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Improving session planning in the plaster room of Sint Maartenskliniek

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Improving session planning in the plaster room of Sint Maartenskliniek

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Preface

During this research at the Sint Maartenskliniek (SMK) I have learnt not only about the SMK, the plaster room, and its challenges, but also about managing a research project, writing a thesis, and my own capabilities. I am proud of what I have achieved and confident that the plaster room can proceed with the results of this research.

I would like to thank several people; without your help this research would have not been the same. I thank all my supervisors. Derya, our discussions have been fruitful to ensure that my work maintained a high academic level. Erwin, your feedback enabled my report to improve greatly and you provided an environment in which I became confident of receiving feedback. Bas, our weekly discussions were of significant guidance for me. Furthermore you provided the data collection so that I could analysis it without delaying the process. Helmie, your expertise in the plaster room ensured that I was always able to see the practical implication of this research.

I would also like to thank all the staff members of the plaster room, I felt welcome in your department and was always free to ask questions. I specifically thank Inge and Hanneke for their time and detailed explanation of the plaster room scheduling. To all colleagues, thank you for your help and ideas during my research, I liked working in this environment with like-minded people. Ingeborg, thank you for your help and feedback. I thank Maartje for introducing me to her research and her model. Rogier, our research projects started at the same time and our talks about them gave me the opportunity to reflect on my work and to learn from you.

Finally, I thank all my friends who supported me during this project. Rianne, thank you for reading my report. Mama, I am so glad for your support in all my decisions. Bart, you have always been there for me during every step, thank you!

Management Summary

Introduction

This research focuses on identifying and assessing interventions that improve the operational performance of the plaster room in the Sint Maartenskliniek (SMK) in Nijmegen. The SMK is currently the leading hospital in the field of posture and movement in the Netherlands and Europe. To maintain this position, the SMK invests in research that improves the logistics of the care process of the hospital. With this research the SMK wishes to improve the operations in the plaster room.

Problem description

Based on a previously conducted case-study in the plaster room, the plaster room's management perceives that waiting times are too long and workload is not balanced throughout the day.

Insight in the current performance and improving this performance is expected to lead to a better work environment for personnel, and more patient friendly care.

Approach

We analyse the current process, and current planning methods. We define measures for performance, which we use to describe the current performance. We provide a baseline measure that can be used as a frame of reference for comparing the performance in the future. We determine problem areas within the current performance, and identify interventions from the literature and from management vision. In light of our findings we propose a simulation model, based on the model of Van de Vrugt (2016). The model simulates the current performance of the plaster room and enables interventions to be implemented. We measure the performance of the interventions, and with these results we determine which intervention(s) improves the performance the most.

Results

The baseline measure shows that 94.3% of the patients wait less than the target; on average they wait 5.6 minutes. This performance is very good. In the current system

overtime occurs rarely; 99.3% of the days no overtime occurs. The average overtime per day is 0.14 minute. The utilization is 81.3%, which means that the plaster room works efficiently. The performance on “hours worked” is within the target.

The performance on balance of workload is low, 41.8% of the times the workload is not correctly staffed. Performance on estimating appointments is even worse, as only 17% of the appointments are correctly estimated.

After assessment with the simulation model we determine the most promising intervention, namely the one which improves the workload balance the most. Estimation of appointment lengths can improve the appointment planning and therefore the workload balance. The model shows that 62.2% of the times the workload is correctly staffed. The most promising intervention is the dynamic capacity reservation, the performance on correctly staffed workload increases to 63.2%. The dynamic capacity reservation reduces the effect of walk-in patients as fewer appointments are scheduled during rush hours in terms of walk-in patients.

Conclusion

The best performance is obtained by implementing dynamic capacity reservation, instead of the currently used static reservation. The “workload correctly staffed” improves to 63.2%, the average overtime increases by 0.21 minute, and all other performances remain the same. Before implementing the intervention where extended opening hours are applied, the plaster room’s management should execute further research towards the expected demand in the extended hours.

This research gives insight in the performance of in the plaster room. Not only did we provide recommendations to improve the performance. We also made it possible to measure the performance in terms of waiting time, balance of workload for staff throughout the day, overtime, hours worked, and utilization. We suggest that these performance measures should be used, so that results of these measures can be compared.

For the scientific community this research contributes to the limited literature of simulation studies conducted in the plaster room. We present performance measures that are more detailed, and demonstrate that dynamic capacity reservation improves operational performance in comparison with static capacity reservation. Other plaster room managers can take the planning methods into account when improving their own performance.

Managementsamenvatting

Inleiding

Dit onderzoek richt zich op het identificeren en evalueren van interventies die de prestatie verbeteren in de gipskamer van de Sint Maartenskliniek (SMK) te Nijmegen. De SMK is een toonaangevend ziekenhuis op het gebied van houding en beweging in Nederland en Europa. De SMK wil deze positie vast houden, daarom investeert zij in onderzoek dat de operationele processen van het ziekenhuis verbeteren. Met dit onderzoek wil de SMK de prestatie van de gipskamer verbeteren.

Probleemstelling

Uit een eerder uitgevoerde case-studie in de gipskamer blijkt dat de wachttijden te lang zijn en de werklast over de dag niet gebalanceerd is.

Met inzicht in de huidige situatie en verbetering van de prestatie bereiken we een betere werkomgeving voor het personeel en meer patiëntvriendelijke zorg.

Aanpak

In dit onderzoek analyseren we het huidige proces en planmethodes. We ontwikkelen prestatie-indicatoren, waarmee we de huidige prestatie meten. Met de prestatie-indicatoren bepalen we de nulmeting. Deze meting kan in de toekomst gebruikt worden om de prestatie te vergelijken. We stellen probleemgebieden in de huidige prestatie vast en identificeren interventies vanuit de literatuur en vanuit de management visie. Aan de hand van onze bevindingen kiezen we voor het maken van een simulatiemodel, op basis van het model van (Van de Vrugt, 2016). Het model simuleert de huidige prestatie van de gipskamer. Met het model beoordelen we de interventies. Hiermee bepalen we de interventie(s) die de prestatie het meest verbetert en makkelijk toepasbaar is.

Resultaten

De nulmeting toont aan dat 94.3% van de patiënten minder lang wachten dan de doelstelling; gemiddeld wachten patiënten 5.6 minuten. Deze prestatie is zeer goed. In het huidige systeem komt overwerken nauwelijks voor; in 99.3% van de dagen wordt er niet overgewerkt. De gemiddelde duur van overwerken per dag is 0.14 minuten. De productiviteit is 81.3%, dit betekent dat de gipskamer efficiënt werkt. De prestatie op inzetbaarheid is binnen de doelstelling.

De balans in werklast is laag, in 41.8% van de tijdstippen is de werklast niet goed afgesteld op het personeel. De prestatie op in schatten van de afspraak duur is nog slechter, slechts 17% van de afspraken wordt goed ingeschat.

Na implementatie in het simulatiemodel bepalen we de meest belovende interventie, deze verbetert de balans van de werklast het meest. Het correct inschatten van de afspraak duur verbetert de balans in werklast. Het model laat zien dat in 62.2% van de tijdstippen de werklast goed verdeeld is over het personeel. De meest belovende interventie is dynamische capaciteit reservering, deze verbetert de goed afgestelde werklast met 63.2%. De dynamische capaciteit reservering vermindert het effect van inlooppatiënten. Inlooppatiënten zorgen voor een onverwachte vraag naar zorg, waardoor de wachttijden oplopen en de werklast niet meer goed verdeeld is. Door minder geplande afspraken toe te laten tijdens momenten waar historisch gezien veel inlooppatiënten aankomen vermindert dit de onbalans.

Conclusie

De beste prestatie wordt gehaald door het implementeren van een dynamische capaciteit reservering, in plaats van de nu gebruikte statische reservering. De prestatie gebalanceerde werklast stijgt naar 63.2%, de gemiddelde overwerk duur stijgt met 0.21 minuten en alle andere prestaties blijven gelijk. Voordat de bedrijfstijd uitbreiding ingevoerd gaat worden, moet het management van de gipskamer nadenken over de invulling van deze uren gelet op de personeelsbezetting. Wij stellen voor om onderzoek te doen naar de verwachte vraag in deze extra uren.

