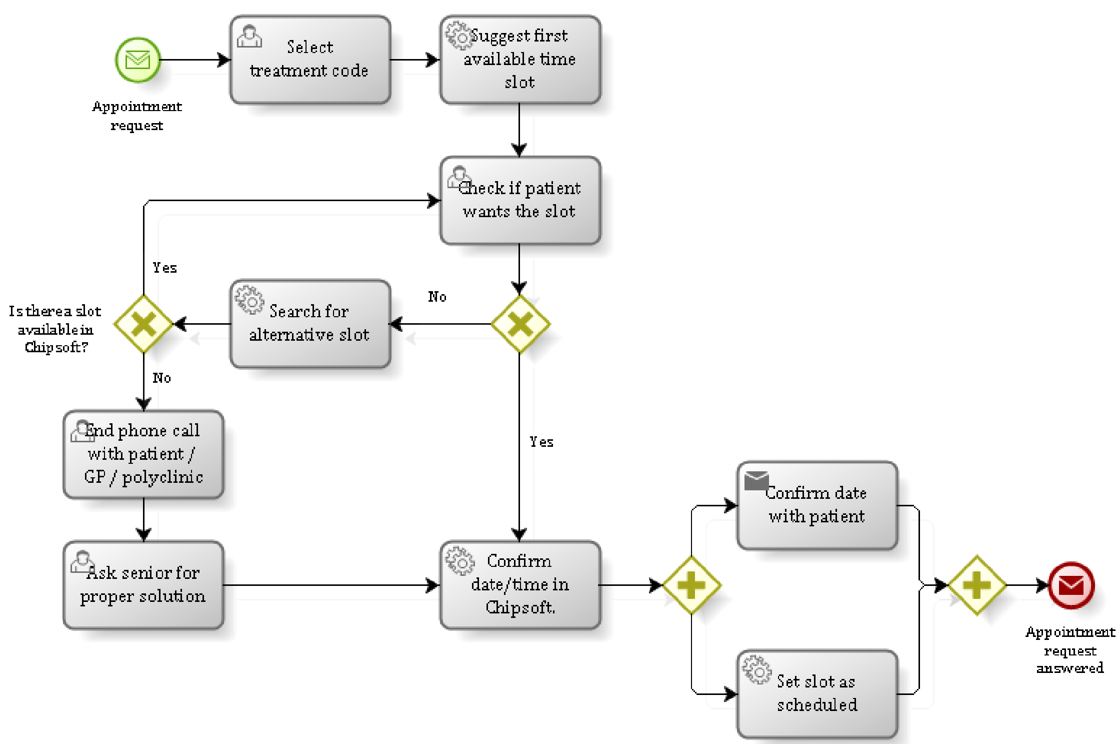


Figure 5 - Appointment scheduling of outpatients from the perspective of a secretary assistant. Icons: the person represents a person's task; gears represent a computer task; an envelope represents a message task.

When Chipsoft has found a suitable time slot, using the treatment code, it returns this slot to the secretary. The secretary then will discuss with the appointment requester whether the appointment slot is suitable. If not, there might be other suggestions from Chipsoft. However, when Chipsoft has no more valid time slot options (within the passed standard of four weeks), the secretary will ask the department coordinator for an alternative. The coordinator then looks for slots in the appointment schedule where the RD could accommodate the requester's appointment. If a suitable slot is found, the secretary will confirm the appointment.

2.3.2. Scheduling emergency patients

Earlier, we mentioned that we can look at inpatients as emergency patients with a lower urgency than emergency patients from the ED. Patients from the ED need to an examination within 60 to 120 minutes, depending on the urgency as well as the level of crowding at the ED. The ED gives this timeframe because of the Service Level Agreements that the ED wants to meet. This ensures a short throughput time of patients from the ED. Preferably, inpatients are also examined within a short time frame, but there are no specific service level agreements about those patients. Most of the time, SKB-W tries to help inpatients within two days, as they occupy beds at the hospital’s clinics.

The appointment blueprint reserves several slots for emergency patients, as we mentioned earlier. If these are free, the emergency patients can be helped during that time slot. However, in most cases, these emergency slots are already filled because of by-passing of the schedule (Section 1.3.1.). When there are emergency patients that need an ultrasound examination but there are no more emergency slots available, the RD has to figure out when they are examining the patient. Sometimes this might mean that the emergency patient is helped as soon the first ultrasound examination is finished, sometimes it is done during the breaks. Most of the times the RD can meet the priorities of other departments, meaning they ensure that the patient is examined as soon as these departments request it. However, helping these emergency patients is perceived as stressful and inefficient. The perception of inefficiency comes from the fact that the coordinator, radiologists, and technicians have to decide when an emergency patient will be examined.

2.3.3. Recording data about the scheduling process

During the process of appointment planning and the ultrasound examinations, a big number of data is stored. The data that Chipsoft records about the appointment scheduling process and the appointments in itself are recorded to ‘Chipsoft Agenda’ (CSA) and ‘Chipsoft Radiology’ (CSR).

CSA stores the data of appointments that are made according to the common appointment scheduling methods. The patients that CSA registers were appointed to a slot within the blueprint schedule (Section 2.2.5.). When a patient with an appointment in the blueprint schedule gets examined, the data about the examination is stored in both CSA and CSR.

CSR stores some of the data that can be found within CSA, but also other data. In CSR, we find information about certain times involving a patient’s appointment, such as the patient’s arrival time and departure time (like in CSA). Not included in CSR, is the information about to which blueprint the appointment belonged, since the rules for the common scheduling method were broken in the moment of scheduling. This means that emergency patients and other patients that receive a last-minute appointment cannot be planned within the blueprint schedule because their characteristics do not suffice with the constraints that are attached to an appointment slot within the blueprint. Even though the appointment cannot be stored in CSA, CSR will store the most relevant data about the appointment such as the arrival time, starting time, ending time, et cetera.

2.4. Analysis of the current situation

In this section, we analyze the performance of the current appointment system. The data we use is data from CSA and CSR of the year 2016. First, Section 2.4.1. discusses the distribution of patient types. Second, Section 2.4.2. discusses the distribution of examination groups within those patient type distributions. Third, Section 2.4.3. analyzes the daily utilization and utilization of each ultrasound room.

2.4.1. Distribution of patient types

We identified 9970 unique examinations at the RD of SKB-W in the year 2016. Of those patients, 8143 are identified as outpatients, and 1827 are identified as emergency patients.

Outpatients

All outpatients can be found in CSA, because their appointments are always scheduled according to the blueprint schedule. We identify 8143 patients that can be classified as outpatients. Those patients are the patients that belong to the examination groups regular, abdominal, biopsy, mammapoli, duplex, and musculoskeletal (MSU).

The number of outpatient arrivals varies over the year. We identify the number of arrivals per quartile (three months) in Figure 6.

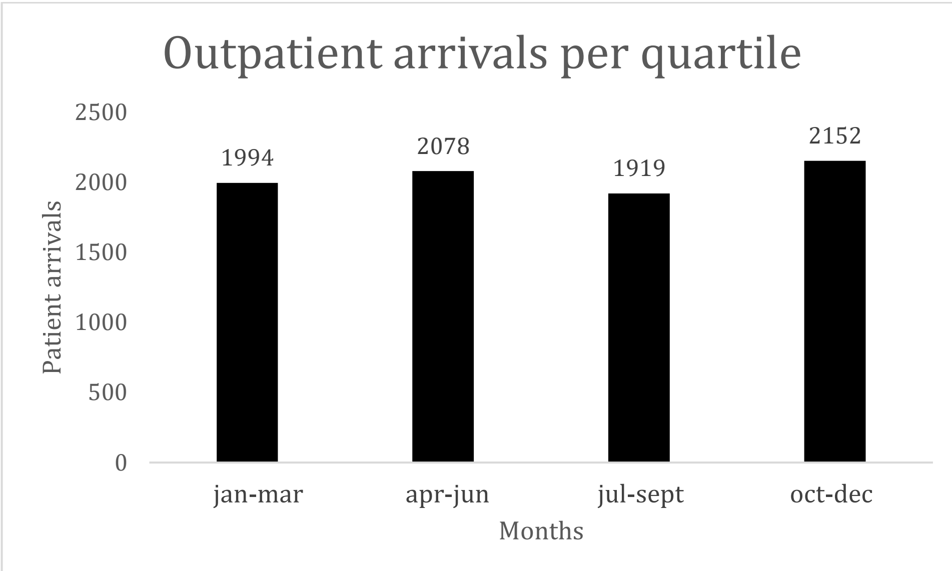


Figure 6 - Outpatient arrivals per quartile. (n=8143, data from CSA, 2016)

Because outpatients arrive according to the appointment schedule, we cannot give an arrival rate of outpatients per hour. Their arrivals are dictated by the appointment schedule, but they very likely do not represent the actual outpatient arrival process when there would be no appointment schedule. Therefore, to determine the arrival rate of outpatients at the RD of SKB-W, we use the following calculation:

$$\frac{\#\ outpatients\ per\ year}{\#\ days\ that\ the\ RD\ is\ open\ \times\ \#\ opening\ hours\ per\ day}$$

The total number of days that SKB-W is open is based on the number of working days in 2016, which means: all weekdays, excluding national holidays. This amount adds up to 261 days. The opening hours of the RD are from 8:30 to 17:00, which is 8,5 hours. We ignore the breaks here because patients can arrive during the breaks as well. When we fill out the equation we get 8143 / (261 * 8,5) = 3,67 patients per hour. This translates to the arrival of one outpatient every 16 minutes. In Table 1 we give the outpatient arrivals with seasonality adjustment, based on the arrivals in Figure 6.

Patient arrivals per quartile cannot be influenced, but capacity could be adjusted to match the expected arrival rates. In Chapter 4 we will use the arrival rate per quartile again.

Table 1 - Outpatient arrival per quartile per hour. (n= 8143, data from CSA, 2016)

Months	Outpatient arrivals per hour
Jan-Mar	3,57
Apr-Jun	3,78
Jul-Sep	3,49
Oct-Dec	3,91

Emergency patients

We look for ED patients and inpatients in the CSR dataset. Most duplex carotids patients can be found in CSA. In CSR, we look up all unique examinations with appointment time 00:00, which means that the appointment could not be attached to an appointment slot of the blueprint. The total amount of those examinations adds up to 1584 patients.

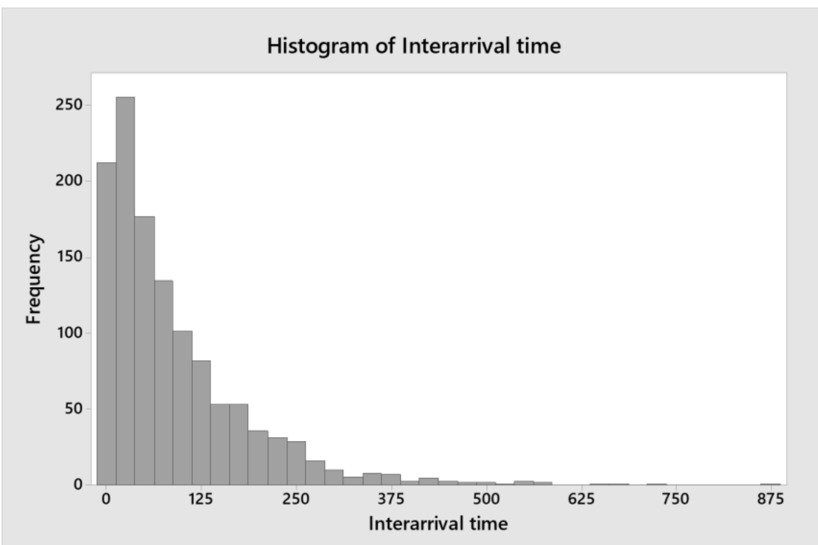


Figure 7 - Inter-arrival times of emergency patients at SKB-W. (Data from CSR, n=1124, 2016)

The number of duplex carotids patients in CSA amounts 243. The total number of emergency patients is therefore 1584 + 243 = 1827.

Emergency arrivals for ultrasounds do not vary significantly during the week. However, patient arrivals from the ED follow a certain pattern during the day, observes Aron van Stiphout (2017). He identifies an arrival rate for every hour, which we will do as well for all emergency patients, as we assume that all emergency arrivals follow this same pattern. Before we adjust the arrival rate per hour specifically, we determine the average arrival rate per hour.

To identify the average arrival rate, we analyze the interarrival times of arrivals that occur on the same day. The histogram of the interarrival times has the shape of a negative exponential distribution (Figure 7). Making Figure 7, we only looked at the interarrival times of emergency patients that arrived on the same day. Which means that we do not calculate the time arrival of the last patient on one day, followed by the first arrival on the next day. From the shape of the histogram, we may assume that the arrival process for these emergency patients follows a negative exponential distribution. We cannot derive the parameter (mean of the interarrival times) for our exponential distribution from the graph, because we did not incorporate all emergency patients when making this graph. Even though the histogram cannot incorporate all emergency patients, we assume that all emergencies arrive according to the negative exponential distribution because this distribution is commonly used to identify customer arrivals (Robinson, 2014).

The parameter of the negative exponential distribution is the mean inter-arrival time. We determine this mean inter-arrival time with the same equation that we used for outpatient arrivals. If we use this formula, we assume that all emergencies are helped during opening hours of the RD, which is helpful in our further analyses in this chapter and following chapters.

$$\frac{\#\, emergency\ patients\ per\ year}{\#\, days\ that\ the\ RD\ is\ open\ \times\ \#\, opening\ hours\ per\ day}$$

When we fill out the equation, we get 1827 / (261 * 8,5) = 0,82 arrivals per hour on average. That means that a patient arrives every 60 / 0,82 = 73 minutes. As we said earlier, emergency arrivals vary per hour (van Stiphout, 2017). If we look at the pattern for emergency arrivals between 8:30 and 17:00, we get the adjusted arrival rates per hour in Figure 8.

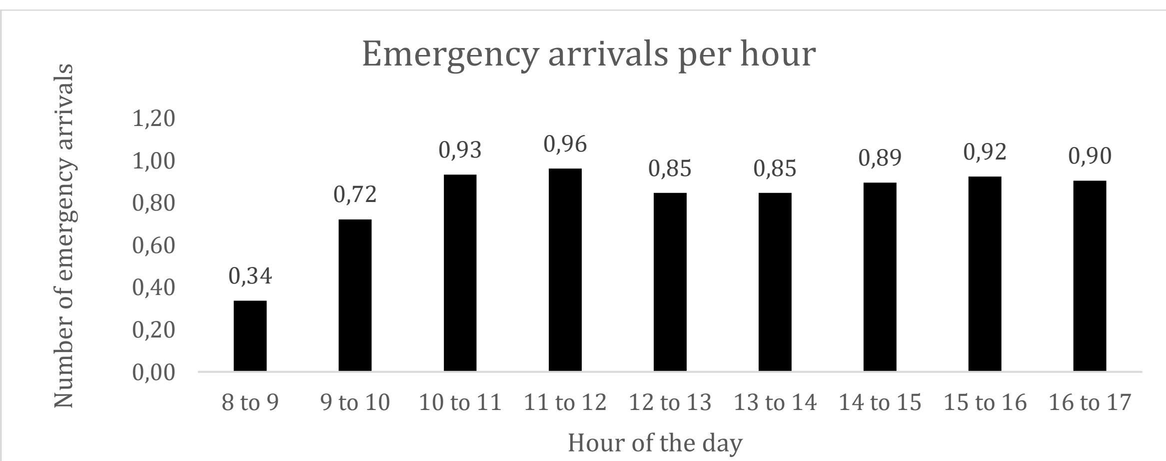


Figure 8 - Emergency arrivals per hour, adjusted to the arrival pattern of Van Stiphout (2017). (Data from CSR, 2016. n=1827)

Figure 8 shows that in the morning, there are few arrivals. From 10 to 12 we see that more emergencies arrive. During the break, from 12 to 13, the arrival pattern slightly declines again and afterwards it slowly rises towards the end of the day. This means that before noon, the RD needs room for emergencies to examine all patients on time. During the afternoon, emergency slots must be available as well. In practice, the RD reserves a slot for emergencies around 10 a.m., before noon, and around 2 a.m., which is not enough to serve all emergency patients. As a result, most emergency patients are examined in between scheduled appointments, increasing the workload for technicians.

2.4.2. Distribution of examination groups.

We determine the distribution of patient types for outpatients and emergency patients.

Outpatients

As we mentioned in Section 2.2.5., the blueprint schedule reserves room for patients that require specific examination groups. Treatment codes are required to determine if a patient can be appointed a specific time slot. In Appendix A, we give the treatment codes for the three rooms. Table 1 shows when each program took place in 2016, and where. It gives a broad idea of the allocation of programs within the blueprint schedule.

Table 2 - The usual weekly planning of programs within the appointment grid per room and part of the day.

	E10 morning	**E10 afternoon**	**E4 morning**	**E4 afternoon**	**E3 morning**	**E3 afternoon**
Monday	Regular	MSU	Regular	Regular		
Tuesday	Regular	MSU	Mamma	Regular	Regular	Duplex
Wednesday	Regular	MSU	Regular	Regular	Regular	
Thursday	Regular	MSU	Mamma	Regular	Regular	Duplex
Friday		MSU	Regular	Regular	Regular	

Neither CSR data, nor CSA data, can clearly indicate which examinations took place in which program. Thus, to analyze whether the appointment blueprint reserves enough room for patient arrivals per examination group, we look at the block planning in Table 2. The way the blueprint schedule allocates programs, should reflect the number of patients that fall within the program. Accordingly, judging from Table 2 we could expect that 16 out of 25 patients are regular, biopsy or abdominal patients (which all fall within the regular program), 5 out of 25 patients are MSU patients, 2 out of 25 patients are mammapoli patients, and 2 out of 25 patients are duplex patients.

To assess whether this division of programs reflected the patient arrivals in 2016, we look at the distribution of examination groups. We identify the examination group of a patient by the treatment codes that are associated with each examination group. Below, Table 3 shows the distribution of examination groups for outpatients.

For each examination group, we give the proportion of the total number of outpatient appointments as well as the average access time for each examination group. The access time is measured by CSA. We consider biopsy patients and abdominal patients as part of the group regular patients because their examinations take place in the regular appointment slots. We can see that the biggest groups (regular, abdominal, and MSU) have relatively high access times.

Table 3 - Overview of all appointments, categorized by group. (Data from CSA, n=8143, 2016)

Examination group	*Number of appointments*	*Average access time (days)*	*Proportion of the total number of appointments (%)*	*Reserved capacity according to block planning (%)*
Regular	4787		58	64
Regular	*2711*	*19*	*33*	
Abdominal	*1984*	*26*	*24*	
Biopsy	*92*	*6*	*1*	
Mammapoli	840	10	10	8
Duplex	579	24	7	8
MSU	1973	19	24	20
Total	**8143**	**14**	**100**	

We analyze whether these high access times might be caused by a lack of reserved room for the corresponding patient type. Table 3 shows the reserved capacity for each examination group, versus the needed capacity for each examination group. The table clearly shows that if the schedule does not reserve enough capacity, the access times are higher.

Almost all examination groups have high access times. Abdominal patients have the highest access time. It is the third biggest examination group. We consider abdominal patients part of the regular program because most regular slots in the morning accommodate abdominal treatment codes, so that abdominal patients can use regular patient slots (Section 2.1.2.). However, these slots also accommodate other treatment codes that are part of the regular program, while the regular program has many other slots that do not accommodate abdominal treatment codes. These slots are mostly in the afternoon.

The access time for duplex patients is also high. Even though it appears that the appointment schedule reserves enough room for these examinations, the contrary seems to be the case. The high access time can be explained by the organization of the duplex program. The program accommodates emergency slots for duplex carotids patients, and outpatient slots for duplex patients (Appendix C). The emergency slots are twice as long and take up a relatively large portion of the duplex program, resulting in a lower reserved capacity percentage than we see in Table 3.

Only biopsy and mammapoli patients perform well on the measure access time. Biopsy patients have a low access time because it is the smallest group of patients and there are relatively many biopsy slots. Access times for mammapoli patients are probably low because during the mammapoli program it is not possible to schedule any other examination groups.

Emergency

For the emergency patients, we use a different approach to determine the group distributions. This is more difficult and less precise, because CSR does not clearly show which emergency patient arrived through the ED and which emergency patient arrived through one of the clinics. However, Aron van Stiphout (2017) identifies which patients went from the ED to the RD. After comparing the patients that Van Stiphout (2017) found in his data-analysis to the emergency patients we identify, we conclude that in 2016, around 2 out of 3 emergency patients (excluding duplex carotids patients) arrived through the ED. That means that 1 out of 3 emergency patients (excluding duplex carotids patients) are inpatients. Table 4 summarizes these findings and gives the distribution of emergency patients.

Table 4 – The distribution of examination groups among the emergency patients (Data from CSR. n=1829, 2016).

Examination group	Number of patients	Proportion of the total number of emergency patients (%)
Emergency	1062	58
Inpatients	524	29
Duplex carotids	243	13
Total	1829	100

ED patients and duplex carotids patients make up for 71 percent of all emergency patients. This big proportion of uncertain demand causes a high level of uncertainty in the appointment schedule. The workload for technicians must be perceived as high, since these patients must be examined within a short time period, depending on the service level agreement and the patient's condition. Inpatients affect workload less, since SKB-W emphasizes less on the throughput times of these inpatients, and because their urgency is lower. Even though the RD uses emergency slots, it is difficult to allocate room for all emergency patients in the appointment schedule because SKB-W wants to avoid capacity loss.

2.4.3. Daily utilization and room utilization

Here we determine the daily utilization of resource capacity and the average utilization of the different ultrasound rooms.

Daily utilization

The daily utilization rates can be seen in Table 4. To determine the utilization of the resources of SKB-W we need information about:

- *The average number of minutes of planned appointments per room*

  We sum up the examination times of all scheduled appointments for each day. We find averages for every day by dividing the daily expected examination times by the number of available days (e.g.: 'Total examination time of all Mondays' / 'Number of Mondays'.). Afterwards, that figure is divided by the number of available rooms.
- *The average gross time that rooms and technicians are available according to the appointment blueprint*

  CSA registers the time frames in which a room is available every day. From the beginning of the day, until the end of the day. By summing up those time frames we get the number of minutes that a room is available. For this measure, we subtract the opening time of the ultrasound rooms from the closing time. By dividing that figure by the number of operational rooms on that day, we get the average gross time.
- *The average net time that rooms and technicians are available*

  This is the gross time, minus the times that room is not available within the gross time frame. A room is not available when there is no technician available for that room, when it is time for a break (usually 15 minutes at 10:15 and 15:00, and 60 minutes at 12:00), or when there is a blockade for that room in the appointment schedule. Blockades occur when there are not enough personnel available or when the room is used for other activities than ultrasounds. It might not always be the case that a room is not available when a blockade is issued, but we assume that it is in most cases.

- *Mean number of ED emergencies per day per room*

  In Section 2.4.1., we mentioned that emergency arrivals do not vary significantly. However, if an ultrasound room is not operational, the workload for examining all emergency patients shifts to the other rooms that are operational during that day. On Monday and Friday, SKB-W has a net of 2 rooms available, and on Friday 2,5. On Tuesday and Thursday, all 3 rooms are available.

Table 5 shows the average utilization of resource capacity – with all patients included in G. The table shows how the utilization is calculated: we divide the total amount of time that is spent on examinations by the net time that rooms and technicians are available. This results in high utilization rates.

Table 5 - Utilization of resource capacity for ultrasounds at the radiology department of SKB-W. (Data from CSA & CSR, n=9970, 2016)

	A	B	C		
	Average number of minutes of planned appointments per day per room	**Net time available per day per room**	**Gross time available per day per room**	**B / C: Utilization of net time (without emergencies)**	**A / B: Utilization of resource capacity (without emergencies)**
Mo	315	384	470	81,6%	82,0%
Tu	313	387	492	78,6%	80,9%
We	334	392	478	82,0%	85,4%
Th	291	375	478	78,5%	77,7%
Fr	250	301	387	77,7%	83,0%

	D	E	F	G
	Mean number of emergencies per day per room	**Mean expected time used for emergencies per day per room (D * 25)**	**A + E: Minutes of planned and emergency appointments per day per room**	**F / B: Utilization of net time (with emergencies)**
Mo	4,4	88,0	403	**105%**
Tu	2,9	58,7	371	**96%**
We	2,9	58,7	393	**100%**
Th	2,9	58,7	350	**93%**
Fr	3,5	70,4	320	**106%**

We can see that the utilization rates are just below or above 100%. This guarantees that technicians are working overtime: technicians and radiologists are working during their breaks and during moments that the blueprint schedule contains blockades. Sometimes these blockades are inserted into the blueprint schedule to serve emergency patients, so the net time available is not represented completely truthfully, and the high utilization rate we see here could partially be interpreted as overly dramatic. However, it is difficult to distinguish the exact number of blockades used to serve emergency patients and therefore we still address the high utilization rate as alarming; the RD must enable itself to accommodate more capacity for emergency patients. Since SKB-W indicates that there is a possibility to use room E3 more to examine patients, this required capacity increase is possible. In the next subsection (Room utilization), we look at the utilization of the different ultrasound rooms. Accordingly, we give suggestions for the use of this room as a place where emergency examinations can take place.

Room utilization

We determine the utilization of the ultrasound rooms (Table 5) in a way that is similar to the calculation of the daily utilization. Instead of looking at a specific day, we look at an ultrasound room. Table 6 displays the utilization of the three rooms.

Table 6 - Room utilization without and with emergency arrivals. (CSA & CSR, n=9970, 2016)

	Utilization of net time without emergencies (%)	*Utilization of net time with emergencies (%)*
E10	92,6	101
E3	66,9	82
E4	84,4	111

E4 looks like the busiest room. In practice however, technicians assist each other when one room is idle and another room is very busy. The data presents information about where the examination should have taken place instead of where it *actually* took place. Nevertheless, utilization appears high for rooms E10 and E4. We know that most appointments take place in E10 and E4, so spreading the appointments over the three rooms – and with that, lowering utilization in E10 and E4, and raising it in E3 – will not directly lead to a utilization below 100% in E10 or E4. The utilization rates show that the RD of SKB-W might really be facing a problem of ‘low capacity’ and that technicians are working overtime. This is a clear sign of a high workload.

However, since there are still some open slots in the appointment schedule that can be filled, we cannot reject that defragmentation could be the solution to the problems concerning the high access times and high workload. In Chapter 3 we look for methods to assess possible solutions within the concept of defragmentation.

2.5. Conclusions

In this chapter, we describe all relevant aspects considering the processes surrounding ultrasounds at the RD of SKB-W, as well as the performance of those processes. We conclude this chapter by answering the two research questions that we wanted to answer with our analysis of the system and its performance.

Section 2.1, 2.2, and 2.3 answer RQ 1: *How does SKB-W organize their healthcare processes and categorize their patients, and what resources, appointment scheduling methods, and resource capacity planning does SKB-W use for their healthcare delivery process?*

We described the different types of patients: outpatients, inpatients, and emergency. By grouping these different types of patients per examination group (regular, mammapoli, biopsy, abdominal, musculoskeletal, duplex, duplex carotids) using treatment codes, the RD appoints the different types and groups of patients in the appointment slot that is most suitable in combination with the patient's medical characteristics. Suitable slots are found with the medical application Chipsoft. If Chipsoft cannot find any slot that is acceptable for either the hospital or the patient, the coordinator of the RD will look for a solution. He can bypass the rules that are set within the appointment blueprint that serves as the rule of thumb for Chipsoft.

A patient can be appointed to one of the three ultrasound rooms: E10, E4, or E3. Depending on the programs that the RD runs on a certain day, a technician that is specialized to carry out examinations within that program is available in the room. We explained the healthcare delivery process. Within this healthcare delivery process, there is an element of inefficiency: patients need to wait in the ultrasound room while the technician discusses his or her findings with the radiologist. We cannot solve this problem in this research since it falls outside of our scope. However, we think that if this discussion will not take place during the examination process, each examination would take less time, and the workload will be lowered.

Section 2.4. answers research question 2: *What is, as result of the current appointment scheduling policies and resource capacity planning, the current performance of the appointment schedule?*

We find that under a yearly demand of 9970 patients – with 8143 outpatients and 1827 emergency patients (in our analysis, consisting of patients from the emergency department, duplex carotids patients, and inpatients) – the utilization per day, as well as the utilization per room is too high. Our data analysis shows that most of the utilization amounts over 100%, which indicates that there is overtime work during breaks. We conclude that new resource capacity allocation may help with spreading the workload, but might not be sufficient to lower the utilization rates. We need to look for new variations of the existing appointment schedule to manage the examination of emergency patients in order to lower the workload. The knowledge that there are some holes in the appointment schedule will be used in Chapter 3. In Chapter 3 we will look at different patient categorization methods as well as scheduling policies that enable the RD to lower the workload and increase accessibility.

3. THEORETICAL FRAMEWORK AND LITERATURE REVIEW

This chapter is divided into three sections. Section 3.1 gives the scope for our literature review with the theoretical framework for healthcare planning and control (Hans, et al., 2012). Section 3.2 looks for appointment scheduling and capacity allocation solutions with a structured literature review. In Section 3.3. we draw conclusions.

3.1. Theoretical framework

In our problem analysis, we find that low resource capacity might be a problem for the RD of SKB-W. However, as Hans et al. (2012) state 'more capacity' is the universal panacea for many healthcare managers, and the challenge for improvement lies within tactical allocation and strategic organization of the available resources. To find such solutions, we use the hospital planning and control proposed by Hans et al. (2012). Figure 9 shows the framework, as well as the scope of our research within the framework which is indicated by the purple box.

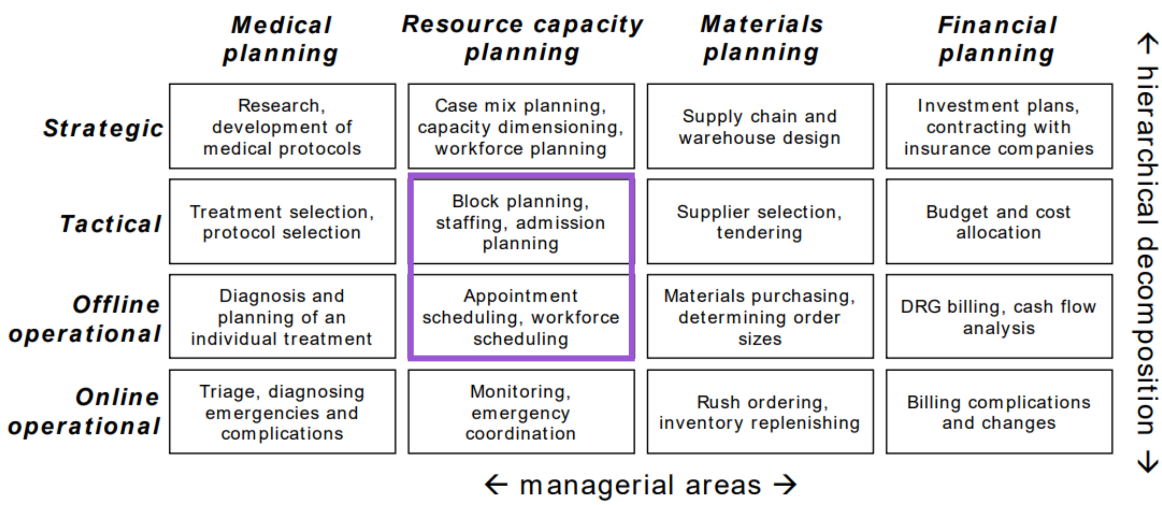


Figure 9 - Framework for hospital planning and control (Hans et al., 2012). The purple box identifies the scope of this research: we try to influence both the tactical and offline operational resource capacity planning.

We break down the four different hierarchical levels, and what problems at the RD occur at those levels. The first level is *strategic*, which involves decision making to translate the organization's mission into the design of the healthcare delivery process. Strategic leveled problems at the RD are problems such as long walking distances from the ultrasound room to the radiologist's office, which are a result of the floor planning; and too few ultrasound technicians, an amount based on the number of rooms available and demand for healthcare delivery. Decisions that lead to these problems are decisions made by managers of SKB-W.

These problems are difficult, and possibly expensive to influence, but have a strong effect on the resource capacity planning.

The second level is *tactical,* in between strategic and operational, which addresses the organization of operations, and execution of the healthcare delivery process, on a longer planning horizon than the operational level. Our core problem 'high fragmentation of resource capacity allocation' falls within the tactical level. The way the appointment grid looks, as well as the variety in pathological programs are a result and cause, of block planning and restrictions in the appointment system, which are tactical planning decisions.