Dit onderzoek geeft inzicht in de prestatie van de gipskamer. Niet alleen hebben we aangetoond hoe de prestatie verbetert kan worden. Ook hebben we het mogelijk gemaakt de prestatie op basis van wachttijden, balans in de werklast over de dag, overwerken, inzetbaarheid en productiviteit te meten. In volgend onderzoek in de gipskamer kunnen deze prestatie-indicatoren gebruikt worden, de resultaten kunnen dan direct worden vergeleken.

Voor de wetenschappelijke gemeenschap draagt dit onderzoek bij aan de kleine hoeveelheid simulatiestudies die zijn uitgevoerd in de gipskamer. We geven gedetailleerde prestatie-indicatoren en stellen vast dat een dynamische capaciteit reservering de operationele prestatie verbetert ten opzichte van een statische capaciteit reservering. Andere gipskamers kunnen de huidige planningsmethoden van de SMK als voorbeeld nemen als ze hun eigen prestatie willen verbeteren.

Contents

List of Abbreviations

FTE	Full-Time Equivalent
KPI	Key Performance Indicator
OCT	Orthopaedic Cast Technician; Dutch *gipsverbandmeester*
SMK	Sint Maartenskliniek

Terminology

Inpatients	Patients staying overnight in the hospital
Orthosis	A support, brace, or splint used to support, align, prevent, or correct the function of movable parts of the body
Outpatients	Patients who are not being admitted to the ward
Outpatient department	Part of a hospital designed for treatment of outpatients

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Chapter 1

Introduction

This chapter provides background information on why we perform this research, outlines the problem, and sets the research objectives and research questions. It concludes with the outline of the report.

Background

We live in an ageing society. Not only is the life expectancy rising, but also the population as a whole is declining. This has a wide influence on the society and its services. As we grow older we need healthcare services more often. Therefore the demand for healthcare services continues to grow.

Healthcare costs rise due to the growth in demand and technical innovations, that are (almost always) more expensive. There is a need to minimize the overall expenses within the medical field. Competition between healthcare suppliers will decrease costs, but healthcare suppliers should also work on decreasing their cost by working more efficiently.

To achieve this efficiency, investigation of current operations is necessary. We see a trend in hospitals moving their focus towards efficient operations. The Sint Maartenskliniek (SMK) is no exception.

The SMK specializes in posture, movement, and the control thereof, where the best care for the patient is most important. SMK has multiple locations in the Netherlands; the headquarters in Nijmegen provides a centre for orthopaedic, rheumatism, and rehabilitation care. The SMK serves patients from all over the Netherlands and even from Germany. In total 43.6% of the patients travel more than 50 kilometres to Nijmegen (Sint Maartenskliniek, 2015). The SMK defines itself as “the clinic for posture and movement” and they state that they are the leading hospital in this field in Europe (Raad van Bestuur van de Sint Maartenskliniek, 2013).

As the SMK aims to maintain its leading position, while battling the growing costs and demand, they decided to establish a department focused solely on its healthcare operations. In August 2014 this department started with a set of projects, which create a continuous trend in improving the operations of the hospital. In all three care centres multiple projects started and this research is part of a project in the orthopaedic centre.

The orthopaedic centre provides care for specialised complex treatments and patient groups. For this care, patients from all over of the Netherlands are referred to the SMK. The orthopaedic centre also has a more regional function for less complex treatments. The orthopaedic centre consists of an outpatient department, operating rooms, nursing unit, and the plaster room.

The orthopaedic centre treats all sub specialities, divided in specified units. Specialised orthopaedic care includes treatment of rare congenital malformation, growth disorders, revision surgery of artificial joints, and reconstructive surgery of the spine. For each unit the SMK defines their expectation with respect to growth and case-mix changes (Raad van Bestuur van de Sint Maartenskliniek, 2013). For the orthopaedic centre this means that the demand for care is growing and they anticipate a shift to more complex care.

To keep up with the growing cost and demand, and the shift in case-mix while providing good, patient centralized care the orthopaedic centre needs to improve its efficiency. In this research we focus on the plaster room.

1.1 Problem description

Patients in the plaster room have very different care paths, some need just one visit, and others visit twice a week over a time frame of multiple weeks. The frequency of visits of each patient is highly variable. Each treatment in the plaster room also has a high variability in treatment length. Furthermore there are a large number of patients who do not have an appointment before going to the plaster room. These so-called walk-in patients are mostly sent through from the outpatient clinic. The number of walk-in patients fluctuates every day and throughout the day. Based on the above described insights, we conclude that it is difficult to estimate the demand, frequency and treatment length of appointments.

The staff in the plaster room, who provides treatment, is called Orthopaedic Cast Technician (OCT). The OCTs are not only available for treatment in the plaster room but also they go to the ward when a patient needs treatment and cannot come to the plaster room. They also assist during operations where plaster is applied. The combination of these treatments in the hospital requires the staff to move between departments in the hospital. Therefore the staff availability for treatment in the plaster room is not constant during the day, and it is not known beforehand as treatments in the ward are not planned in advance.

Earlier in the project of the orthopaedic centre, a case-study in the plaster room was performed. It was found that patients waiting times are too long and staff experiences an unbalanced workload throughout the day. Within the plaster room there is a knowledge gap on which operation research methods can be used to improve the performance. This research is conducted to address this knowledge gap.

Before the gap can be closed we need to analyse the process and performance of the plaster room, from this analysis we can identify improvement areas and propose interventions. These interventions must be tested before implementation in practice. The most promising intervention(s) is found, based on the test results.

1.2 Research objective

The objective of this project is *to analyse the current process and performance of the plaster room as well as to identify and assess interventions that improve the current performance in terms of patient waiting times and balance of workload*.

In order to achieve this objective we need to investigate the current operational performance of the plaster room at the SMK, define measures for this performance, design interventions that improve the performance and recommend intervention(s) for implementation.

To accomplish the research objectives we have set the following goals:

1. Describe current operational processes in the plaster room of the SMK.
2. Define performance measures and analyse current performance with them.
3. Perform literature review on plaster room operations to gather and generate ideas for interventions.
4. Build model to measure performance of the interventions.
5. Describe the effect of the interventions on the performance.
6. Give recommendations to the SMK on implementing the intervention(s).

1.3 Research questions

In line with the research objective and goals, we state the following research questions:

1. What are the current operational processes in the plaster room at the Sint Maartenskliniek, and how are they organized?
2. What should be the measures for the performance of the operational processes?
3. What is the current performance of the operational processes in the plaster room at the Sint Maartenskliniek?
4. What is written in the literature concerning operational processes in the plaster room, and which interventions can we find?
5. How can we test the selected interventions?
6. What is the expected performance of the interventions?
7. Which insights does this research give and which interventions can the SMK implement?

Chapter 2 gives insight into the current operational processes in the plaster room. We define the stakeholders and based on their process we describe the operations in the plaster room. In Chapter 2 we also discuss the current planning methods.

In Chapter 3 we find important indicators for each stakeholder, from these indicators we define the Key Performance Indicators (KPIs). For each KPI we calculate a baseline measure, which we use later on in the research and can be used by the SMK in the future.

Chapter 4 discusses the literature findings with the respect to plaster room operations, appointment planning, and models used in similar studies. From these findings we propose interventions we want to investigate.

Chapter 5 introduces the simulation model that we use to evaluate the interventions.

Chapter 6 describes the results of the experiments we do with the interventions in the model.

Chapter 7 completes the report with a conclusion, and discussion as well as recommendations for the organization, and future research.

Chapter 2

Process analysis

In this chapter we analyse the current operational processes in plaster room. Our goal is to identify any problems within these processes. Before we can identify how we can improve the processes, we need to analyse the stakeholders which is done in Section 2.1. Section 2.2 focuses on the plaster room characteristics, while Section 2.3 discusses the planning and control.

2.1 Stakeholders

To identify areas of improvement in the current processes, we describe the relevant stakeholders in this process and divide them into three groups.