The third level is *offline operational*, which involves the short-term decision making inherent to the healthcare delivery process, and planning operations in advance. SKB-W predetermines who can be a planning actor. The problem 'large amount of planning actors' was one of the roots to the initial problems that we described in Chapter 1.

The last level is *online operational*, which deals with monitoring the healthcare delivery process and reacting to unforeseen and unanticipated events. Some planners might want to treat an outpatient as soon as possible, while others might prefer to treat an inpatient first. The decision that the planner in question makes, is on the online operational level. Therefore, the problems 'wide variety of priority norms' and 'unjust occupation of emergency time slots' are on the offline operational level. It is difficult to make changes on the online operational level directly because these decisions react to unforeseen and unanticipated events, and different actors react in different ways.

3.2. Appointment scheduling and analysis methodologies in the literature

The literature review on appointment scheduling of Van de Vrugt (2016) categorizes literature according to a taxonomy with two axes. One axis represents the scheduling horizon, which contains capacity allocation; near-online planning; and online planning. The other axis distinguishes the number of appointments and resource types, with one appointment to one resource ('1-1'); one appointment to multiple resources ('1-m'); multiple appointments to one resource ('m-1'); and multiple appointments to multiple resources ('m-m'). Moreover, Van de Vrugt subdivides her literature into four different research types: accessibility, profitability, utilization, and completion types. For this research, the literature related to capacity allocation and online planning, for '1-1' and '1-m', with aims for accessibility and utilization, is used. These are subjects that fit with the scope we set out in Section 3.1.

At the capacity allocation level of appointment scheduling, the available resource capacity is divided over time and different customer types, which strongly relates to the problem of SKB-W. One appointment – one resource ('1-1') also fits with the appointment scheduling methods of SKB-W. In '1-1', a patient requests one appointment for a system with one research type (Van de Vrugt, 2016). When a patient needs an ultrasound, the ultrasound is in most cases the only needed examination. However, there are also ultrasounds where more than only one technician, or radiologist, is examining the patient. Because of the presence of these situations, we also looked for useful sources in the part of the literature review involved with '1-m' capacity planning. Table 6 shows the amount of literature available per subject.

Table 7 – Available literature in Van de Vrugt (2016) divided per planning horizon and customer types. (n=342)

	Tactical		**Operational**	
	1-1	1-m	1-1	1-m
Accessibility	26	1	30	12
Utilization	58	1	43	13
A & **U**	78	2	60	18

3.2.1. Analysis methodology: simulation modeling

Van de Vrugt (2016) also classifies literature by analysis methodologies that the researchers use, but does not give clear considerations about the suitability of each analysis methodology for a certain type of research; Cayirli and Veral (2003) do. They classify the literature on research methodologies in appointment scheduling as analytical (queueing theory and mathematical programming), simulation-based, or case studies. Analytical studies can provide the optimal solution to a simplified scheduling problem, while simulation studies are only able to approach that optimum.

Cayirli and Veral (2003) state that the advantage of simulation studies over analytical methods lies in the ability to model complex outpatient queueing systems and represent environmental variables and to experiment with those models. Additionally, simulation is suitable for modeling situations where stochasticity and variability have great influence on the system. Finally, they state that simulation studies offer the ability to experiment with multiple new scenarios that give insights on the analysis of outpatient clinics in regard to staffing requirements and planning and management of the clinic. However, these are also typical characteristics of the earlier mentioned analytical approaches.

Robinson (2014) gives more considerations for the choice of simulation modeling over analytical approaches such as queueing theory, linear programming, dynamic programming, and generic algorithms. The first reason would be that modeling variability is easier when using simulation, in comparison to analytical approaches. And it is vital that the researcher accounts for variability when attempting to predict the performance of a system (Robinson, 2014). The second reason is that for simulation modeling we need fewer assumptions than when we would use analytical approaches. Therefore, simulation modeling gives a more detailed representation of the system than an analytical model. Third, we could say that a simulation model is more understandable for managers, and therefore more transparent than analytical models. The visualization options of simulation modeling create a better understanding of the system. And this better understanding occurs for both managers, and the researchers themselves. Because of a better understanding of the system, we enable ourselves to generate more options for action. The fourth reason is about creativity. A good simulation model is flexible in use, which means that it is relatively easy to implement the desired options for actions. Such a model enables the user to be creative when generating solutions. So, in addition to a higher quantity of options for action, as we said before, the options are also more creative. Therefore, by the time the simulation model is ready to be used for experimentation, users of the model will find many results in a relatively short time-frame. And like Hans, et al. (2012) stated, we must be more creative to find tactical and strategical solutions to improve healthcare planning and control instead of focusing on 'more capacity'. We consider simulation modeling to be the most suitable analysis methodology for finding these solutions.

In the literature review of Van de Vrugt, we search for the number of studies related to our fields of interest as we proposed it in the beginning of this section. Our field of interest now consists of simulation studies related to '1-1' and '1-m' appointment systems for tactical or operational planning, striving for accessibility, utilization, or both. For tactical planning ('1-1' resource capacity allocation) in the categories of accessibility or utilization, or both, Van de Vrugt (2016) finds that 35 out of 78 studies use simulation as the analysis methodology. For the same types of studies that are used for the situation '1-m', 2 out of 2 studies use simulation as the analysis methodology. In the field of operational planning ('1-1' online) and in the categories of accessibility or utilization, or both, Van de Vrugt finds that 27 out of 60 studies use simulation as the analysis methodology. For the same types of studies that are used for the situation '1-m', 17 out of 18 studies use simulation as the analysis methodology. This analysis can also be seen in Table 7. This table is an updated version of Table 8 and shows that a big proportion of the de literature of Van de Vrugt (2016) is relevant for our own literature review.

3.2.2. Structure of the literature review

We look for literature about resource capacity allocation models and models that use effective scheduling policies for situations that are like the situation of SKB-W. Table 8 shows the proportion of literature related to simulation.

Table 8 - Literature given by Van de Vrugt (2016), related to '1-1' and '1-m' appointment systems for tactical or operational planning, striving for accessibility, utilization, or both. (n=364)

	Tactical		**Operational**	
	1-1	1-m	1-1	1-m
Accessibility	15/26	1/1	16/30	11/12
Utilization	23/58	1/1	19/43	12/13
A & **U**	35/78	2/2	27/60	17/18

SKB-W wants to balance accessibility and utilization, so we look at the studies that balance those measures. Below in Figure 10, we give exclusion criteria and eliminate a number of articles accordingly.

Studies that yield accessibility and utilization for tactical and operational planning.

- n=158

Seperating tactical and operational planning.

- n(tactical)=80
- n(operational)=78

Exclude all studies that do not use simulation

- n(tactical)=37 (-43)
- n(operational)=45 (-33)

Exclude studies where the title or abstract suggests that the simulation model is not suitable for our study because of e.g. the environment, or assumptions that affect the nature of the study.

- n(tactical)=12 (-25)
- n(operational)=8 (-37)

Keep studies that use a hands-on simulation approach that is reproducable within 10 weeks.

- n(tactical)=3 (-9)
- n(operational)=3 (-5)

Figure 10 - Selection of literature in Van de Vrugt (2016). (n=183)

For both the tactical and operational planning, we have three studies that use a simulation approach that is usable and interesting for our study. The references to both studies are listed below.

Tactical planning

A. Cayirli, T., & Gunes, E. D. (2014).
B. Cayirli, T., Yang, K. K., & Quek, S. A. (2012).
C. Lian, J., DiStefano, K., Shields, S. D., Heinichen, C., Giampietri, M., & Wang, L. (2010).

Operational planning

D. Klassen, K. J., & Rohleder, T. R. (2004).
E. Lee, S., Min, D., Ryu, J. H., & Yih, Y. (2013).
F. Rohleder, T. R., & Klassen, K. J. (2002).

We use a concept matrix (Table 9) with six concepts that we find important:

1. Discrete event simulation
2. KPI measurement: accessibility or utilization or overtime work
3. Patient classification
4. Multiple scheduling policies
5. Addressing fragmentation
6. Case-study – based on empirical data

Table 9 - Concept matrix for the literature review.

	1	**2**	**3**	**4**	**5**	**6**
Cayirli & Gunes (2014)	X			X		X
Cayirli & Yang & Quek (2012)		X	X	X		
Lian, et al. (2010)	X	X	X		X	
Klassen & Rohleder (2004)	X	X		X	X	
Lee, et al. (2013)	X	X	X	X		X
Rohleder & Klassen (2002)	X	X	X	X		X

The concept matrix shows that Lian et al. (2010), Lee et al. (2013), and Rohleder & Klassen (2002) are interesting for our study. They tick 4, 5, and 5 out of six boxes respectively. The three articles all mention the influence of patient classification, which is part of SKB-W's problem. However, Lian et al. (2010) do not consider multiple scheduling policies. Therefore, we use forward search, to find whether other studies that refer to Lian et al. (2010) consider multiple scheduling policies. Lee et al. (2013) and Rohleder & Klassen (2002) mention the same concepts but approach the problem of operational planning differently.

3.2.3. Tactical planning: defragmentation

The core problem of SKB-W is the high fragmentation of resource capacity allocation. Van de Vrugt (2016) refers to different studies that integrate capacity (tactical) and appointment (operational) decisions: Cayirli and Gunes (2014) tests different appointment systems for a general practitioner that works with walk-ins, by (de)fragmenting the schedule; Cayirli and Yang (2012) design an appointment rule that considers an appointment system with no-shows and walk-ins; and Lian et al. (2010) test on the effectivity of defragmentation specifically to improve accessibility and utilization. Due to its emphasis on defragmentation, we study the latter more intensively.

Lian et al. (2010) describe that conventional appointment scheduling processes are intrinsically inefficient due to their tendency to generate fragmented time slots. This statement is mainly aimed at schedules where appointment blocks are built with time slots, similarly to SKB-W's appointment schedule. To reduce schedule fragmentation, Lian et al. (2010) propose a rule that increases the appointment acceptance rate and clinic time utilization if demand matches service supply. The appointment acceptance rate refers to the rate of appointments that both the hospital and the patients consider to be acceptable as a moment of examination. If either of the parties does not find the proposed appointment slot acceptable, we look for a different slot. Defragmentation of the appointment schedule by reducing the use of appointment blocks for a specific small set of examinations will lead to a higher acceptance rate. This means that the grouping of examinations – and therefore, patients – must be reassessed.

A forward search on Lian et al. (2010) leads us to Huang, Y.L. (2016) who made patient groups based on their average examination times. By pooling patients with similar examination times, he ensures that the average examination time per patient group positively affects waiting time and idle time in regard to demand and no-show rate. Huang (2016) considered grouping patients of 6 different groups in one to six groups. By using four groups Huang (2016) simulated the best configuration, resulting in the lowest total cost for average waiting time, average over time, and average idle time. For SKB-W it may be interesting to look at the examination times for the current patient groups, but this falls outside of the scope of this research. Because SKB-W works with different specialisms and not every technician is specialized in examining every type of patient. However, it may be possible to pool patients, based on the specialisms of each technician. Right now, SKB-W uses a similar approach but does not consider the possibility to combine e.g. regular patients with 'mammapoli' patients. We should consider this solution, as well as other combinations. Both Lian et al. (2010) and Huang (2016) show that regrouping patients can have a positive effect on the total costs.

Defragmentation, as described by Lian et al. (2010), was tested for online planning. However, the method also seems applicable for capacity allocation, as Huang (2016) shows. SKB-W can improve that acceptance rate for appointment slots by allocating more treatment codes to the set of codes within an appointment slot. Accordingly, more appointment slots will be suitable for certain examinations.

3.2.4. Operational planning: open access policy

In addition to tactical planning, the RD of SKB-W also makes operational planning decisions when, e.g., accommodating examinations for unforeseen emergency patients. To ensure that the tactical planning solution is implemented well, we should also consider the operational planning decisions, and how we might be able to influence those online decisions through appropriate appointment scheduling methods.

On the capacity allocation level, there are suggestions for appointment systems that use operational planning methods to schedule appointments on a short notice. Rohleder and Klassen (2002) and Klassen and Rohleder (2004) do this within one or two days after the appointment request. Lee et al. (2013) do this for requests on the same day. The method of Lee et al. (2013) affects the resource capacity allocation by structurally reserving time slots to serve patients with same-day requests. SKB-W uses open access system to a certain extent by reserving several time slots in the appointment schedule for same-day (emergency) patients. However, the system is not executed the way it should, because there is the unjust occupation of reserved time slots, as Chapter 1 described. The operational scheduling policy of Lee et al. (2013) effectively serves same-day patients automatically as a result of the resource capacity allocation methods. Therefore, the study by Lee et al. (2013) shows parallels with the case of SKB-W. We explain the findings of Lee et al. (2013) in the paragraph below.

The simulation study by Lee et al. (2013) shows that accessibility and utilization in a healthcare facility can be maximized with different types of appointment schedules. Lee et al. (2013) simulate an open access system and an overbooking system. The two systems are not combined. We will only explain the open access system because the number of no-shows at SKB-W is not of a significant value. In an open access system, the appointment schedule has a few slots available for same-day patients, but it does not make any changes in the total number of daily available appointments. Patients are encouraged to be seen on the day they call so that utilization and accessibility for those same-day patients can be maximized. Lee, et al. (2013) conclude that the proportion of same-day appointments is important in the selection of an appointment system. Since open access performs considerably well under the condition that the proportion of same-day patients is low (which is the case for the RD of SKB-W) it is an interesting appointment scheduling technique for SKB-W.

A forward search on the research by Lee et al. (2013) leads us to a study by Bobbie, A (2016). He also concludes that advanced scheduling methods combined with open access blocks for walk-ins and emergencies are helpful when we aim for decreasing waiting time and access time. It can also lead to a lower probability of overtime work when the time reserved is sufficient to meet demand. However, Bobbie (2016) also addresses that uncertainty in daily demand can lead to an increase of the idle time of the technicians. Since an important objective of SKB-W is high utilization without having a workload that is as high as it is right now, our model should also record the idle time of an ultrasound room. When we bring together the most important KPIs that Bobbie (2016) and Lee et al. (2013) propose, we conclude that our model must measure: average overtime work, the proportion of unmet daily demand, average waiting time, average utilization rate, average access time, and average idle time. Lee et al. (2013) use constants to make a total cost function out of the measured KPIs. The constants add weight to each KPI. The simulation returns the most suitable scheduling policy, which is the scheduling policy that yields the lowest costs in respect to the importance of each KPI.

3.3. Conclusions

In this section, we draw conclusions from our literature review and answer the research questions that we posed in Chapter 1.

3: What analysis methodology is most suitable for testing new patient categorizations as well as different ways of capacity allocation, according to the literature?

We choose simulation modeling over analytical approaches. It enables us to incorporate details and variability to an extent that analytical approaches do not allow us to. In addition to the technical advantages, there are also communicative advantages. The visualization aspect of simulation makes for an understandable model with understandable outcomes that can serve as a bridge between the researcher and management. It creates a better understanding of the system for both parties and therefore encourages both parties to think creatively about possible solutions. In Chapter 4 we will conduct discrete event simulation experiments which should help convince SKB-W of the effectiveness of our ideas for improvement.

4: What are the different approaches for patient categorization and capacity allocation we can assess, according to the literature?

The first approach for improvement would be based on defragmentation of the schedule, by regrouping patients. Our literature study suggests that we should group patients according to the specialisms that technicians can carry out. This can be very useful when the number of all-round technicians at the RD of SKB-W increases since this enables us to allocate all types of patients to a certain appointment slot. If more patients of different patient groups can be helped on a shorter notice, it means that we can bring back the access time of several patient groups.

The second approach considers a partial open access appointment system. This means that we combine a complex appointment system (as SKB-W has right now) with open access blocks to accommodate same-day patients or patients with an examination request that needs to be fulfilled by the next day. Accordingly, we have capacity for both emergency patients and clinical patients. This should bring down the high utilization rates we found in Chapter 2. We use these approaches in the discrete event simulation experiments in Chapter 4.

4. SIMULATION STUDY

This chapter answers the last two research questions '*What is the modeled performance of the current appointment scheduling policies and resource capacity planning?*' and '*What is the modeled performance of the new categorization and scheduling approaches in question 4 and what configuration has the best performance?*'. In Section 4.1. we describe the conceptual model. In Section 4.2. we explain the validation and verification of the model. In Section 4.3. we explain what experiments we will conduct. In Section 4.4. we analyze the results of the experiment. In Section 4.5. we end the chapter with conclusions.

4.1. Conceptual model

This section describes the conceptual model. Section 4.1.1. gives a model description, Section 4.1.2. elaborates on the input data and Section 4.1.3. give the assumptions and simplifications.

4.1.1. Model description

We created a discrete event simulation model of the appoint scheduling process for ultrasound rooms at the RD with the program Plant Simulation 13. The model evaluates the performance of the appointment scheduling policies over the course of 261 days, which is the number of days on which SKB-W's RD scheduled ultrasound appointments in 2016. The simulation model appoints patients to time slots from the blueprint schedule. After modeling the current situation, we experiment with a variety of alternative blueprint schedules and the use of open access policies.

Figure 11 is a screenshot of the simulation model. In Figure 12 we show the patient flow for outpatients and emergency patients, according to the categorization in Chapter 2. Each patient type has their own arrival rate. Outpatient arrivals show seasonality over the course of the year, like we addressed in Section 2.4.1. Emergency arrivals vary hourly (Section 2.4.1.). For both outpatients and emergency patients, there is a subdivision into examination groups: there are five outpatient groups and three emergency groups. The outpatient groups are Regular (R_1), Mammapoli (R_2), Abdominal (R_3), Duplex (R_4), and MSU (R_5). The emergency groups are ED patient (E_1), Inpatient (E_2), and Duplex Carotids (E_3). We identify each group with a treatment code so that we can appoint (a set of) treatment codes to the blueprint schedule. We allocate treatment codes to the slots of SKB-W's blueprint schedule (Appendix C) as shown in Table 10.

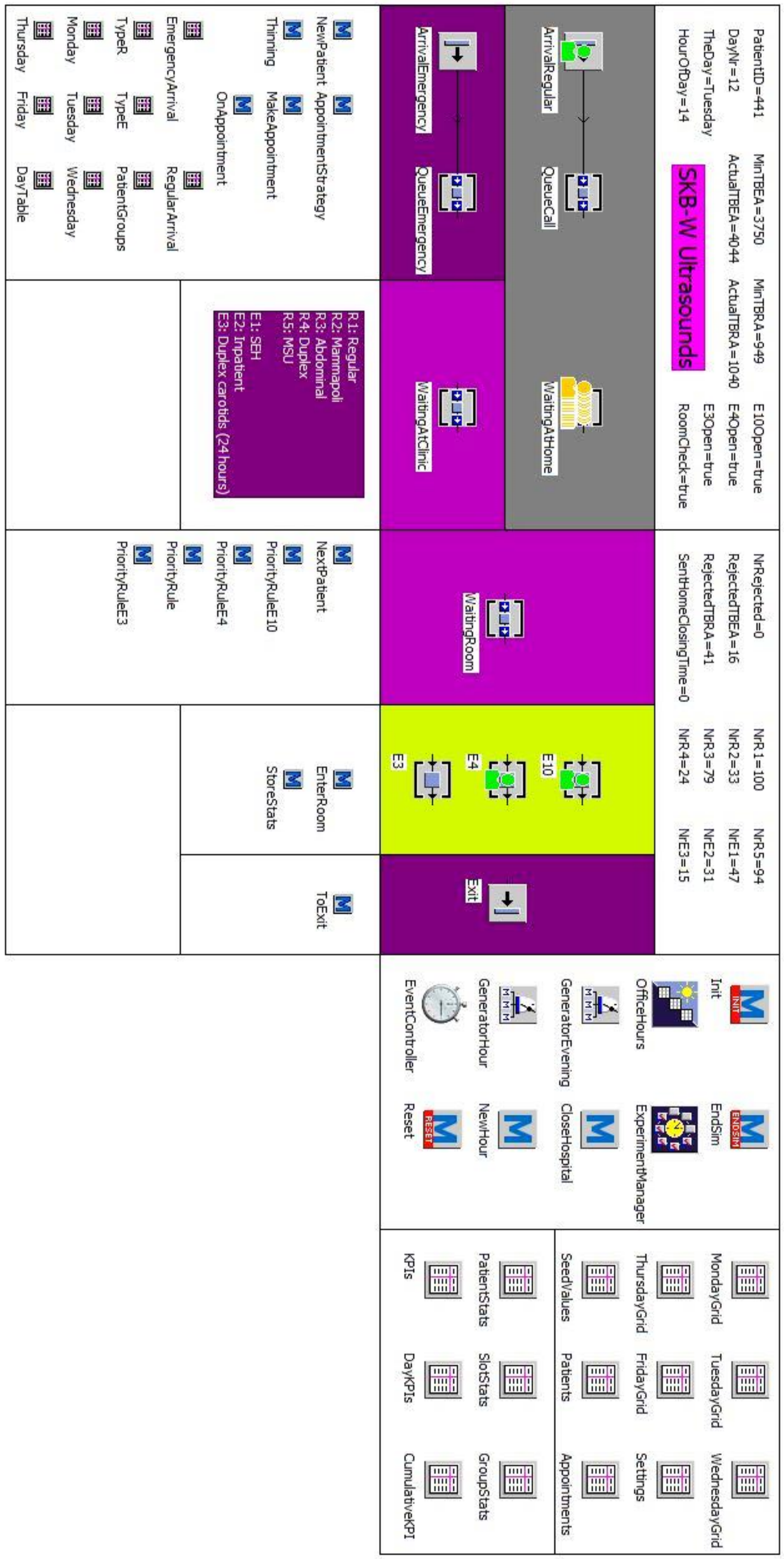


Figure 11 - Screenshot of the simulation model of SKB-W.

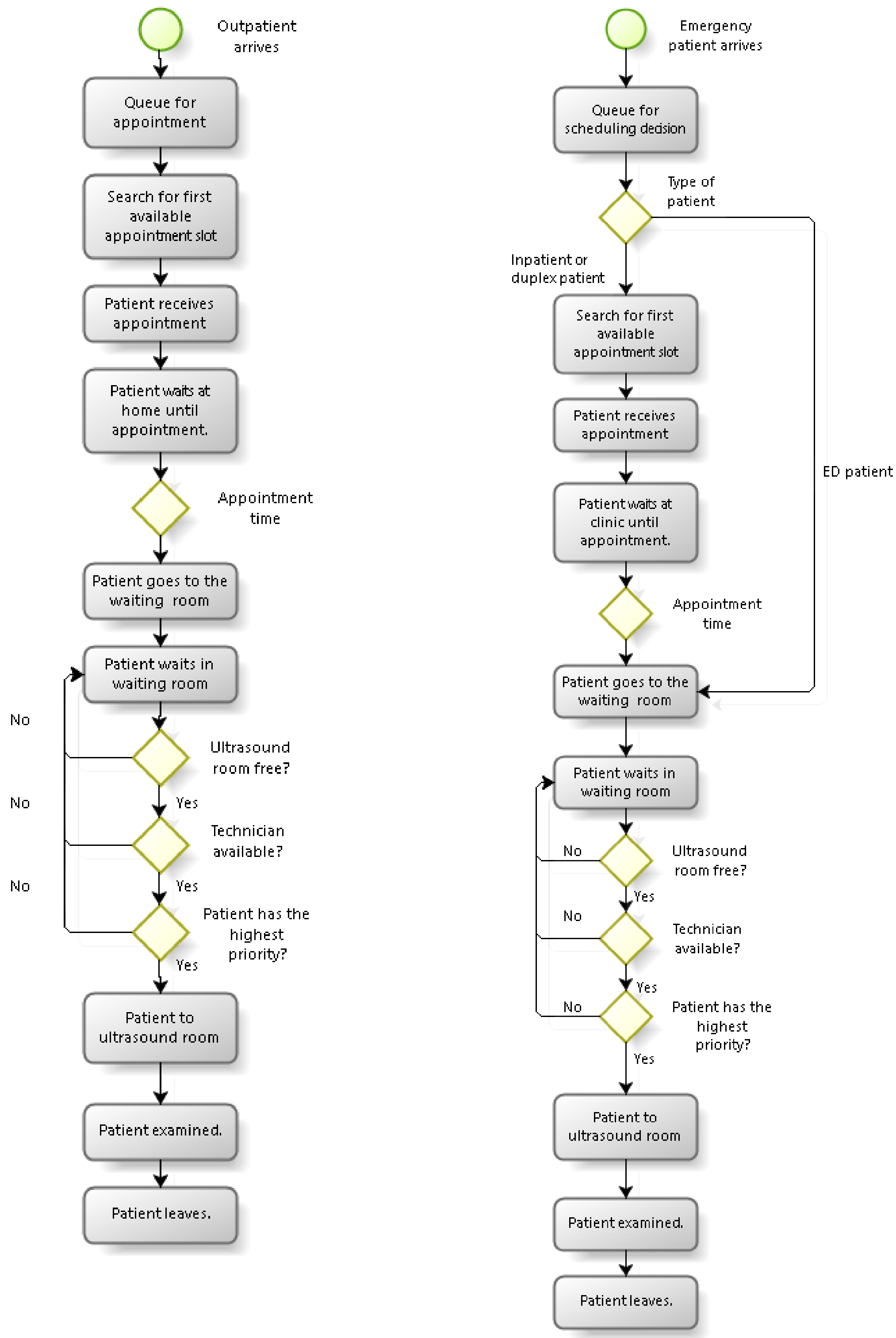


Figure 12 - Process flows for outpatients (left) and emergency patients (right) in the simulation model.

Table 10 - Allocation of treatment codes within the slots of the existing blueprint

Slot type in blueprint	Treatment codes
Biopsy	R_1
Combi	R_1, R_3
Duplex	R_4
Duplex carotids	E_3, R_4
Emergency	E_1, E_2, E_3
Extension/Break	E_1, E_2, E_3
Inpatient	E_2
Mamma OSS	R_2
Mammapoli	R_2
MSU	R_5
Regular	R_1, R_3
Target/Regular	R_1, R_3

The model contains tables with the blueprint schedules for every day (referred to as MondayGrid, TuesdayGrid, et cetera, in Figure 11). Each slot is filled with the treatment codes that belong to the slot type (Table 10). Some slots contain multiple treatment codes. For example, the fairest way to create enough abdominal and regular slots in the blueprint schedule was by allowing both examination groups to be appointed to all regular slots. This means that abdominal examinations can take place in the afternoon, which is something that SKB-W does not do now.

The model uses an appointment rule to schedule patients. After a patient arrival, the appointment rule seeks the first possible free time slot that is accommodated for the treatment code that belongs to the patient. We set the planning horizon to six weeks, which is more than the passed standard of four weeks that SKB-W must use. If the system cannot find an appointment within six weeks, the patient will not be appointed to the schedule. According to their appointment day and time, patients go to the hospital to be examined and leave after the examination (Figure 12). There are no follow ups.

The model uses a priority rule that ensures that patients are examined on time and in the rooms that they were appointed to. The rule treats emergencies and outpatients differently.

Emergencies are helped in any operational ultrasound room as soon as another patient leaves and therefore have the highest modeled urgency. Outpatients are prioritized based on the room that they are appointed to and their appointment time. If an ultrasound room is operational and free, and there are multiple patients that are appointed to that room in the waiting room, the priority rule seeks the patient with the earliest appointment time. In the case that no patients appointed to the room are in the waiting room, the priority rule seeks any other patient with the earliest appointment time. Hence, the ultrasound rooms help each other.

After 261 weekdays, the model measures the following KPIs:

- Number of examined patients per group
- Average access time per group
- Average waiting time per group
- Average number of patients examined during overtime
- Average slot utilization
- Average capacity utilization
- Number of patients sent home before closing time

We assess our experiments on the KPIs 'average access time' or 'average waiting time', 'average capacity utilization', and 'average number of patients examined during overtime'. The remaining KPIs are more descriptive; they show the side effects, instead of the direct effect, of the experiments. We use them as a control variable.

4.1.2. Assumptions and simplifications

For the model, we use numerous assumptions and simplifications, which are required to approach the real situation. Below, we list all assumptions and simplifications, in some cases along with remarks that clarify the choice for the assumption or simplification.

Assumptions and simplification for the simulation model:

- Each timeslot is 25 minutes long.
- Each appointment has an expected duration of 25 minutes. In combination with the previous assumption increases, this increases the modularity of the blueprint schedule. Modularity enables the user of the model to be creative with implementing solutions.
- Service times for each ultrasound room follow a Normal distribution with μ = 25 minutes, σ = 2,5 minutes, minimum = 15 minutes, and maximum = 35 minutes. This assumption is required because we did not measure the service times in our analysis.

- Patients only arrive during office hours (8:30-18:00).
- Outpatients arrive according to the negative exponential distribution, which varies per season (Section 4.1.3.).
- Emergency patients arrive according to the negative exponential distribution, which varies per hour (Section 4.1.3.).
- We model the punctuality of patients with the uniform distribution with a = 15 minutes early, and b **=** 3 minutes late. Secretary assistants say this is a reasonable assumption.
- After 18:00, all patients remaining in the waiting room or ultrasound room are sent home (without examination).
- Patients are assigned to an examination group, based on the empirical distribution in Table 3. Table 13 gives the adjusted distributions for our model.
- There are no coffee breaks. Ultrasound rooms operate from 8:30-12:15 and 13:30-18:00. The afternoon break is modeled by closing each room three time slots in a row.
- The latest possible appointment slot starts at 16:50. All examinations after a day's last available appointment time are considered overtime-examinations.
- All patients that are examined after the last plannable appointment slot before the break starts, are considered overtime patients. For example, a room is open until the break (12:15), but the last plannable slot ends one slot earlier (11:50); any patient that is treated in the remaining time, is considered an overtime patient.
- The planning horizon is 5 weeks instead of the real passed standard of 4 weeks. Any patients that can only get an appointment after 5 weeks are declined. If the planning horizon is modeled shorter, the number of declined becomes too high.

We experiment with a run length of 500 days and a warm-up period of 239 days. With a warm-up period of 239 days and a run length of 500 days, the model simulates 261 working days (starting on a Monday).

4.1.3. Input data

In Chapter 2 we discussed the number of treated outpatients and emergency patients per year. We saw that there is a certain seasonality for outpatient arrivals, as well as a daily arrival pattern for emergencies (Section 2.4.1.). We use these empirical distributions for both arrival patterns in our simulation model.

All patients arrive according to a Poisson process. Hence, we can use the negative exponential distribution for arrivals in our simulation. We incorporate seasonality of outpatient arrivals and hourly variability of emergency arrivals with a procedure that is called Poisson thinning. Throughout the day, patients arrive with intensity λ_{max}, which means that arrivals are exponentially distributed with $1/\lambda_{max}$. As a patient arrives, the simulation accepts the arrival with a probability of $\lambda_{current\ period} / \lambda_{max}$. For outpatients, this rate varies per quartile (Table 11). For emergencies, the rate varies per hour (Table 12).

Table 11 - Arrival rate of outpatients per quartile in the simulation model.

Days	$\lambda_{current\ period}$
1 to 66	3,46
67 to 131	3,66
132 to 196	3,38
197 to 261	3,79

Table 12 - Arrival rate of emergencies and inpatients per hour in the simulation model.

Hour	$\lambda_{current\ period}$
8 to 9	0,34
9 to 10	0,72
10 to 11	0,93
11 to 12	0,96
12 to 13	0,85
13 to 14	0,85
14 to 15	0,89
15 to 16	0,92
16 to 17	0,9

A uniform distribution determines to which group a new arrival belongs. Table 13 shows the respective distributions of outpatients and emergencies.

Table 13 - Distributions of inpatients and outpatients in the simulation model.

Patient group	***Treatment code***	***Fraction per type (%)***
Outpatients		
Regular	R_1	34
Mammapoli	R_2	10
Abdominal	R_3	25

Duplex	R_4	7
Musculoskeletal	R_5	24
Emergencies		
ED patients	E_1	53
Inpatients	E_2	27
Duplex carotids	E_3	20

4.2. Validation and verification

Verification took place while building the simulation model. By constant testing and monitoring, we ensured that the model runs properly. With visual inspections, we checked whether the arrival rates and examination times represented reality.

For validation of the model, we used black-box validation; a method that determines whether the overall model represents the real world with sufficient accuracy for the purpose at hand (Robinson, 2014).

When we look at Table 14 and compare the number of patients in the simulation model with the number of patients in the real situation, we can see that the numbers for outpatients are very close to each other. For emergency patients, this is slightly different. That is mainly caused by the relatively small number of emergency arrivals in combination with the thinning procedure. However, this does not affect performance of the model, since ED patients and Duplex carotids patients are treated similarly: they have the highest urgency and are never scheduled.