2.1.1 Patients

The most important stakeholders in the plaster room are the patients. Two types of patients are treated in the plaster room, namely inpatients and outpatients. Inpatients are patients who stay in the hospital for at least one night. Outpatients are patients who visit the hospital for diagnosis or treatment, but are not being admitted for overnight care in the ward. Both inpatients and outpatients can have an appointment made on a previous day or get an appointment when they enter the plaster room. The latter means that the appointment is planned on the same day as the appointment takes place; we define this appointment as unplanned because at the start of this day they are not scheduled. Thus, we classify four types of patients:

Planned inpatients patients with an appointment scheduled on a previous day and staying overnight in the hospital

Planned outpatients	patients with an appointment scheduled on a previous day and not being admitted to the ward
Unplanned inpatients	patients without an appointment and staying overnight in the hospital
Unplanned outpatients	patients without an appointment and not being admitted to the ward

The unplanned patients are in this report referred to as walk-in patients, because their appointment is unplanned until their need for an appointment in the plaster room is known. Their appointment is scheduled on the same day. The term "walk-in" is more descriptive than "unplanned", because the appointment is scheduled when the patient walks into the plaster room area.

2.1.2 Staff

Orthopaedic Cast Technician

The Orthopaedic Cast Technician (OCT) treats the patients in the plaster room, assists during operations where plaster is applied and assists with plaster related problems in the ward. The OCT treats all patients and does not have a specified list of patients he treats. Furthermore one of the OCT is responsible for the personnel planning. For the plaster room the OCT is a stakeholder, without him the plaster room is not functional and with his needs not being met the quality of care decreases.

Planning staff

The planning staff is located at the front desk in the plaster room. Here patients arrive and register. The planning staff welcomes the patients, registers them in the system as "in the waiting room", handles several administrative tasks, and makes new appointments for the patients. As a stakeholder the planning staff is important as they plan the appointments.

Medical specialist

The medical specialists play an important role in the plaster room in two ways. First, they are available for consultations, in case a patient has to see the specialist before treatment can continue. Second, specialists play an important role in the number of patients who visit the plaster room. Walk-in patients often visit the plaster room after an outpatient appointment with the specialist.

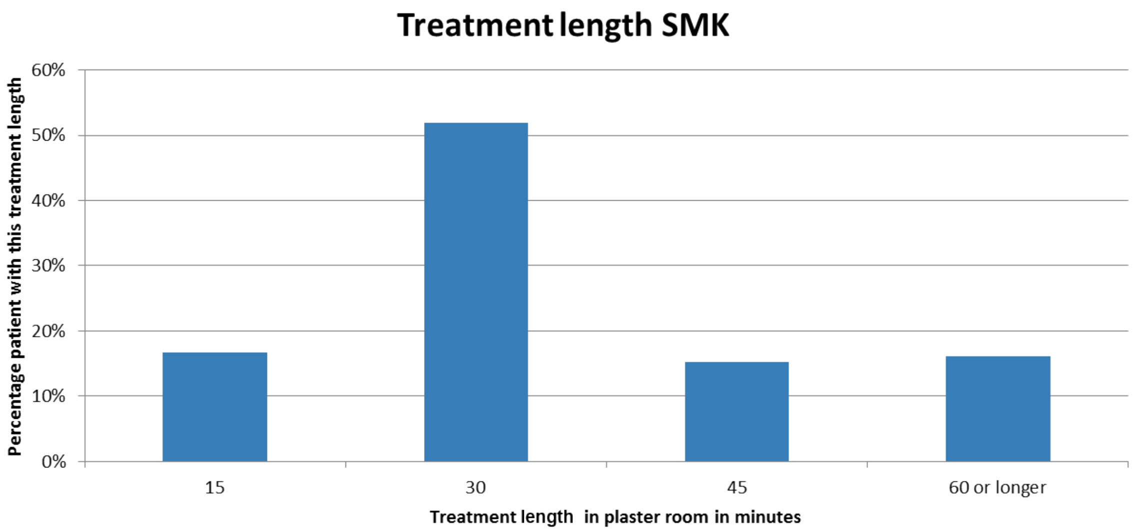

Figure 2.1: Treatment length, N=12101; data from July 2015 to December 2016, source hospital data

2.1.3 Management

The management of the SMK is very patient orientated, but is also interested in the efficiency, productivity, and satisfaction of employees. For the plaster room management is an important stakeholder, because changes towards improvement are influenced by the management.

2.2 Plaster room characteristics

The plaster room consists of six treatment rooms, a waiting area, an office, a front desk, and a workbench. The workbench is a central desk where plasters and orthoses are altered. One of the treatment rooms is large enough to fit a bed. This room is used when an inpatient is tied to bed. In each treatment room one patient is treated at a time.

The treatments involve applying and removing plaster, fitting braces and other orthoses, and giving advice in how to use the orthosis. Treatments can also involve wound treatment, which is special for the plaster room of the SMK. The average treatment length is 38.1 minutes. Figure 2.1 shows the percentage of appointments that have certain duration. We can see that in the SMK 52.0% of the patients are treated for 30 minutes. Some treatments are very complex and therefore take much longer, the treatment length can be up to two hours.

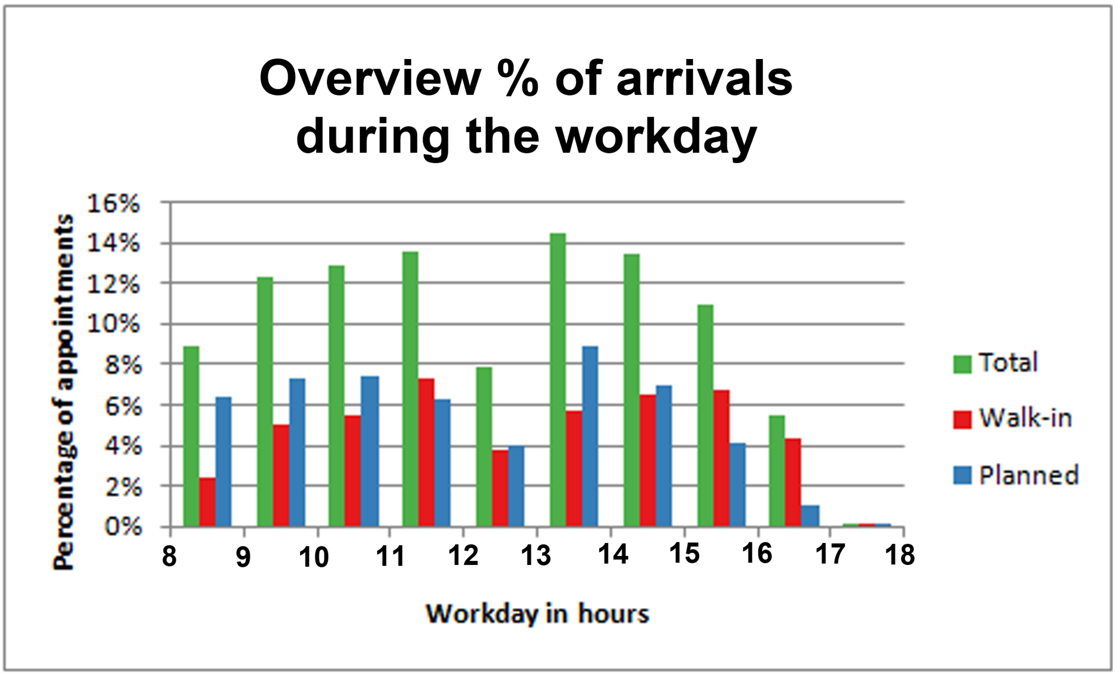

Figure 2.2: Overview number of patients, N=18873; data from July 2015 to December 2016, source hospital data

The plaster room is open from Monday to Friday, from 8:00 to 17:30. On average the plaster room has 47.7 appointments per day. Of all appointments 47.5% are planned on the same day. Figure 2.2 shows the percentage of patients over the workday there is a distinction between planned and walk-in patients. We can especially see that at the end of the day, between 15:00 and 18:00, the percentage of the walk-in patients is high. We can also conclude from this figure that the end of the day, between 16:00 and 18:00, is exceptionally quiet. At 17:00 some OCTs end their workday, but at least two OCTs stay until 17:30.