In Table 15 we adjusted the access times for the 'reality' by eliminating weekend days, since our simulation model only simulates weekdays. Accordingly, we assume that 21 days, in reality, are 15 days in the simulation model. We can see that all access times are very close to each other.

Table 14 - Number of examined patients per examination group in the simulation model and in the data. (Data from CSA and CSR, 2016. n=9770)

Group	*Simulation*	*Reality*	*Error*
Outpatients	8176	8143	+ 0,4%
Regular	2776	2803	
Mammapoli	821	840	
Abdominal	2025	1984	
Duplex	572	579	
MSU	1982	1937	
Emergencies	1854	1829	+ 1%
ED patients	963	1062	
Inpatients	518	524	
Duplex carotids	372	243	

Table 15 - Access times of inpatients per examination group in the simulation model and in the data. (Data from CSA, 2016, n=8143)

Group	*Simulation*	*Reality*
Regular	18,8	16
Mammapoli	9,6	8
Abdominal	18,8	20
Duplex	17,4	19
MSU	17,1	15

Based on the black-box validation and the additional argumentation we conclude that we have a valid simulation model for experimentation with different appointment blueprints. Of course, there are many more restrictions that influence the way that the RD operates, but assessment of these influences is not the objective of this model. We strive to give a simplified representation of reality that gives insight into the operational effectiveness of different solutions. We recognize that the model is not, and cannot be, a perfect representation of reality, but suffices as a representation of reality for assessment of our objectives.

4.3. Experiments

This section explains what experiments we conduct with our simulation model. In Chapter 2 we argue whether defragmentation could be the solution to what seems to be a capacity problem. So first we test how an increase or decrease of capacity could affect the KPIs (category 1). Chapter 3 discusses how to use simulation modeling to test the effects of our ideas. We conclude that we can use defragmentation based on the regrouping of patients (Huang, 2016) as well as open access blocks in the appointment schedule (Bobbie, 2016) as possible solutions (category 2 and 3, respectively). We test both solutions separately, and choose the best performing schedules for each category. In the next step, we combine the methods of the best performing schedules of the defragmentation and open access approaches (category 4). The schedule that performs best in category 4 is then modeled in such a way that it could be used by SKB-W (category 5). In short, our experiments are divided into the following categories:

1. Appointment blueprints under the current restrictions and scheduling policy, with increased or decreased capacity.
2. Defragmentation of the current appointment schedule by regrouping patients.
3. Open access policy for several examination groups.
4. Combining the best results from defragmentation and open access.
5. Creating a new blueprint schedule that allows open access patients in daily periods.

For the first category, we decrease and increase the number of available time slots for each examination group with 20%. This will show the influence of capacity allocation in appointment scheduling. The list of experiments for the first category can be seen in Table 16.

Table 16 - Simulation experiment design for category 1.

Exp.	***Capacity (%)***
C1	100 (current)
C2	80
C3	120

For the second category, we look at the effects of defragmentation by regrouping patients. Table 17 shows the patient groupings for the experiments in the second category. We will not simulate for the entire solution space of examination group combinations because not all combinations of examination groups would make sense from a medical perspective. Specialisms are the main argument for the groupings: most technicians must be able to examine the entire set of patients, given the groupings we create. For example a technician specialized in mammapoli scans is also likely to be able to conduct or assist with duplex scans, and therefore this could be a valid patient grouping (Experiment DF4).

Because emergencies will always be prioritized over outpatients, we treat emergencies as a separate group. The lowest level of fragmentation is therefore in our case, fragmentation into two groups.

Table 17 - Simulation experiment design for category 2.

Exp.	*Patient sets*	*# Groups*
DF1	R_1, R_2, R_3, R_4, R_5, [E_1, E_2, E_3]	6 (current)
DF2	[R_1, R_3], R_2, R_4, R_5, [E_1, E_2, E_3]	5
DF3	[R_1, R_5], R_2, R_3, R_4, [E_1, E_2, E_3]	
DF4	[R_2, R_4], R_1, R_3, R_5, [E_1, E_2, E_3]	
DF5	[R_3, R_5], R_1, R_2, R_4, [E_1, E_2, E_3]	
DF6	R_1, R_3, [R_2, R_4, R_5], [E_1, E_2, E_3]	4
DF7	R_2, R_4, [R_1, R_3, R_5], [E_1, E_2, E_3]	
DF8	R_2, R_5, [R_1, R_3, R_4], [E_1, E_2, E_3]	
DF9	R_4, R_5, [R_1, R_2, R_3], [E_1, E_2, E_3]	
DF10	R_2, [R_1, R_3, R_4, R_5], [E_1, E_2, E_3]	3
DF11	R_4, [R_1, R_2, R_3, R_5], [E_1, E_2, E_3]	
DF12	[R_1, R_2, R_3, R_4, R_5], [E_1, E_2, E_3]	2

For the third category, we use the open access policy for several sets of examination groups, while the rest of the patients will receive an appointment according to the current blueprint schedule. Since patients are examined on the same day with this open access policy, we look at the average waiting time per group instead of access time. To test the open access policy, we will use open access for 1/3, 2/3, or 3/3 outpatients (*OA groups)*. We categorize the open access experiments on basis of the fraction of patients that belong to an OA group. The grouping of patients is based on the same argument we used for the second category; for some specialisms, it would make sense to use the open access policy, and for others not. We consider the mammapoli examinations (R_2) to be ill-suited for open access policies because they are part of a multidisciplinary program. Table 18 shows the experimental design for our third category type.

In Table 18, we refer to groups E_1 and E_3 as OA groups in the current situation. This makes sense because these patients go to the waiting room of the RD without an appointment. Even though we do not consider Mammapoli examinations as a suitable group for open access policies, we think it is valuable to assess the effect it could have on the system, if this group would make use of the policy.

Table 18 - Simulation experiment design for category 3.

Exp.	*OA groups*	*Non-OA groups*	*OA-fraction*
OA1	E_1, E_3	R_1, R_2, R_3, R_4, R_5, E_2,	0 (current)
OA2	R_1, R_4, E_1, E_2, E_3	R_2, R_3, R_5	1/3
OA3	R_1, E_1, E_2, E_3	R_2, R_3, R_4, R_5	
OA4	R_3, R_4, E_1, E_2, E_3	R_1, R_2, R_5	
OA5	R_2, R_4, E_1, E_2, E_3	R_1, R_3, R_5	
OA6	R_4, R_5, E_1, E_2, E_3	R_1, R_2, R_3	
OA7	R_1, R_2, R_3, E_1, E_2, E_3	R_4, R_5	2/3
OA8	R_1, R_2, R_5, E_1, E_2, E_3	R_3, R_4	
OA9	R_1, R_3, R_4, E_1, E_2, E_3	R_2, R_5	
OA10	R_1, R_4, R_5, E_1, E_2, E_3	R_2, R_3	
OA11	R_1, R_2, R_3, R_4, R_5, E_1, E_2, E_3		3/3

For the fourth category, we want to combine the best groupings from categories 2 and 3. The experiment design can be seen in Table 19.

Table 19 - Simulation experiment design for category 4.

Exp	*Winner DF*	*Winner OA*
DO1	DF2/DF3/DF4/DF5	OA2/OA3/OA4/OA5/OA6
DO2	DF2/DF3/DF4/DF5	OA7/OA8/OA9/OA10
DO3	DF6/DF7/DF8/DF9	OA2/OA3/OA4/OA5/OA6
DO4	DF6/DF7/DF8/DF9	OA7/OA8/OA9/OA10
DO5	DF10/DF11	OA2/OA3/OA4/OA5/OA6
DO6	DF10/DF11	OA7/OA8/OA9/OA10

In this category, we look at the average access times as well as the average waiting times. Out of the combinations in Table 19, we will then consider what the main characteristics of the best performing configurations are.

In the fifth category, we create a blueprint schedule for our best performing patient groupings in category 4. We strive to create a realistic schedule that could be implemented by

SKB-W. For our new blueprint schedule, we set open access slots for the chosen outpatient groups in ultrasound room E3. This, of course, increases capacity, but for this solution, the hospital does not require an extra ultrasound room.

We set the arrival time of the open access patients that arrive in the morning as an arrival time in the afternoon, by adding four hours to their time of creation in the simulation model. This way, we assure that all open access outpatients arrive in the afternoon, and their waiting times are measured correctly.

Figure 13 summarizes the approach for our simulation study. The solution space of our problem is big, because there are many variables we can adjust in the simulation model. This stepwise approach enables us to approach the problem systematically. We measure the significance of the improved schedule only for category 5. We test the significance by analyzing the plotted results of the current situation and the modeled performance of category 5. We do not use this significance test for the other categories because it would take too much time (the run length with the required 15 replications for short confidence intervals amounts 30 minutes). Since we use the stepwise approach below, we only look at the significance of the improvement after reaching the last step: experimentation for category 5.

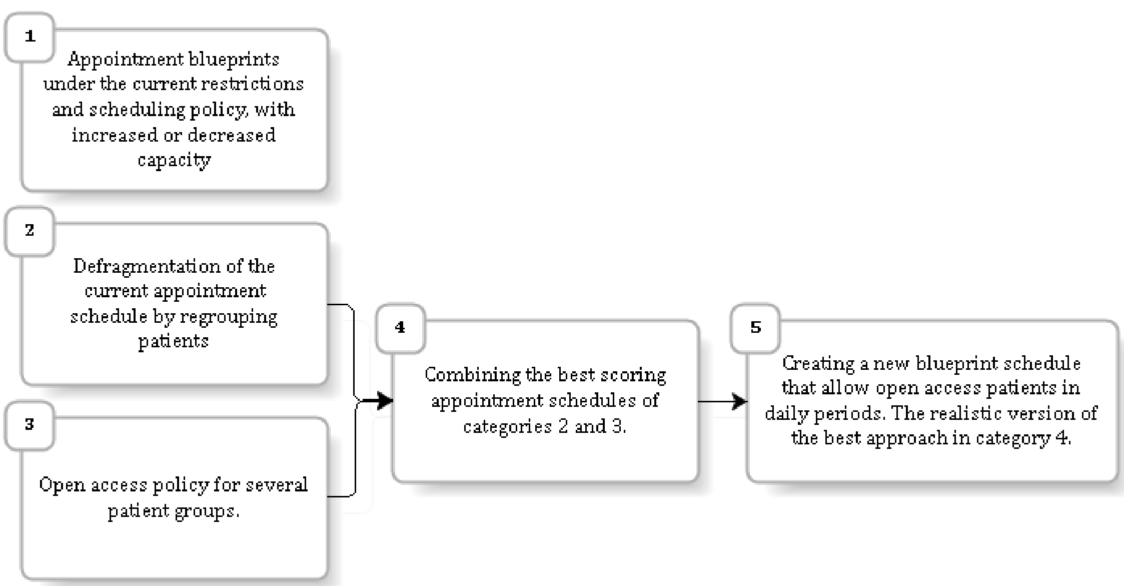


Figure 13 - Stepwise approach for the simulation study with categories 1 to 5.

4.4. Result analysis

This section discusses the results of the five categories. Appendix D contains a full overview of all simulation results, we the best results of category 2, 3, and 4 are highlighted. In Section 4.4.5., we test whether there is a significant improvement in comparison to the current system.

4.4.1. Category 1

In the first category, we simulated the effects of a 20% decrease or an increase of capacity. The results can be seen in Table 20.

Table 20 - Simulation results for category 1.

1	Average access time (days)								
Exp	R1	R2	R3	R4	R5	E2	Total	Average capacity utilization	Average number OTPs
C1 (100%)	18,8	9,6	18,8	17,4	17,1	0,6	16,3	0,87	9,73
C2 (80%)	23,2	22,5	23,1	22,6	23,6	0,6	21,5	0,73	6,34
C3 (120)	0,4	1,4	0,4	2,8	0,9	1,0	0,8	0,93	13,24

With this category, we can see what effect an increase or decrease of capacity could have on the average access time, capacity utilization, and number of overtime patients (OTPs) per day. In Experiment C2, where we decrease capacity with 20%, it becomes clear that the access times of all outpatient groups approach the planning horizon of 25 days. This means that the appointment schedule is saturated and many patients were declined. In Experiment C3, where we increase capacity by 20%, the access times are very low. It is interesting that such a small increase of capacity could make such a big difference. A side effect of the increased capacity is the increasing demand. Because of the increased capacity, the planning horizon of 25 days is not needed, because most appointments can be planned within 3 days. Therefore, there are no rejected patients (which are present in the current situation) and the total amount of patients (in other words: demand) is higher than currently.

Capacity utilization is low in Experiment C2. The utilization in a low-capacity system will stay relatively low, because several slots in the appointment schedule are appointed to emergencies (while emergencies are not appointed to these slots), and because we did not decrease the amount of slot for emergencies. In Experiment C3, we see that the system with more capacity has a higher capacity utilization, because of the presence of more patients each day. More slots are required to treat all patients, and therefore a higher rate of slots is filled than in the systems with lower capacity.

The number of OTPs becomes higher when capacity utilization becomes higher. This should be no surprise since more patients with their own punctuality and required examination times are present. This increased variability, together with the presence of more patients, causes a higher probability on overtime. In Experiment C2 we can see that it also works the other way around: with a lower capacity utilization, the number of OTPs is also lower.

4.4.2. Category 2

In category 2 we experiment with different patient groupings. In Table 21 below, are the results of these experiments.

Table 21 - Simulation results for category 2. The best performing experiments per fragmentation degree are marked gray.

2	Average access time (days)								
Exp	R1	R2	R3	R4	R5	E2	Total	Average capacity utilization	Average number OTPs
DF1	18,76	9,58	18,75	17,36	17,09	0,58	16,33	0,87	9,73
DF2	18,75	9,58	18,76	17,36	17,09	0,58	16,33	0,87	9,72
DF3	4,28	9,58	4,26	17,35	4,30	0,75	5,39	0,90	10,67
DF4	18,76	2,95	18,75	2,96	17,09	0,58	14,67	0,88	9,97
DF5	18,76	9,58	18,75	17,36	17,09	0,58	16,33	0,87	9,73
DF6	18,76	3,97	18,75	4,00	3,96	0,58	11,81	0,88	10,31
DF7	4,27	9,62	4,27	17,35	4,29	0,58	5,38	0,90	11,16
DF8	10,03	9,58	10,04	10,05	17,09	0,58	11,02	0,88	10,78
DF9	11,55	11,55	11,56	17,36	17,09	0,58	12,53	0,88	10,53
DF10	11,99	9,58	11,99	12,03	11,92	0,58	11,08	0,88	10,81
DF11	8,37	8,39	8,36	17,35	8,35	0,64	8,49	0,89	10,72
DF12	8,96	8,95	8,96	8,94	8,96	0,57	8,47	0,89	10,79

This category clearly shows that when the biggest examination groups are put together, access times will be lower. There are more slots available per examination group of two or more big examination groups can share each other's time slots. Since the time slots are shared, the access times for the grouped examination groups are almost equal. The effects of defragmentation show big improvement possibilities for SKB-W without the need of increasing capacity.

Judging by the access times, experiments DF3, DF7, and DF11 outperform the other experiments in their respective classes with 5, 4 and 3 groups (these classes were shown in Table 17). In these experiments, we can see that the examination groups that were not grouped differently are not affected by the regrouping of other examination groups. However, differences between the longest and shortest access times become smaller when the number of examination groups becomes smaller. This makes sense, because like we said earlier; more time slots are shared, as well as most of the available capacity.

We do not see big differences in capacity utilization nor the number of OTPs per experiment. Only for DF3 and DF7, we can see that the average numbers of OTPs differ significantly from the other experiments in their classes. The main cause of this difference is the number of rejected patients: the lower the number of rejects, the higher the number of patients that could get an appointment, the higher the number of patients per day, and ultimately, the higher the number of OTPs.

We find the lower access times more important for this category, and therefore, we choose Experiment DF3, DF7, and DF7 to have the best results in their classes.

4.4.3. Category 3

In this category, we divide our examination groups into open access groups and scheduled groups. In the current situation, we could see emergency patients and duplex carotids patients as open access patients since they could walk in the hospital at any time. Here, we experiment with bigger groups of open access patients. The results of this category can be seen in Table 22 below.

The average waiting times for almost all experiments are significantly higher than in the current situation (OA1). The only experiment that does not show a big difference, is experiment OA5. In OA5, the groups mammapoli and duplex are the outpatient groups with open access. These are the two smallest groups of patients. The results show us that the bigger the group of patients with open access becomes, the higher the average waiting time becomes.

Table 22 - Simulation results for category 3. The best performing experiments per open access degree are marked with gray.

3	Average waiting time (minutes)								
Exp	R1	R2	R3	R4	R5	E2	Total	Average capacity utilization	Average number OTPs
OA1	18,01	11,77	5,53	4,88	10,45	18,01	10,41	0,87	9,73
OA2	27,71	31,36	23,24	30,92	10,64	5,82	22,24	0,92	18,09
OA3	21,86	26,60	20,62	9,10	9,49	5,82	17,58	0,91	16,23
OA4	16,90	24,14	22,76	27,53	11,55	5,90	17,89	0,92	16,69
OA5	17,28	11,16	18,41	9,86	5,82	17,28	11,63	0,90	15,16
OA6	32,76	17,74	22,11	20,89	5,84	32,76	20,21	0,90	17,14
OA7	66,12	74,18	64,39	17,97	28,32	5,87	51,85	0,92	21,99
0A8	16,90	24,14	22,76	27,53	11,55	5,00390	17,89	0,94	22,57
0A9	57,88	20,61	56,38	66,75	22,08	6,12	44,08	0,92	22,01
0A10	43,89	45,44	32,79	46,54	46,01	6,30	39,97	0,94	23,35
OA11	88,55	76,23	87,84	85,81	6,56	88,55	76,95	0,95	29,30

Average capacity utilization also becomes higher when the number of open access patients increases. This then results in a higher number of OTPs, as we saw in the two previous categories as well. The differences in average capacity utilization are not significant in either of the categories. On the other hand, the differences in the number of OTPs are very significant for the lowest open access degree (1/3), ranging from 15 to 18, where experiment OA5 has the lowest number of OTPs. In the second category, these differences are less significant.

In the lowest open access degree, experiment OA5 has the best performance because both the waiting time and the number OTPs are low. In the second open access degree, experiment OA8 has the best performance, because it has the lowest average waiting time.

4.4.4. Category 4

In this category, we combine the best-performing groups from defragmentation degree 1, 2, and 3 of category 2 with the best-performing groups from open access degree 1 and 2 of category 3. When we combine both categories we have configurations as shown in Table 23.

Table 23 - Experiment configuration for category 4. The unique experiments are marked with gray.

Exp	Configuration	Scheduled groups or sets	OA groups
DO1	DF3 + OA5	[R_1, R_5], R_3	R_2, R_4, E_1, E_2, E_3
DO2	DF3 + OA8	R_3, R_4	R_1, R_2, R_5, E_1, E_2, E_3
DO3	DF7 + OA5	[R_1, R_3, R_5]	R_2, R_4, E_1, E_2, E_3
DO4	DF7 + OA8	R_3, R_4	R_1, R_2, R_5, E_1, E_2, E_3
DO5	DF11 + OA5	[R_1, R_3, R_5]	R_2, R_4, E_1, E_2, E_3
DO6	DF11 + OA8	R_3, R_4	R_1, R_2, R_5, E_1, E_2, E_3

Experiments DO1, DO2, and DO3 are unique. DO4, DO5, and DO6 turn out to have the same configurations as one of the first three experiments, which makes them duplicates of the other simulations. Therefore, we only simulate the first three experiments. The results of these experiments can be seen in Table 24 (access times, capacity utilization, and the average number of OTPs) and Table 25 (average waiting times).

Table 24 - Simulation results for category 4: average access time, average capacity utilization, and the average number of overtime patients.

4	*Average access time (days)*								
Exp.	*R1*	*R2*	*R3*	*R4*	*R5*	*E2*	*Total*	*Average capacity utilization*	*Average number OTPs*
DO1	4,28	0,00	4,26	0,00	4,29	0,00	3,34	0,93	15,93
DO2	0,00	0,00	0,00	17,35	0,00	0,00	1,07	0,94	15,93
DO3	4,27	0,00	4,27	0,00	4,28	0,00	3,34	0,93	15,93

In Table 24 we see that the access time is 0 days for the open access groups. There is also one group that has no open access and still has an access time of 0 days in experiment DO2, which is group R_3 (Abdominal). Because there are many slots available for this group every day, all patients can be helped within 24 hours and therefore the rounded down access time amounts 0 days. Total access times for experiments DO1 and DO3 are the same because the same groups are scheduled. Even though the total average access time for experiment DO2 is significantly lower than in experiment DO1 and DO3, we think that it is better to have equal access times for most examination groups instead of a high access time for one group. Based on access time, experiment DO1 and DO3 have the best performance.

Capacity utilization is the same in experiments DO1 and DO3 and just 1% higher in experiment DO2 which would not make a big difference for the system's performance. The average number of OTPs is the same for all experiments. Based on these two KPIs we cannot say which experiment performs best.

Table 25 - Simulation results for category 4: average waiting times.

4	*Average waiting time (minutes)*						
Exp.	*R1*	*R2*	*R3*	*R4*	*R5*	*E2*	*Total*
DO1	13,85	22,94	12,63	26,40	14,53	6,35	15,01
DO2	44,12	53,31	27,57	7,09	46,36	6,30	37,19
DO3	12,13	21,75	11,94	22,62	12,12	6,12	13,36

Table 25 shows low average waiting times for the experiments with smaller numbers of open access patients (DO1 and DO3), as we also saw in category 3. Waiting times for experiment DO3 are the lowest. Apparently, this is caused by grouping the three biggest examination groups R_1, R_3, and R_5. Based on the KPI average total waiting time we can conclude that experiment DO3 has the best performance. Since experiment DO1 and DO3 had the best performance in Table 24 as well, we conclude that experiment DO3 has the best overall performance.

The combination of defragmentation and open access results in an appointment schedule that accommodates room for more patients while lowering access times and slightly increasing waiting times. Because of less certainty about the arrivals of open access patients, the average number of OTPs increases slightly. This negatively affects the workload. To decrease this workload, we should increase the certainty for open access patient arrivals. We could do this by setting a timeframe in which these open access patients may arrive. Which means that patients should know that for example during the afternoon, there is an open access block where they are welcome to get their examination. We execute one final experiment for this approach, with the groupings of our best performing experiment: DO3.

4.4.5. Category 5

In this category, we have an open access block in room E3 every afternoon. During this open access block, the outpatient groups mammapoli (R_2) and duplex (R_4) arrive and are helped. Normally, mammapoli patients and duplex patients are examined by the same radiologist and technician, which makes up for a valid configuration of the blueprint schedule where we make efficient use of our human resources. Normally, room E4 is used for mammapoli examinations.

However, since the only examinations that take place in the afternoon in E3 are duplex examinations, it is easier to adjust our simulation model accordingly. With this new configuration, we get a new block schedule as shown in Table 26.

Table 26 - New block schedule for category 5.

	E10 morning	**E10 afternoon**	**E4 morning**	**E4 afternoon**	**E3 morning**	**E3 afternoon**
Monday	Regular	MSU	Regular	Regular		Open access
Tuesday	Regular	MSU	Emergency	Regular	Regular	Open access
Wednesday	Regular	MSU	Regular	Regular	Regular	Open access
Thursday	Regular	MSU	Emergency	Regular	Regular	Open access
Friday		MSU	Regular	Regular	Regular	Open access

With the new blueprint schedule, the modeled performance is as shown in Table 27.

Table 27 - Simulation results for category 5.

	Average access time (days)								
	R1	*R2*	*R3*	*R4*	*R5*	*E2*	*Total*	Average capacity utilization	Average OTPs
C1	18,8	9,6	18,8	17,4	17,1	0,6	16,3	0,87	9,73
C5	4,27	0,00	4,27	0,00	4,29	0,00	3,34	0,81	11,12
	Average waiting time (minutes)								
	R1	*R2*	*R3*	*R4*	*R5*	*E2*	*Total*		
C1	18,01	11,77	5,53	4,88	10,45	18,01	10,41		
C5	6,97	7,36	7,03	8,14	7,08	4,94	7,01		

Appendix E contains the boxplots that show that there are significant improvements in the new configuration. Positive effects of this blueprint schedule are the lower access times and waiting times, as Table 27 shows. Unfortunately, the average number of OTPs does not decrease in comparison to the current situation (where it amounts 9,73). However, as we addressed earlier in this section; as accessibility improves, demand increases. This is also the case for this simulation. The new appointment schedule is accessible for 8572 outpatients, which is 5% more than in the current situation (8143 outpatients). It must be no surprise that this small rise in daily demand causes the number OTPs to increase slightly.

4.5. Conclusions

This section answers research question 4 and 5. In Section 4.1 and 4.2 we answered research question 5: *What is the modeled performance of the current appointment scheduling policies and resource capacity planning?*

We created a simulation model that measures KPIs that indicate accessibility of the appointment schedule as well as the workload on technicians. We experimented with a run length of 500 days, a warm-up period of 239 days, and 4 replications. The modeled performance of the current situation is very similar to the performance found in the data, with slight errors for the access times of the smaller examination groups.

Sections 4.4. and 4.5. answer research question 6: *What is the modeled performance of the new categorization and scheduling approaches in question 4 and what configuration has the best performance?*

We simulated alternative blueprint schedules and scheduling policies in five different categories. We describe the categories and finding for these categories below. Appendix D gives and overview of all KPI scores per experiment.

In category 1, we see that capacity adjustments make a big difference for accessibility and number of overtime patients. With lower capacity, the accessibility was lower; resulting in high access times of 5 weeks and more rejected patients (3574).

In category 2, we show that defragmentation by patient categorization could improve the accessibility of the appointment schedule. Grouping patients into as big as possible groups improves accessibility greatly. Even though making one big patient group gives good results in the simulation, it would not be applicable in reality because of the different specialisms of technicians.

In category 3 we conclude that small open access groups affect the average number overtime patients per day slightly. On the other hand, big open access groups could be a big setback for the average waiting times and hence increase the workload heavily.

Category 4 showed that combining the best patient groupings out of category 2 and 3 mostly has positive effects on improving accessibility. However, waiting times and the number overtime patients remain too high in the current configurations, which means that the perceived workload would remain high if these categorizations and policies would be implemented directly.

In category 5 we see that if we adjust the simulation model, and set a timeframe where open access patients are welcome, we get a schedule that is accessible and results in low waiting times (Table 28).

Table 28 - Simulation results in category 5 from Section 4.4.

Average access time (days)								
R1	*R2*	*R3*	*R4*	*R5*	*E2*	*Total*	Average capacity utilization	Average number overtime patients
4,27	0,00	4,27	0,00	4,29	0,00	3,34	0,81	11,12
Average waiting time (minutes)								
R1	*R2*	*R3*	*R4*	*R5*	*E2*	*Total*		
6,97	7,36	7,03	8,14	7,08	4,94	7,01		

There is a slightly increased number of overtime patients. Because of the low waiting times, the perceived workload should be lower: there is a straightforward policy concerning emergency patients, and there are generally fewer patients in the waiting room. The defragmented schedule with open access blocks for mammapoli and duplex patients performs very well and has potential to be implemented at the RD of SKB-W. Chapter 5 elaborates on the conclusions in this chapter, including remarks on the requirements for the new blueprint schedule and scheduling policies, and gives recommendations for SKB-W.

5. CONCLUSIONS, RECOMMENDATIONS, AND DISCUSSION

In Section 5.1, we answer the research questions once more. In Section 5.2 we give recommendations for SKB-W, considering implementation of elements within the experiments, and conducting further research on this subject. Lastly, in Section 5.3. we reflect on the research project.

5.1. Answering the research questions

In Chapter 1, we pose several research questions, which we answere by the end of every chapter. Here, we state our most important findings for each chapter, as it gives a stepwise approach towards solving the problem of high fragmentation of resource capacity allocation.

Chapter 2 discusses SKB-W's patient categorization, the core processes concerning healthcare and appointments scheduling, and the resources that the RD uses to facilitate those processes. We analyze how the RD performs under these conditions.

The radiology department (RD) has three ultrasound rooms that can serve one patient at a time. SKB-W distinguishes three different types of patients: outpatient, inpatient, and ED patients. However, since inpatients and ED patients are treated similarly by the RD, we refer to these two types as one: 'emergency patients'. By grouping patients per examination group, using treatment codes, the RD appoints the different types and groups of patients in the appointment slot that is most suitable in combination with the patient's medical characteristics.

SKB-W uses programs to examine patients from the same examination group subsequently. These programs are designed to increase efficiency within the healthcare delivery process, as well as to make the appointment scheduling process easier. However, the appointment scheduling process does not become easier because the programs that SKB-W uses are not entirely dedicated to merely allocate patients from the examination group that fall within the program.

For 2016, we find that there were 9970 ultrasound patients, of which 8143 are outpatients, and 1827 can be labeled as emergency patients. The first performance indicator we look at, is the average access time of patients. The current scheduling policies affect the access times of most examination groups of the outpatients. Most access times average 20 days. Abdominal patients must wait an average of 26 days before they can get their examination, which is the highest average access time. 26 days comes very close to the passed standard (Dutch: '*treeknorm*') of four weeks, which means that not all abdominal patient arrivals can be accepted and are referred to another hospital. Duplex patients also have a high average access time of 24 days, because there are few duplex slots within the duplex program. Biopsy patients have a low average access time of 6 days, because it is the smallest examination group and because biopsy patients are treated as regular patients by the blueprint schedule. This means that a small group has access to a big number of suitable slots. With the group abdominal, this is vice versa, which explains their high access time.

With the knowledge about the high access time, combined with the knowledge from the answer to question 1, we can give an advice for lowering access times. We advise SKB-W to either dedicate the program entirely to merely the patients that fall within the examination group (e.g., exclusively abdominal examinations on Monday morning without any regular examinations), or create bigger examination groups (e.g., abdominal patients and regular patients are one big group and can use all of each other's slots).

Utilization is the second performance indicator. We consider utilization of the gross time (office hours; the time in between the breaks) and the utilization of the net time (gross time minus additional breaks, schedule blockades, and unavailability of technicians). The net time in the data is lower than the real net time, because CSA counts blockades as not-plannable time, while the block slots are in some cases reserved for emergencies. Utilization of the gross time amounts approximately 80%. This means that the additional 20% of capacity is lost because of additional breaks, schedule blockades, unavailability of technicians, or appointment slots that are not filled. The utilization of the net time amounts around 100%, which means that technicians work overtime at the end of the day and during some breaks. We consider the high utilization as alarming; however, we also think that this measure turns out to be lower in reality, as blockades sometimes do not represent the absence of a technician, but merely a place for an emergency patient. Although SKB-W's problem looks like a capacity problem, we assume in Chapter 2 (and show in Chapter 4) that defragmentation is the solution to the high utilization of the net time.

In Chapter 3 review literature on suitable modeling approaches for the implementation of new scheduling approaches. We choose discrete event simulation modeling over analytical approaches. It enables us to incorporate details and variability to an extent that analytical approaches do not allow us to. With the simulation model, we can experiment with many new blueprint schedules, which analytical approaches are not suitable for.

The first simulation approach for improvement would be based on defragmentation of the schedule, by regrouping patients. Our literature study suggests that we should group patients according to the specialisms that technicians can carry out. This enables us to allocate all types of patients to a certain appointment slot.

The second approach considers a partial open access appointment system. This means that we combine a complex appointment system (as SKB-W has right now) with open access blocks to accommodate same-day patients or patients with an examination request that needs to be fulfilled by the next day. Accordingly, we have capacity for both emergency patients and clinical patients. In Chapter 4 we use these approaches in the simulation model.

In Chapter 4, we created a simulation model that measures KPIs that indicate accessibility of the appointment schedule as well as the workload on technicians. We experimented with a run length of 500 days, warm-up period of 239 days, and 4 replications. The modeled performance of the current situation is very similar to the performance found in the data. With the simulation model, we experiment with new blueprint schedules. The results of those simulations can be compared to the current performance as well.

In our simulation study we find that when we defragment the schedule by creating new, bigger groups, the access times for those bigger groups drop, while the other access times remain the same. Our experiments on fragmentation show that it is best to group the examination groups regular, and musculoskeletal, by which their modeled average access times drop from 19, 19, and 17 days respectively to an average of 4,3 days for all three groups.