The SMK aims that planned patients do not wait more than 15 minutes, walk-in patients should not have to wait more than 30 minutes. In Figure 2.3 we see the waiting time for all patients. It shows that even though the majority of patients wait less than 5 minutes, some patients have an extensively long waiting time.

Patients coming from all specialities (orthopaedics, rehabilitation, rheumatism, internal medicine, and sports) are treated in the plaster room. However, 95% of the patients come from the orthopaedics centre.

Multiple groups of patients are treated by OCTs, all these treatments are scheduled in the plaster room agenda. We determine patients in the operating room, patients in the ward, inpatients who visit the plaster room, and all other patients who visit the plaster room. Furthermore, we can describe the patient process in the plaster room

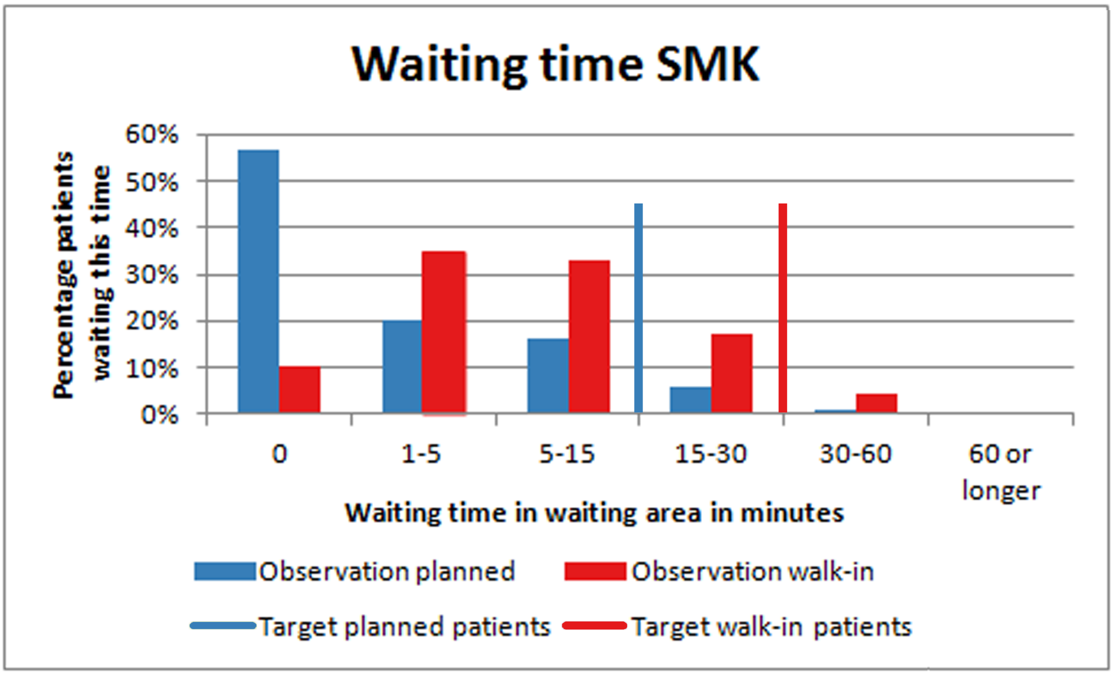

Figure 2.3: Overview waiting times all patients, N=9952; data from July 2015 to December 2016, source hospital data

based on three trajectories:

1. Only treatment in the plaster room, this treatment can involve all treatment types given in the plaster room.
2. Patient gets consultation in the plaster room, either from the OCT or from a medical specialist, and further treatment is given.
3. Plaster is removed, patient is sent to radiology or another department in the hospital. After this trajectory the patient comes back to the plaster room for further treatment.

After the treatment multiple exits are possible:

1. The patient does not need a new appointment and leaves the plaster room without a new appointment.
2. The patient needs a (set of) new appointment(s), plans these with the planning staff and leaves to return at the next scheduled day.
3. The patient has another appointment in the plaster room later that day, the patient leaves but will return this day.
4. The patient has another appointment at another department in the hospital and it is not known whether he returns to the plaster room.

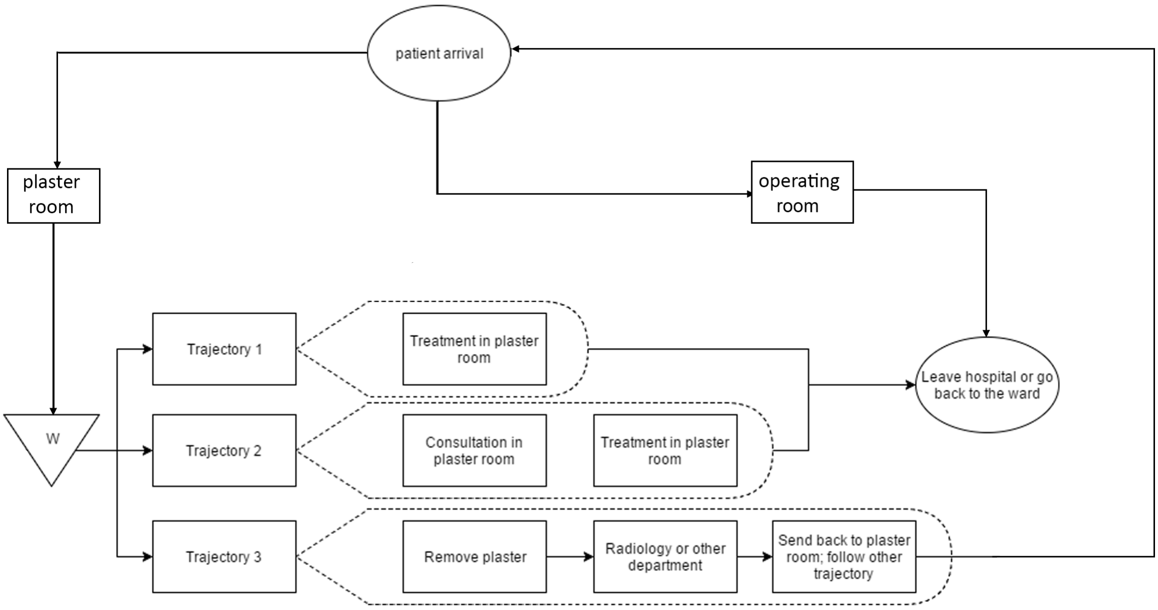

Figure 2.4: Overview of patient flow

The last group of patients consists of patients who return in the plaster room for continuation of treatment after consultation on the same day and of patients who do not return on the same day.

Figure 2.4 shows the process of patients, as described above, we see the operation room and the plaster room, the rest of the hospital is left out for this overview, as it is out of scope of our research. As the process surrounding the operation room is also out of scope, we do not involve this process in this figure. Figure 2.4 gives insight in when the patient waits (W) and which trajectories he may follow after entering the plaster room.

The OCTs have multiple treatment tasks during the workday, they include:

1. Treatment of patients in the plaster room.
2. Assist a co-worker during a complex treatment in the plaster room.
3. Assistance in plaster related operations.
4. Assistance in plaster related problems at the ward.

The last two processes are performed in other parts of the hospital, respectively the operating room and the ward. The first two processes are done in the plaster room, as are the other tasks of the staff. Other tasks include, but are not limited to, updating the patient file, ordering supplies, and replenishing the cupboards in the treatment rooms. Staff has activities that include assisting in other parts of the hospital, hence staff is not always present in the plaster room. As these activities are not always expected, the availability of OCTs for activities in the plaster room fluctuates.

2.3 Planning and control

In this section we focus on the planning and control of the plaster room processes. Hans, van Houdenhoven and Hulshof (2011) propose a framework for health care planning and control. This framework describes all managerial areas (medical, resource capacity, materials and financial planning) and all hierarchical levels of control (strategic, tactical, and operation levels). We discuss the planning decisions in the plaster room within the resource capacity planning.

Strategic planning decisions

The plaster room of the SMK is one of the largest in the Netherlands with 7.7 Full-Time Equivalent (FTE). On an average daily basis there are 4.8 OCTs available in the plaster room. This staff dimensioning is based on desired utilization, it is not the objective of this research to decrease staff capacity.

The plaster room has six treatment rooms. One of the treatment rooms is large enough to fit a bed, this room is used when an inpatient is tied to bed. In each treatment room one patient is treated at a time. This capacity is fixed, which can lead to a lack of resources.

Furthermore, the plaster room has a central staff member who is responsible for the appointment scheduling. Having this staff member allows the plaster room to apply complex appointment rules.

Tactical planning decisions

In the current system the plaster room uses static capacity reservation, which means that each day three agenda slots are reserved for walk-in patients. The amount of walk-in patients over the day is not equal. So having a static reservation can create busy hours and quiet hours.

Capacity is also reserved for consults that require availability of a medical specialist. This consults are planned by a central planner outside the plaster room, as this requires a wide overview over all departments. Almost 50% of the available mornings or afternoons are blocked for these consults. This can create problems as other patients need an appointment, but do not require a consult and are not eligible for a reserved spot. This can cause long access times for this patient.

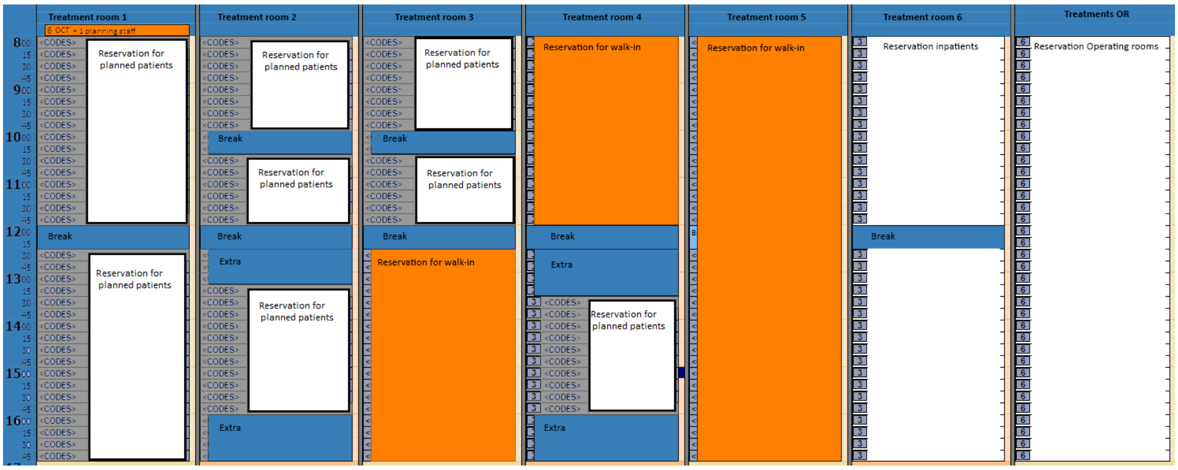

Figure 2.5: Capacity blocking for operations and walk-in patients

Figure 2.5 shows the capacity reservation before scheduling any appointments.

The staff planning is made three months in advance and is then open for request for a day off. The final planning is published six weeks in advance, minor changes can occur because of sickness. Once the planning is made, it is not likely to be changed even though the demand is more or less unknown at this point. Creating this inflexibility early in the process can create problems later on, such as being overstaffed or understaffed.

Staff is planned so that there are five or more OCTs each day. Each staff member works shifts of nine consecutive hours each day. The problem here lays again in the inflexibility. We take away the opportunity to respond to a demand increase or decrease.

Furthermore, when making the staff planning the demand is not known and is not correctly estimated. Therefore it can happen that during a busy day there are too few OCTs. In the current system, the planning staff try to solve this problem by reserving more capacity for walk-in patients. It would be better to adjust the staff to the demand, instead of the other way around as currently is done.

Operational planning decisions

Appointments are scheduled at the first available appointment slot. Appointment slots start at 8:30 and are 15 minutes long. When an appointment is scheduled the treatment length is estimated and the appointment is scheduled accordingly. At first appearance this practice is better than not estimating the treatment length. However, we question whether or not the estimation is done correctly.

Appointments in the operating room are not scheduled by the planner of the plaster room, but are scheduled in the agenda of the plaster room by the planner of the operating room. The schedule of the operating room is constantly changing, therefore demand from the operating room is not known. As treatments in the operating room have priority staff should be available, but with an unknown demand planning is almost impossible.

For each day one OCT is coordinator of that day. He is responsible for breaks. When the planning staff is in doubt whether a walk-in patient can be treated at this moment, the coordinator decides what to do. The coordinator is a great idea, however as this coordinator rotates each day different decisions are made.

Patients in the waiting room are served following a first come, first serve principle. Neither planned patients nor walk-in patients have priority. This can lead to long waiting times for planned patients, which we want to avoid.

When walk-in patients arrive at the plaster room, they receive an available appointment slot, which suits the patients estimated appointment length. If this appointment slot is within 30 minutes the patient takes a seat in the waiting room. It also happens that there is no appointment slot available within 30 minutes, when the patient is willing to wait longer, he waits elsewhere in the hospital. The planning staff will decide, in consultation with the coordinator, if a walk-in patient can take a seat in the waiting room and wait for treatment or decide that the plaster room is too occupied and the patient gets an appointment for a later time, or another day.

2.4 Conclusion

In this chapter we analyse all operational processes in the plaster room, as our goal is to identify the processes and how they are organized.

Our first step is to identify the stakeholders: patients, staff, and management.

We determine two main patient groups, walk-in patients and planned patients. 47.5% of all patients are walk-in patients, which means that their appointments are scheduled within the same day. For the appointment planning this means that only 52.5% of the demand is known in advance.

The patient process is also characterized by long and complex treatments, which vary a lot in treatment length. A correct estimation of the treatment length is essential as the appointment planning relies on this estimation. Problems with overlapping appointments, causing long waiting times, can arise as the estimation is not done correctly.

The planning of OCTs is done in advance and staff works in nine hours shifts. The opening hours of the plaster room are Monday to Friday, from 8:00 to 17:30. This planning cannot be altered at short notice. This inflexibility can create problems, as the staff levels are not adapted to the demand, but demand is adapted to the numbers of staff members available that day.

The tasks of the OCT, other than providing treatment in the plaster room, include assisting in the ward and assisting during operations. These tasks are often unpredictable in terms of frequency and length. This creates unknown staff availability for the plaster room treatments.

A central planning staff member is present in the plaster room. In the current planning of appointments, the estimation of the treatment length determines the length for which the appointment is planned. The appointment scheduling procedure reassembles list scheduling, where the first task is scheduled at the first available slot. Both having a central planner and planning the appointments for an estimated length are good practices. Problems can occur when the estimation is not done correctly, as the planning can then create overlap or gaps between appointments. Both create an unbalanced workload.

Long and complex treatments, highly varying treatment length, 47.5% of demand is not known beforehand, a fixed staff planning, and an unknown required amount of staff for other tasks cause a complex appointment planning.

With all these, now known, aspects we investigate the performance of the current system in the next chapter and find problem areas in the performance.

Chapter 3

Performance analysis

In this chapter we identify the important indicators for each stakeholder group. Using these indicators we define the KPIs in Section 3.2. After which we perform a baseline measurement of the current performance with the defined KPIs in Section 3.3. We define KPIs because there is no structural measurement method for the performance in the plaster room yet. Being able to measure the performance is essential, when trying to implement improvement of the performance. After defining the KPIs these measures we use hospital data to establish a baseline measure, which can be used as comparison to the performance in the plaster room after implementation of the intervention(s). The KPIs The KPIs provide a structural measurement method, and can be used in future research with respect to the performance.

3.1 Indicators

First we interview staff and management to find indicators of interest. We then perform an extensive data analysis and with the knowledge of the data analysis we choose the final KPIs.

The stakeholder groups in the plaster room are patients, staff, and management.

For patients we found the following indicators: waiting time, appointment within the same day, and access time. Waiting time can be seen as an important indicator as waiting is a waste of time for the patient. Walk-in patients prefer an appointment on the same day, knowing how many times this happens tell us about the performance of the plaster room. Furthermore for planned patients it is important to have the appointment as close to their preferred date, which is captured in the access time.

The indicators for staff are overtime, workload balance throughout the day, workload balance between weekdays, and correctly estimated treatment lengths. Overtime is an elongation of the workday. Workload should be balanced so that staff is not too busy one moment and idle the next. It is important to spread the workload equally throughout the day and subsequently the week. For planning it is important that the treatments are correctly estimated.