When we use an open access policy, we see the best results if we let the smaller examination groups arrive with open access. The bigger the open access group, the longer the average waiting time becomes. The best performance occurs with the examination groups mammapoli and duplex as open access groups. Because these are two specialisms, we design a new blueprint schedule in the last experiment, where we combine the approaches of defragmentation and open access scheduling.

The best combination of defragmentation yields the block schedule in Table 29. The scheduled outpatients of the regular, abdominal and musculoskeletal examination group have an access time of 4,3 days, while the open access patients have no access time at all. The total average access time therefore amount 3,3 days, in comparison to the modeled 16,3 days in the current situation. The new scheduling policy also yields a lower average waiting time of 7,0 minutes, in comparison to 10,4 minutes in the current situation. There is a slight increase in the average number over overtime patients going from 9,7 in the current situation to 11,1 in the new situation, which is a result of the open access policy as well as the increased number of patients. Because of the improved accessibility, all patient requests can be accepted, which results in a 5% increase of number of examined outpatients.

To implement this strategy, SKB-W needs to ensure that one all-round technician is available in the afternoons to examine patients during the open access blocks. Also, radiologist that is specialized in the fields of mammapoli and duplex examinations must be present during these open access blocks. This is already the case on most days of the week. The extra opening hours for ultrasound room E3 should not be a problem, as the coordination of the RD already mentioned that this is possible. We can conclude that the new schedule we propose should need little investment in comparison to a physical increase of capacity. The investment will pay itself back as well, since SKB-W can examine 350 more patients in a year (Appendix D).

Table 29 - New block schedule for the combination of defragmentation and open access. Regular and MSU blocks are still denoted, but both examination groups can use either of the blocks because of the grouping of regular, abdominal, and musculoskeletal patients. Inpatients, duplex carotids patients, duplex patients, and mammapoli patients use the open access blocks.

	E10 morning	**E10 afternoon**	**E4 morning**	**E4 afternoon**	**E3 morning**	**E3 afternoon**
Monday	Regular	MSU	Regular	Regular		Open access
Tuesday	Regular	MSU	Emergency	Regular	Regular	Open access
Wednesday	Regular	MSU	Regular	Regular	Regular	Open access
Thursday	Regular	MSU	Emergency	Regular	Regular	Open access
Friday		MSU	Regular	Regular	Regular	Open access

The main research question of this study is stated as follows: *'How can SKB-W apply defragmentation of resource capacity allocation in order to solve the initial problems 'high access times for outpatients' and 'high workload for technicians'?'*

First, we could ask whether we could find a solution for the initial problems. The answer is: partially. We could not solve the workload problem entirely. However, we do believe that the perceived workload becomes lower when there is a straightforward rule for handling emergency arrivals. This perceived workload cannot be expressed in figures, whereas the number of overtime patients can. There is no improvement for the number of overtime patients, because incorporating open access increases variability in demand.

Defragmentation of the appointment schedule by making big patient groups turned out to be very effective for decreasing access times. The open access blocks we use in Table 29 are used to examine duplex, mammapoli, and duplex carotids patients, as well as inpatients. Patients from the emergency department may arrive at any given time are examined as soon as an ultrasound room sends away a patient. These unforeseen arrivals from the emergency department may increase the waiting time for outpatients, but decreases the waiting time for emergency patients, yielding a lower average waiting time for all patients.

5.2. Recommendations

First, consider grouping the regular and abdominal patients entirely. For now, the abdominal group is partially grouped with the regular group, causing some patients of the examination group regular to be allocated in slots that are preferably used for abdominal patients. If technicians are well-rounded enough to examine patients from the groups regular, abdominal, and musculoskeletal, we would recommend to also make musculoskeletal patients part of the new big group, as the simulation results of the new blueprint schedule that this can yield an average waiting time of approximately 4 days.

Second, consider a new categorization for the patient type 'emergency'. Having the patient type emergency consist of the emergency department's patients, duplex carotids patients, and inpatients, makes sense. These examination group share the characteristic 'higher urgency', and all patients are unforeseen. The RD can accommodate room for most emergency patients with slots at the end of the morning (before the break) and at the end of the day, when the arrival rate for emergencies is highest. This increases accessibility for outpatients, and sets clear rules for 'how to deal with emergency patients'.

Third, let programs in the schedule be programs – if the new patient groupings will not be valid due to unforeseen restriction. Do not schedule other examination groups within the program. That causes fragmentation of the program. Currently this is clear for the patient group mammapoli where the rules on planning within the program are very strict. In this research, we show that access times can decrease by avoiding fragmentation of the appointment schedule.

Fourth, and maybe most importantly, create clear protocols that eliminate the need for by-passing of the rules and restrictions of the blueprint schedule, as well as improve the handling of emergencies. We already suggested that a clear approach towards handling emergencies, by examining them as soon as possible, decreases waiting times. It also lowers the perceived workload. This rule for handling emergency arrivals, also seems to be the easiest to implement, since it can be used as a rule of thumbs.

5.3. Discussion

In this section we discuss the limitations of our research. These limitations affect our final outcomes, and are drawbacks for putting our recommendations into practice.

First, for the data analysis we used data from CSA and CSR. Both data sources gave many duplicates, which made it difficult to find precise data about the number of patients and the number of patients per group or per program. Therefore, we made multiple assumptions, such as the proportion of inpatients and ED patients for the patient type 'emergency'. Such assumptions might negatively affect the representation of reality in the simulation model. However, we accounted for this possible error by treating inpatients and ED patients similarly in the simulation: both groups had the same urgency.

Second, in the simulation model, we assume that for all examinations there is an equally distributed service time with mean 25 minutes. However, in Chapter 2 we explained that there are different time slot lengths. Since these timeslot lengths would decrease the modularity of our model, we did not use different time slot lengths. This decreased the variability in the simulation model, which affects the trustworthiness of the results.

Third, we allow examination groups to make use of an open access policy in the simulation model, resulting in appointment scheduling methods that would not be realistic at all. We used these methods mainly to show what the effect would be if an examination group of a certain size would be treated differently. Eventually, we adjusted the best possible schedule to a certain degree in order to make it a realistic situation, which also improved its performance. In further research, the recommendation would be to implement realistic and creative solutions, and measure their performance. This study mainly shows a range of possibilities for the use of our simulation models, while further research should focus on creating an implementable schedule.

Fourth and finally, simulation is an attractive tool that is very effective when it comes to selling an idea. The idea that the outcomes of our experiments can solve the problem of high access times seems very effective. However, there are many assumptions that make the model differ from the real situation. When it comes to staffing, our simulation model does not consider that the personnel of the radiology department can become sick as well. Situations like those are the moments that the workload may be highest. One must keep in mind that the simulation model is merely a representation of reality, and that there are many factors that could still affect the expected outcomes.

5.4. Further research

The first problem we encountered that was outside the scope of this research, was the inefficiency in the examination process, considering the consultation between technician and radiologist. We expect that examination times may be shorter if SKB-W would find a way to get rid of consultations for standard procedures. We expect that this requires better trained technicians, and a new way to disseminate information from the technician to the radiologist. If examination times are shorter, there is more spare time in between examinations, resulting in a lower workload.

The second problem we encountered had to do with analyzing the data from CSA and CSR. Every actor has another approach towards recording examinations, which leads to an omission in databases. Analysis of the data therefore requires assumptions or estimates on the number of patients, while this information should be easier to access. A better organized data directory, make the analysis of business processes easier, and is therefore recommended.

Plant Simulation is an expensive simulation program that is free to use for students from the University of Twente. The last recommendation for further research would be expanding this research project, by letting a student use Plant Simulation to simulate other new blueprint schedules, based on the suggestions of the RD. With our simulation results, we already showed that there are many ways to schedule patients. We could test the effectiveness of using a new approach for a whole year in only 6 minutes. What we tested in this study was only a small fraction of the entire solution space. This means that there are many more creative solutions towards appointment scheduling to be tested, but there are also possibilities to conduct scenario analyses.

We advise that SKB-W hires another student who can use the simulation model to further help the RD with the implementation of the ideas we brought up in this study. It is also possible to use the tool for other departments in the hospital. A condition for this to work, is that the other department uses an appointment schedule as well, as the tool mainly measures the effects of new scheduling and categorization methods.

6. LITERATURE

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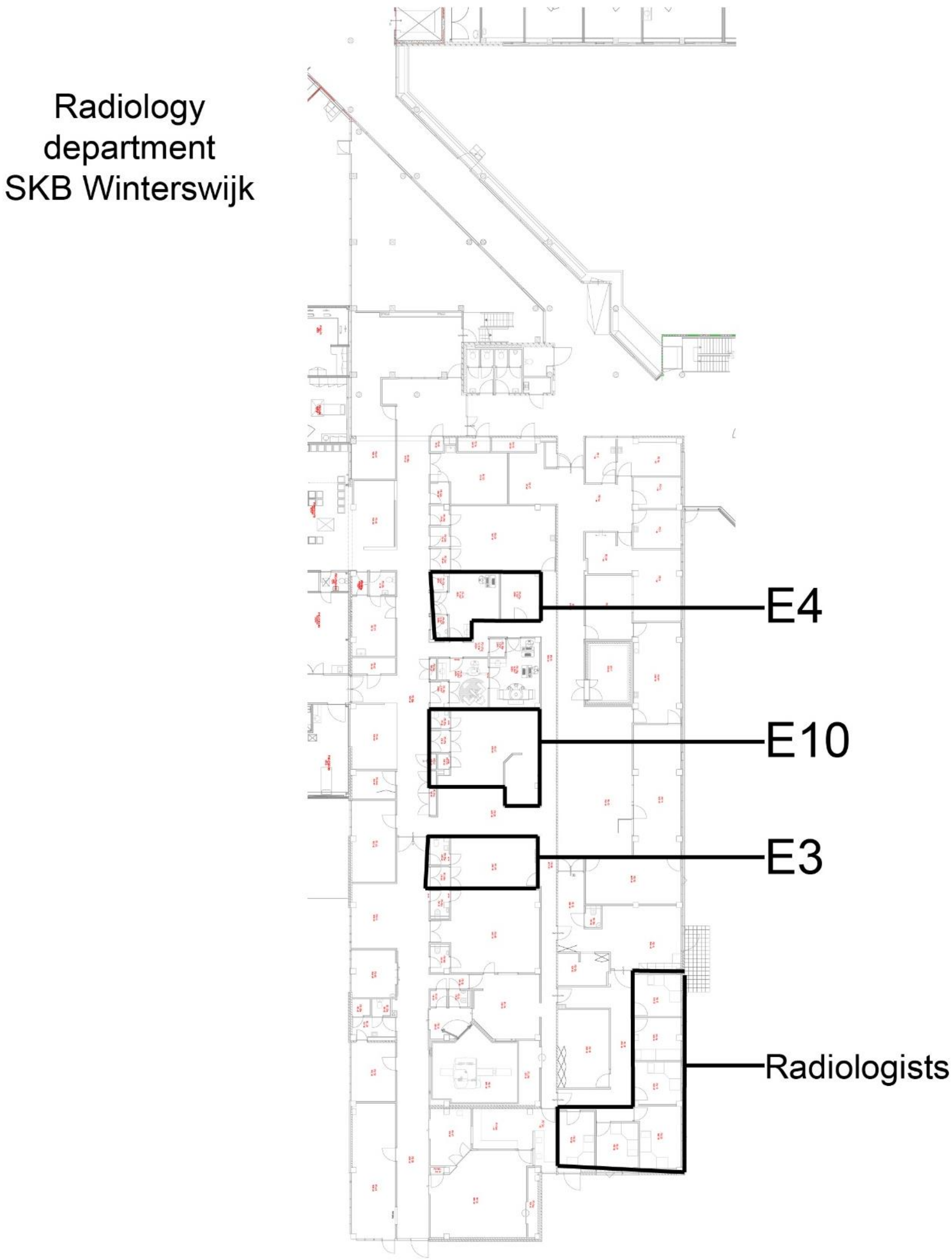
APPENDIX A – ALL TREATMENT CODES PER EXAMINATION ROOM

E10	Regular	Clinical	Emergency	Joints	Shoulders
	1370, 2970, 2971, 4076L, 4076R, 6971, 7050, 7070, 7072, 7073, 7074, 7077, 8470, 9067L, 9067R	1370, 2970, 2971, 4076L, 4076R, 6971, 7050, 7070, 7072, 7073, 7074, 7077, 8470, 9067L, 9067R	0000	*4070L, 4070R, 4071L, 4071R, 4072L, 4072R, 4073L, 4073R, 4074L, 4074R, 4075L, 4075R, 4077L, 4077R, 7076, 9070, 9071L, 9071R, 9072L, 9072R, 9073L, 9073R, 9074L, 9074R, 9075L, 9075R, 9078L, 9078R*	*4078L, 4078R*

E4	Regular	Abdominal	Emergency	Mammapoli	Target/Regular	Biopsy	Polyclinical	Combi
	1370, 2970, 2971, 4076L, 4076R, 6970, 6971, 6973, 7050, 7070, 7072, 7073, 7074, 7077, 8470, 9067L, 9067R	7070, 7072	0000	*6978*	6970	*0073, 0074, 0075, 0078,* 1370, 2970, 2971, 4076L, 4076R, 6970, 6971, 6973, 7050, 7069, 7071, 7073, 7074, 7077, 8470, 9076L, 9076R, 9080	0077, 1370, 2970, 2971, 4076L, 4076R, 6970, 7050, 7069, 7071, 7073, 7074, 7077, 8470, 9076L, 9076R, 9080	0077, 1370, 2970, 2971, 4076L, 4076R, 6970, 6971, 6973, 7050, 7069, 7071, 7073, 7074, 7077, 8470, 9076L, 9076R, 9080

E3	Regular	Abdominal	Emergency	Polyclinical	Duplex	Duplex carotids
	1370, 2970, 2971, 4076L, 4076R, 6971, 7050, 7070, 7071, 7072, 7073, 7074, 7077, 8470, 9067L, 9067R, 9080	7070, 7072	0000	0077, 1370, 2970, 2971, 4076L, 4076R, 6970, 6971, 6973, 7050, 7070, 7073, 7074, 7069, 7077, 8470, 9067L, 9067R	*9739, 9740, EV-100, EV-101, EV-103, EV-700, EV-701, EV-702, EV-703, EV-900, EV-903, EV-904, EV-905, EV-906, EV-907, EV-908, EV-909, EV-910, EV-911, EV-912, EV-913, EV-914*	*1670*

APPENDIX B – FLOORPLAN OF THE RADIOLOGY DEPARTMENT



APPENDIX C – BLUEPRINT SCHEDULES

On the following pages, we give the blueprint schedules from room E3, E4, and E10 respectively.