For management we found “hours worked”, “utilization”, and “efficient use of resources” (treatment rooms) to be indicators. Hours worked indicates whether the staff has worked as much as they should. Utilization indicates whether the given care hours are equal to the working hours. Treatment rooms should be used efficiently otherwise it is a waste of space.

After data analysis we found indicators we could not measure. For these indicators we did not perform a baseline measure and these are therefore not mentioned as KPIs.

In the available data it is not known what the preferred data is. Since this is not registered we cannot perform a measurement for the indicator “appointment within the same day” and the indicator “access time”. For appointment within the same day we want to measure how many walk-in patients are not treated on the same day. We know that some expected long treatments are scheduled for another day, even though the preferred date is today. From the interviews with staff and management we know this does not occur often, but with the preferred date being unknown we cannot do a measurement. The same applies to “access time” as we want to measure if the scheduled appointments are within a range of the preferred date.

In the agenda system the appointments are scheduled in a certain treatment room. However, in practice the rooms are not used in the same manner. The OCTs treat the patient in an available treatment room, regardless of the treatment room the appointment is scheduled to. In addition the OCT also treats patients outside the plaster room, at that time the treatment room is not occupied while there is an appointment scheduled. Since this in practice use of treatment rooms is not registered, it is not possible to measure “efficient use of treatment rooms”.

For the indicators: waiting time, overtime, workload, hours worked, and utilization we define KPIs. These KPIs give us an extensive overview of the performance and indicate where the performance can be improved. For the areas of the performance where improvement is necessary, we find interventions.

3.2 Key Performance Indicators

The KPIs for which we perform a baseline measurement are: waiting time, overtime, workload, hours worked, and utilization. In this section we will explain the calculation methods used.

3.2.1 Waiting time

For the patients we find the waiting time to be the most insightful indicator. Patients should not wait too long, especially when they have an appointment. We divided this KPI in one for patients with an appointment and one for those without an appointment (walk-in). The waiting time for inpatients and outpatients are calculated in the same way. We define the “waiting time” as:

$$T_{waiting}\text{ (planned)} = T_{call\,in} - T_{latest} \tag{3.1}$$

$$T_{waiting}\text{ (walk-in)} = T_{call\,in} - T_{arrival} \tag{3.2}$$

Where:

$T_{waiting}$:	waiting time
$T_{call\,in}$:	start time of the treatment
$T_{arrival}$:	time of arrival at the plaster room
$T_{appointment}$:	appointment time
T_{latest}:	latest of arrival or appointment time.

By taking the latest of arrival time or appointment time, the voluntary waiting time is left out. The voluntary waiting time exists when patients arrive early and cannot be served immediately. When a patient is late, the waiting time is calculated from the arrival time on wards. The walk-in patients do not have a voluntary waiting time, since they cannot arrive early, they get an appointment time as they arrive. We measure the service levels for the waiting time KPIs as the percentage of patients that have waited shorter or equal to the target. These KPIs are measured for each month. We define the “service levels” as:

$$\text{Service level } T_{waiting}\text{ planned} = \frac{\#\,Patients(T_{waiting} \leq Target\,(planned))}{\#\,Patients(T_{waiting}\,is\,known)} \tag{3.3}$$

$$\text{Service level } T_{waiting}\text{ walk-in} = \frac{\#\,Patients(T_{waiting} \leq Target\,(walk\text{-}in))}{\#\,Patients(T_{waiting}\,is\,known)}. \tag{3.4}$$

Where:

$\# Patients(T_{waiting} \leq Target)$: number of patients for whom the $T_{waiting}$ is within target
Target planned: 15 minutes
Target walk-in: 30 minutes
$\# Patients(T_{waiting}\, is\, known)$: total number of patients for whom $T_{waiting}$ is known.

In addition to the service levels we are also interested in the average waiting time overall and specifically for the planned and the walk-in patients.

$$\text{Average } T_{waiting} = \frac{\sum all\, waiting\, times}{\# patients(T_{waiting}\, is\, known)} \tag{3.5}$$

$$\text{Average } T_{waiting} \text{ planned} = \frac{\sum all\, waiting\, times\, of\, planned\, patients}{\# planned\, patients(T_{waiting}\, is\, known)} \tag{3.6}$$

$$\text{Average } T_{waiting} \text{ walk-in} = \frac{\sum all\, waiting\, times\, of\, walk\text{-}in\, patients}{\# walk\text{-}in\, patients(T_{waiting}\, is\, known)} \tag{3.7}$$

3.2.2 Workload

The most important indicator for staff is the unbalance of the workload. We define the workload per time bracket q as:

$$W_q = \sum_{\substack{all\, appointments \\ in\, q}} L_{planned}(Appointment) \tag{3.8}$$

Where:

W_q: cumulative workload per q in minutes
q : time bracket of 15 minutes
$L_{planned}(Appointment)$: the planned length of the appointment in the time bracket in minutes.

This workload is then divided over the number of OCTs working multiplied with the time bracket. So the “percentage relative workload” is given by:

$$\%\, W_{relative} = \frac{W_q}{Capacity_q} \times 100\% \tag{3.9}$$

Where:

$W_{relative}$: Percentage relative workload
$Capacity_q$: staff capacity in q in minutes.

The relative workload should not be over 100%, meaning more workload is available than can be done by the available OCTs, and should not be under 35%, meaning 65% of the available personnel cannot work on direct patient care. Since indirect patient care is not registered, we cannot take this into account. However as we say that as less as 35% of the staff working on direct patient care is still a balanced workload, there will be enough time to do the indirect patient care. For the relative workload we take time brackets of 15 minutes, in which we can start an appointment, and also investigate the workload over the months. We can identify times and months that are more congested than others.

$$\text{Balanced workload} : 35\% \leq W_{relative} \leq 100\% \tag{3.10}$$

$$\text{Understaffed workload} : W_{relative} > 100\% \tag{3.11}$$

$$\text{Overstaffed workload} : W_{relative} < 35\% \tag{3.12}$$

3.2.3 Overtime

In the current situation working in overtime is not common, but when implementing a balanced workload it could happen that it is optimal to place all planned appointment at the end of the day. Then overtime will occur regularly and therefore this KPI will regulate the number of days when working overtime occurred. A day is marked as not worked in over time when after 18:00, there are no patients in the treatment rooms. We want this percentage per year to be up to 100%. We define the "percentage no overtime" as:

$$\%\,No\,overtime = \frac{\#\,Days_{no\,overtime}}{\#\,Days_{total}} \times 100\% \tag{3.13}$$

Where:

$No\,overtime$:	percentage not worked in overtime
$\#\,Days_{no\,overtime}$:	number of days that there was no work in overtime
$\#\,Days_{total}$:	total number of days worked.

Working overtime is not desirable. However, when overtime does occur it is insightful how long this overtime is. Therefore we also calculate the average length of the overtime over all worked days and the average overtime over the days that had overtime.

$$\text{Average } overall\,overtime = \frac{\sum all\,overtime}{\#\,Days_{total}} \tag{3.14}$$

$$\text{Average } overtime\,per\,day\,of\,overtime = \frac{\sum all\,overtime}{\#\,Days_{overtime}} \tag{3.15}$$

3.2.4 Appointment length estimation

The last KPI for staff is the correct estimation of appointment length. When the estimated appointment length does not differ too much from the actual appointment length the planning is accurate and no overlap between appointments will occur. We define correctly estimated appointments when the actual appointment length does not differ more than 10% of the planned appointment length. An overestimated appointment is when the actual appointment length takes less than 90% of the planned appointment length. An underestimated appointment takes more than 110% of planned appointment length. We want to achieve as much as possible correctly estimated appointment lengths. We define the “estimations of the appointment lengths” as:

$$L(Appointment)_{correct} = \frac{A^C}{A^D} \times 100\% \tag{3.16}$$

$$L(Appointment)_{overestimated} = \frac{A^O}{A^D} \times 100\% \tag{3.17}$$

$$L(Appointment)_{underestimated} = \frac{A^U}{A^D} \times 100\% \tag{3.18}$$

Where:

$L(Appointment)_{correct}$: percentage correctly estimated appointment lengths
$L(Appointment)_{overestimated}$: percentage overestimated appointment lengths
$L(Appointment)_{underestimated}$: percentage underestimated appointment lengths
A^D: set of appointments for which the actual length is known
A^C: set of appointments that are correctly estimated
A^O: set of appointments that are overestimated
A^U: set of appointments that are underestimated.

For the performance of the plaster room it is also interesting to know if they estimate the overall time correctly. It can be that the percentage correctly estimated appointment lengths is low, but that overall the amount of time spent time in the plaster room is correctly estimated. We define the “overall deviation” as:

$$Overall\ deviation = \sum_{A^D} \frac{L_{estimated} - L_{actual}}{L_{estimated}} \tag{3.19}$$

Where:

$Overall\ deviation$: is the percentage deviation per year
L_{actual}: the appointment length that is registered
$L_{estimated}$: the appointment length that is estimated at the planning.

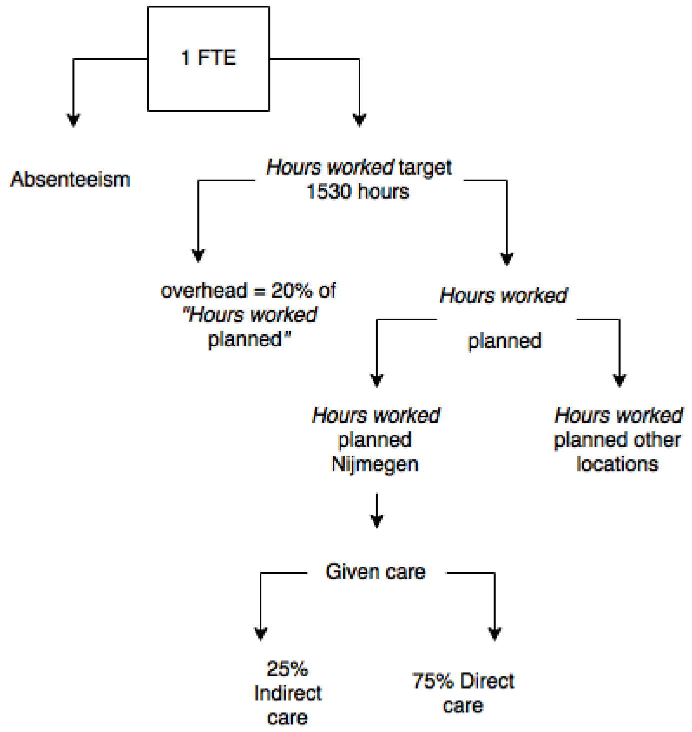

Figure 3.1: Management division of FTE

3.2.5 Hours worked

Management's vision on the performance is different from that of patients or personnel, management is interested in whether the work is done efficiently and whether hospital wide targets are met. Figure 3.1 shows how the hospital would like to spend each FTE. We see that each FTE gives us 1530 hours that the personnel can work, this is divided in pre-conditional processes, such as education, and available capacity for the plaster room. This capacity is divided over the plaster room in Nijmegen and the plaster rooms in Boxmeer and Klimmendaal, as part of collaboration between these hospitals. The given care in Nijmegen should consist of 25% indirect care, we do not have registration of the time spent on indirect care, and 75% direct care, which we can calculate from the data.

The hours worked give us insight in leave and absenteeism and whether the target from the SMK is met. We define hours worked as:

$$Hours\,worked : 0.9 * Hours\,worked_{target} \leq Hours\,worked_{planned} \leq 1.1 * Hours\,worked_{target} \tag{3.20}$$

$$Hours\,worked_{planned} = Capacity_{staff} + overhead \tag{3.21}$$

Where:

$Hours\,worked$:	in agreement with the target
$Hours\,worked_{target}$:	target staff capacity, SMK target for 1 FTE
$Hours\,worked_{planned}$:	net available staff capacity in hours
$Capacity_{staff}$:	hours staff is available from personnel roster
$Overhead$:	overhead, which are 20% of the $Capacity_{staff}$.

We calculate this KPI for one year, as vacations can be taken in specific periods and make monthly measures unbalanced and unreliable.

3.2.6 Utilization

The other KPI for the management is the utilization, it gives insight into efficient use of personnel hours for given care (direct and indirect). Personnel of the plaster room is also detached to other hospitals of the SMK, for example Boxmeer or Klimmendaal. The utilization is calculated only for the plaster room in Nijmegen as the scope of this research is limited to Nijmegen. We define utilization as:

$$Utilization_{Nijmegen} = \frac{Care_{given}}{Capacity_{Nijmegen}} \tag{3.22}$$

$$Care_{given} = Care_{direct} + Care_{indirect} \tag{3.23}$$

Where:

$Utilization_{Nijmegen}$:	percentage utilization in Nijmegen
$Care_{given}$:	all care given in Nijmegen
$Capacity_{Nijmegen}$:	staff capacity for Nijmegen in hours
$Care_{direct}$:	care provided in Nijmegen in hours this care is measured by the treatment time
$Care_{indirect}$:	care that is related to patient care but not captured in treatment time, this care is 25% of the $Care_{direct}$

Table 3.1 summarizes the KPIs discussed in this section.

3.3 Baseline measure of KPI

In this section the results of the KPIs are given. Each result gives us a baseline measurement.

Waiting time

For the calculation of the waiting time we prepared the data so that we had from each appointment the arrival time at the plaster room, the appointment time and the call

Table 3.1: Overview of the Key Performance Indicators

Group	Goal	KPI name	Definition	Measurement method	Measurement target or instrument
Patient	Short waiting time for walk-in patients	Waiting time (walk-in)	Service level $T_{waiting}$ walk-in	$T_{waiting}$ (walk-in) $= T_{call\,in} - T_{arrival}$	Target is 30 minutes
	Short waiting time for planned patients	Waiting time (planned)	Service level $T_{waiting}$ planned	$T_{waiting}$ planned $= T_{call\,in} - T_{latest}$	Target is 15 minutes
	Overall short waiting time	Average waiting time	Average over all patients, walk-in, and planned patients	Average waiting $= \sum \frac{T_{waiting}}{\#Patients}$	Average should be around or lower than the target
Personnel	Balanced workload	Workload	% $W_{relative}$ understaffed, balanced, and overstaffed	% $W_{relative} = \frac{W_q}{Staff_q} \times 100\%$	$W_{relative}$ balanced should be as large as possible
	Not working in overtime	Overtime	% $No\,overtime$	% $No\,overtime = \frac{\#Days_{not\,overtime}}{\#Days_{total}} \times 100\%$	Overtime starts after 18:00; percentage 100%
	Overall short overtime	Average overtime	Average over all days and days in overtime	Average overtime $= \sum \frac{T_{overtime}}{\#Days}$	Average should be as low as possible
	Correct estimation of appointment length	Appointment length	$L(Appointment)$ correct, overestimated, underestimated	$L(Appointment) = \frac{A^{C,O,orU}}{A^D}$	correct should be as large as possible
	Overall correct estimation	Overall deviation	The difference between all appointment lengths	$Overall\,deviation = \sum(L_{estimated} - L_{actual})$	the deviation should be as low as possible
Management	Efficient use of staff	Hours worked	$Hours\,worked$ according to target enough vacation and not too much absenteeism	$Hours\,worked_{planned}$ within $\pm$ 10% of the target	In agreement with target or not
	Efficient use of time	Utilization	$Utilization$ according to worked hours, enough care is given	$Utilization = \frac{Care_{given}}{Capacity_{Nijmegen}}$	Percentage should be around 80%

in time. This results in 41% missing data, meaning that for 41% of the appointments the waiting time and or treatment time was not registered. Also a correction for a bad registration is done, based on the appointment length. Appointments shorter than 10 minutes are not taken into account. 6% of the data is left out because the registered appointment length is less than 10 minutes. In total 47% of the data is not available for this measure. We assume that our data is a good representation of the entire group. For the planned patients we calculate the waiting time, leaving out the voluntary waiting time. Figure 3.2 shows the current service level of the SMK per month. We see some small changes between the months, but overall the service level is 94%, which means that 94% of all patients do not wait too long, following our targets of 15 minutes for planned patients and 30 minutes for walk-in patients.