E3	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
8:30		ABDOMINAL	ABDOMINAL	ABDOMINAL	REGULAR
8:55		REGULAR	REGULAR	REGULAR	REGULAR
9:20		REGULAR	REGULAR	REGULAR	REGULAR
9:45		REGULAR	REGULAR	REGULAR	REGULAR
10:10					
10:25		REGULAR	REGULAR	REGULAR	INPATIENT
10:50		REGULAR	REGULAR	REGULAR	REGULAR
11:15		REGULAR	REGULAR	REGULAR	INPATIENT
11:40		REGULAR	REGULAR	EMERGENCY	EMERGENCY
12:05		EXTENSION/BREAK	EXTENSION/BREAK	EXTENSION/BREAK	
12:30					
13:00		DUPLEX		DUPLEX	
13:20		DUPLEX		DUPLEX	
13:40					
13:45		DUPLEX CAROTIDS		DUPLEX CAROTIDS	
14:30					
14:45		DUPLEX		DUPLEX	
15:05		DUPLEX		DUPLEX	
15:25					
15:30		DUPLEX CAROTIDS		DUPLEX CAROTIDS	
16:15		DUPLEX CAROTIDS		DUPLEX CAROTIDS	
17:00					

E4	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
8:30	ABDOMINAL	MP	ABDOMINAL	MP	REGULAR
8:55	ABDOMINAL	MP	REGULAR	MP	ABDOMINAL
9:20	REGULAR	MP	REGULAR	MP	REGULAR
9:45	REGULAR	MP	REGULAR	MP	REGULAR
10:10	ECHO MAMMA OSS				
10:25		MP	REGULAR	MP	REGULAR
10:35		MP		MP	
10:50	REGULAR		REGULAR		REGULAR
11:15	REGULAR	MP	REGULAR	MP	REGULAR
		MP		MP	
11:40	MAMMA OSS		MAMMA OSS		REGULAR
11:45					
12:05	EXTENSION / START BREAK	EXTENSION / START BREAK	EXTENSION / START BREAK	EXTENSION / START BREAK	EXTENSION / START BREAK
12:30					

13:00	BIOPSY	EMERGENCY	BIOPSY	EMERGENCY	REGULAR
13:25		COMBI		COMBI	REGULAR
13:50	COMBI	COMBI	COMBI	COMBI	EMERGENCY
14:15	EMERGENCY	COMBI	EMERGENCY	COMBI	REGULAR
14:40	COMBI	KLINISCH	COMBI	KLINISCH	REGULAR
15:05	COMBI		COMBI		
15:20		TARGET/REG		TARGET/REG	
15:30					
15:40	COMBI	TARGET/REG	COMBI	TARGET/REG	EMERGENCY
16:05	REGULAR	TARGET/REG	REGULAR	TARGET/REG	EMERGENCY
16:30					
16:35		TARGET/REG		TARGET/REG	
16:55					

E10	MONDAY	TUESDAY	VEDNESDAY	THURSDAY	FRIDAY
8:30	REGULAR	REGULAR	REGULAR	REGULAR	
8:55	REGULAR	REGULAR	REGULAR	REGULAR	
9:20	REGULAR	REGULAR	REGULAR	REGULAR	
9:45	EXTENSION/BREAK	EXTENSION/BREAK	EXTENSION/BREAK	EXTENSION/BREAK	
10:10					
10:25	INPATIENT	REGULAR	INPATIENT	REGULAR	
10:50	REGULAR	EMERGENCY	REGULAR	EMERGENCY	
11:15	REGULAR	REGULAR	REGULAR	REGULAR	
11:40	EMERGENCY	REGULAR	EMERGENCY	REGULAR	
12:05	EXTENSION/BREAK	EXTENSION/BREAK	EXTENSION/BREAK	EXTENSION/BREAK	
12:30					
13:00	MSU	MSU	MSU	MSU	MSU
13:20	MSU	MSU	MSU	MSU	MSU
13:40	MSU	MSU	MSU	MSU	MSU
14:00	MSU	MSU	MSU	MSU	MSU
14:20	MSU	MSU	MSU	MSU	MSU
14:40	MSU	MSU	MSU	MSU	MSU
15:00					
15:15	MSU	MSU	MSU	MSU	MSU
15:35	MSU	MSU	MSU	MSU	MSU
15:55	MSU	MSU	MSU	MSU	MSU
16:15	MSU	MSU	MSU	MSU	MSU
16:35					

APPENDIX D – KPI OVERVIEW OF ALL SIMULATION RESULTS

Cat.	Exp.	ASU	ACU	AU10	AU44	AU3	AAT	NrR	NrE	NrOP	AWT	NrRj
1	S1	0,75	0,87	0,86	0,84	0,74	16,3	8177	1854	9,7	10,4	309
	S2	0,61	0,73	0,75	0,68	0,59	21,5	6519	1853	6,3	9,1	3574
	S3	0,81	0,93	0,90	0,89	0,79	0,8	8790	1855	13,2	11,0	0
2	DF1	0,75	0,87	0,86	0,84	0,74	16,3	8177	1854	9,7	10,4	309
	DF2	0,75	0,87	0,86	0,84	0,74	16,3	8177	1854	9,7	10,4	309
	DF3	0,78	0,90	0,87	0,87	0,78	5,4	8486	1853	10,7	10,9	28
	DF4	0,76	0,88	0,86	0,85	0,74	14,7	8241	1854	10,0	10,6	282
	DF5	0,75	0,87	0,86	0,84	0,74	16,3	8177	1854	9,7	10,4	309
	DF6	0,77	0,88	0,88	0,85	0,75	11,8	8310	1854	10,3	10,5	222
	DF7	0,78	0,90	0,89	0,87	0,76	5,4	8485	1854	11,2	10,5	28
	DF8	0,76	0,88	0,86	0,85	0,76	11,0	8333	1854	10,8	10,5	64
	DF9	0,76	0,88	0,86	0,85	0,76	12,5	8291	1854	10,5	10,2	111
	DF10	0,76	0,88	0,86	0,85	0,76	11,1	8333	1854	10,8	10,7	33
	DF11	0,77	0,89	0,86	0,86	0,77	8,5	8395	1854	10,7	10,5	28
	DF12	0,77	0,89	0,87	0,86	0,76	8,5	8396	1854	10,8	10,8	2
3	OA1	0,75	0,87	0,86	0,84	0,74	16,3	8177	1854	9,7	10,4	309
	OA2	0,81	0,92	0,96	0,90	0,65	4,6	8633	1854	18,1	22,2	60
	OA3	0,79	0,91	0,94	0,88	0,67	5,7	8589	1854	16,2	17,6	87
	OA4	0,80	0,92	0,95	0,90	0,69	4,6	8632	1854	16,7	17,9	60
	OA5	0,78	0,90	0,91	0,87	0,70	14,1	8264	1854	15,2	11,6	282
	OA6	0,78	0,90	0,91	0,86	0,74	11,0	8366	1854	17,1	20,2	222
	OA7	0,80	0,92	1,00	0,92	0,57	4,8	8631	1854	22,0	51,9	87
	OA8	0,82	0,94	0,97	0,92	0,69	1,1	8778	1854	22,6	37,3	28
	OA9	0,80	0,92	1,00	0,92	0,57	4,6	8632	1854	22,0	44,1	60
	OA10	0,82	0,94	0,96	0,91	0,70	0,8	8778	1854	23,4	40,0	0
	OA11	0,83	0,95	1,01	0,94	0,62	0,0	8819	1854	29,3	77,0	0
4	DO1	0,81	0,93	0,93	0,91	0,73	3,3	8572	1854	15,9	15,0	0
	DO2	0,82	0,94	0,97	0,91	0,69	1,1	8778	1854	22,7	37,2	28
	DO3	0,81	0,93	0,95	0,91	0,70	3,3	8571	1854	15,9	13,4	0
5	DO3*	0,71	0,81	0,88	0,83	0,71	3,3	8573	1854	11,1	7,0	0

ASU: Average slot utilization

ACU: Average capacity utilization

AU10/AU4/AU3: Average utilization E10/E4/E3

AAT: Average access time

NrR: Number of outpatients per year

NrE: Number of emergency patients per year

NrOP: Numer of overtime patients per day

AWT: Average waiting time

NrRj: Number of rejected patients per year

APPENDIX E – KPI BOXPLOTS FOR SIMULATION CATEGORIES 1 AND 5

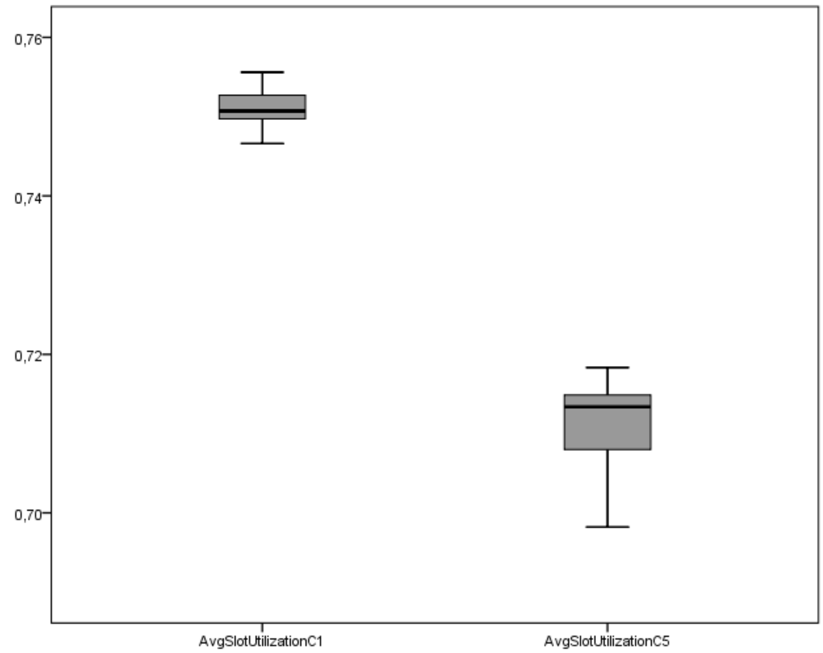


Figure 14 - Boxplot of the slot utilization for category 1 (left) and category 5 (right), n=15. The value for C5 is significantly lower, which a lower utilization of the time slots – which makes sense since the emergency slots for inpatients are not used.

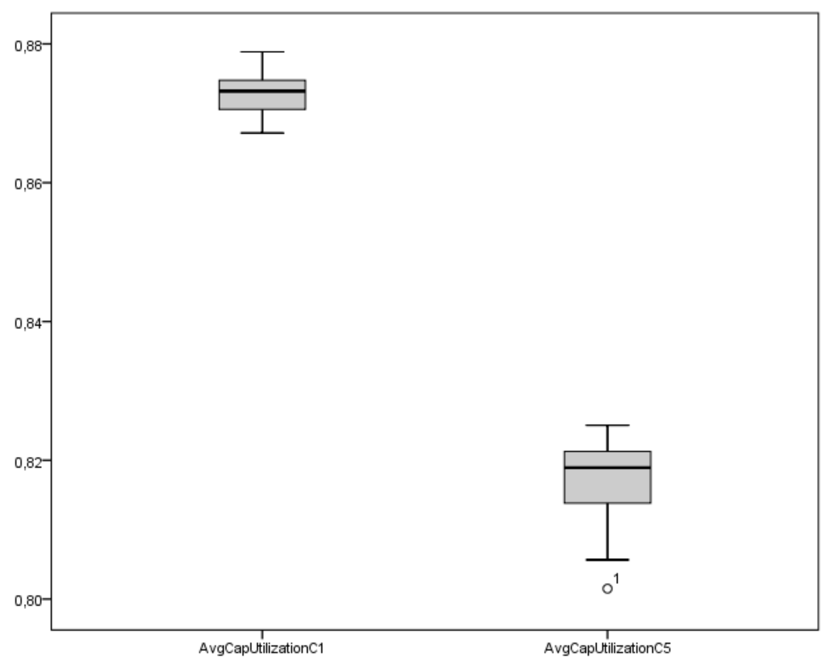


Figure 15 - Boxplot of the capacity utilization for category 1 (left) and category 5, being significantly lower (right), n=15.

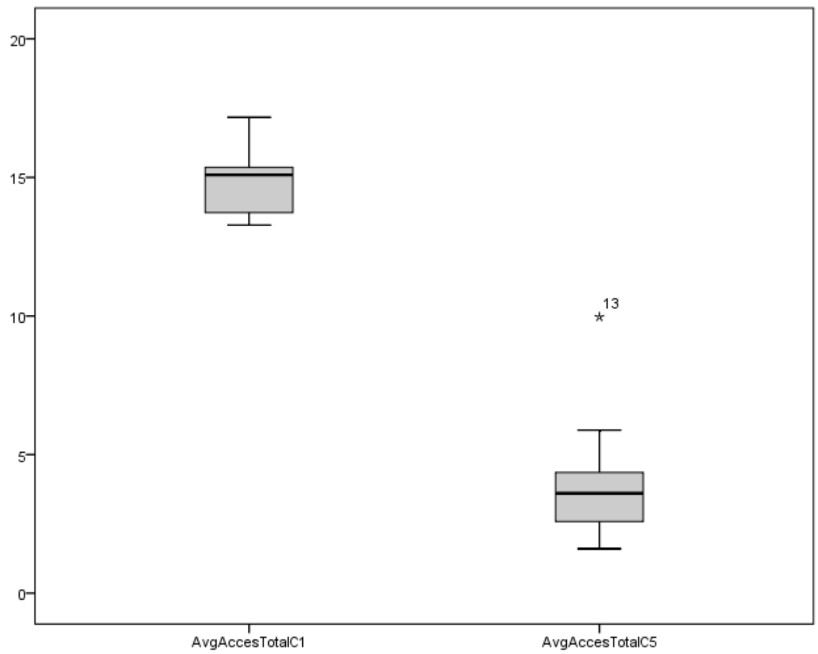


Figure 16 - Boxplot of the average total access time for category 1 (left) and category 5 (right), n=15. The access time is in days. It is visible that the average access time is significantly lower (an average of more than 10 days even) than the access time for the current situation.

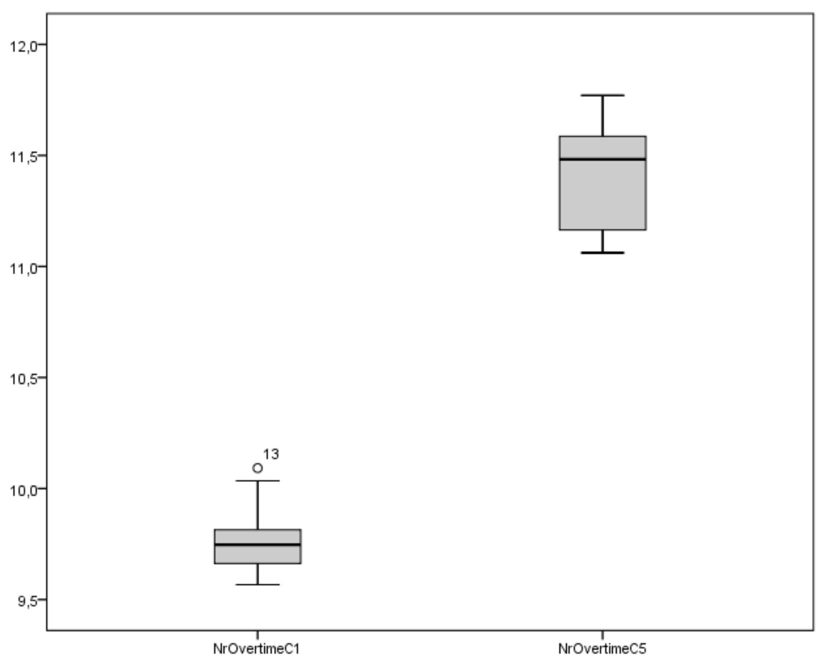


Figure 17 - Boxplot of the number of overtime patients for category 1 (left) and category 5 (right), n=15. The number of overtime patients rises for category 5, as there are less scheduled patients and any patient that is examined after the last scheduled patient before the afternoon break or before closing time is considered an overtime patient.

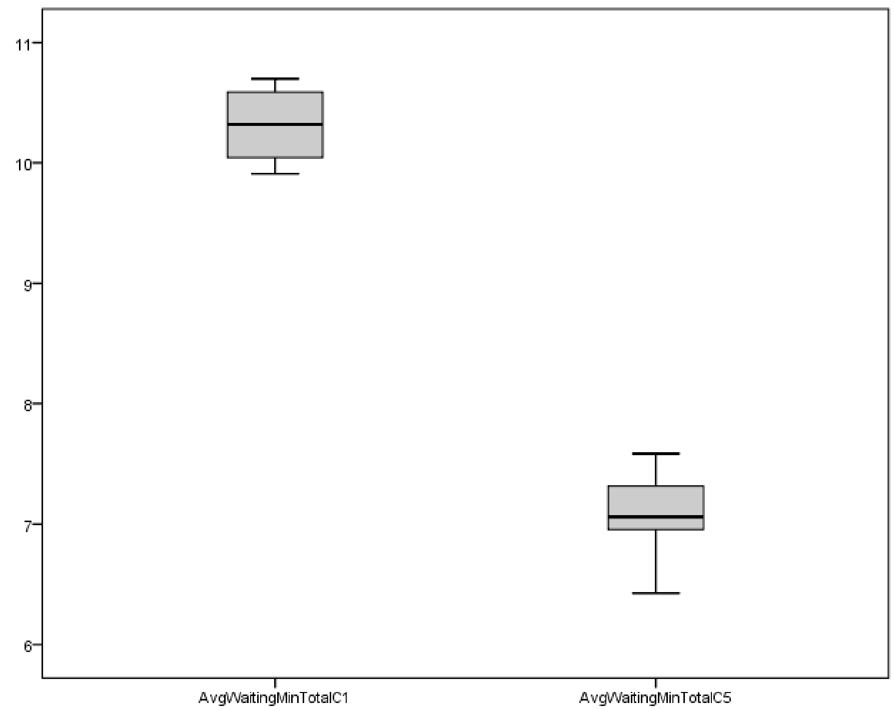


Figure 18 - Boxplot of the average total waiting time for category 1 (left) and category 5 (right), n=15. The waiting time (in minutes) for category 5 is significantly lower.