We are also interested in the average waiting time. For all patients the average waiting time is 5.6 minutes. The planned patient's average waiting time is 3.8 minutes and for walk-in patients it is 9.4 minutes.

Since these service levels and average waiting time do not represent the minimum and maximum waiting time, the box plot for the planned and walk-in patients is given in Figure 3.3 to give a complete view of the waiting times. We take the 99% and 1% percentile in order to compensate for outliers. We see that 75% of all planned patients wait 5 minutes or less. 75% of all the walk-in patients wait less than 13

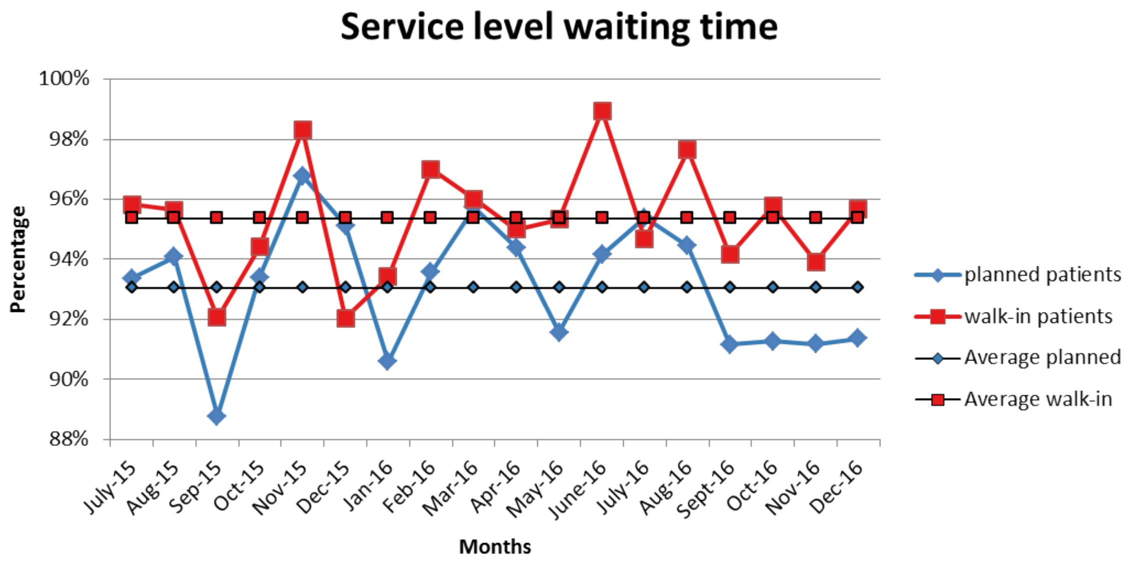

Figure 3.2: Service level of planned and walk-in waiting times, N=9952, 47% of data is not available; data from July 2015 to December 2016

minutes. In these box plots we can clearly see that the waiting times are not a problem for most patients, but that there are a few patients that have a long waiting time.

The service level of the waiting time for planned patients is on average 93%, and for the walk-in patients it is 95.4%. Overall the waiting times are within the targets, and the average waiting time is 5.6 minutes. The planned patient's average waiting time is 3.8 minutes and for walk-in patients it is 9.4 minutes. We conclude that the waiting times are low, most of the time. However, a few patients wait excessively.

Workload

We calculate the workload with the planned appointment length, as the actual appointment length is missing in several occasions. Leaving out these occasions will influence the workload too much. To calculate the workload we need the appointment time and planned appointment length, since all appointments have these variables our data set is complete for the workload calculation. As we divide the workload over the staff capacity in minutes, we need the personnel roster. From this roster we calculate the staff capacity per time bracket of 15 minutes, we take brackets of 15 minutes since this is the smallest time bracket wherein a change in capacity is scheduled. For simplicity we assume the staff only takes a lunch break, the first group between 12:00 and 12:30 and the second group between 12:30 and 13:00. The first group is larger or equal to the second group. The personnel roster is only

Figure 3.3: Box plot of planned and walk-in waiting times

available for 2016. Therefore the workload is calculated for 2016.

We represent the relative workload to be overstaffed (<35%), correctly staffed (between 35% and 100%) or understaffed (>100%). Figure 3.4 shows the percentage overstaffed, correctly staffed, and understaffed per month. We conclude that the distribution of the workload over the month is the same. Therefore we are interested in the workload over the day, we want to know if this does differ. Working in overtime is not taken into account. Figure 3.5 shows workload divided in overstaffed, correctly staffed, understaffed for the workday per time bracket of 15 minutes. We see that the workload over the day differs, especially in the first and last half hour of opening the workload is very low. During the coffee and lunch break the workload also drops a bit, but this is convenient as the staff takes a break and cannot work on a patient's treatment. The drop of workload in the afternoon is, however, a waste of working hours.

The workload distribution is more or less the same in each month, which means that each month the workload is unbalanced and there are no improvements or deteriorations. We can see that each workday the workload is unbalanced, the percentage correctly staffed is only 59.2%, percentage overstaffed is 25.8%, and in 15.0% of times the workload is understaffed. In the morning and afternoon the staff is almost never in balance with the demand, and during the day there are busy hours.

Overtime

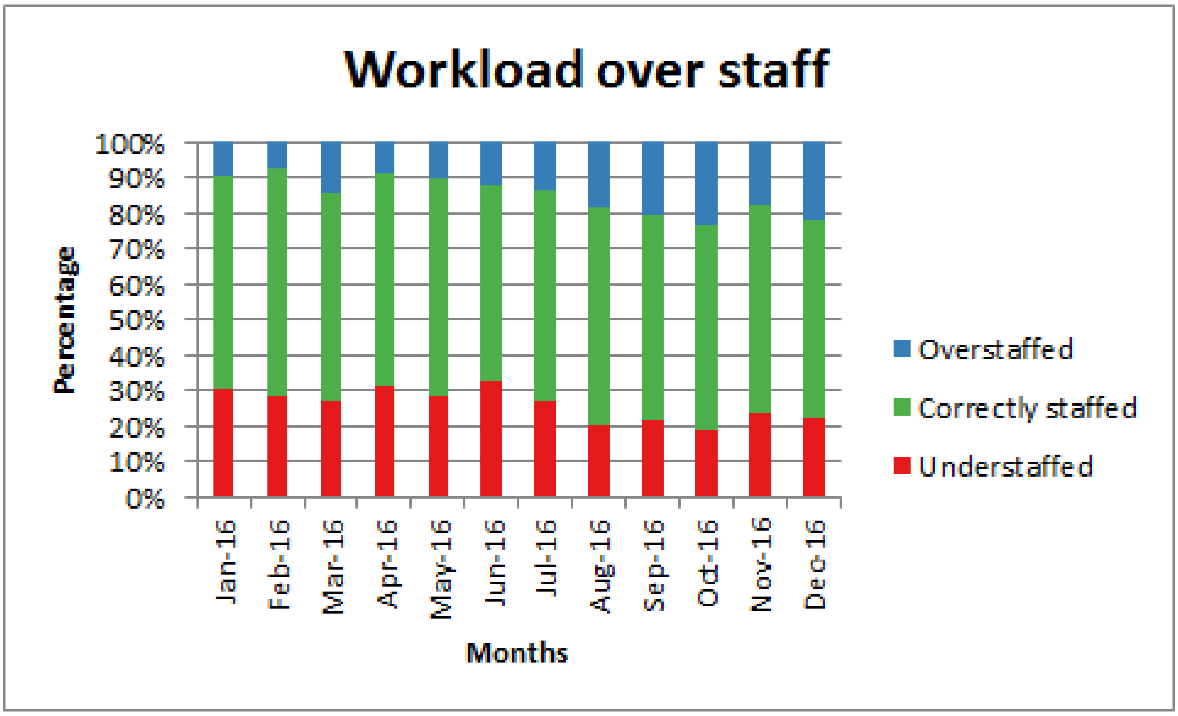

Figure 3.4: Relative workload per month, N=12840, data set complete; data from July 2015 to December 2016

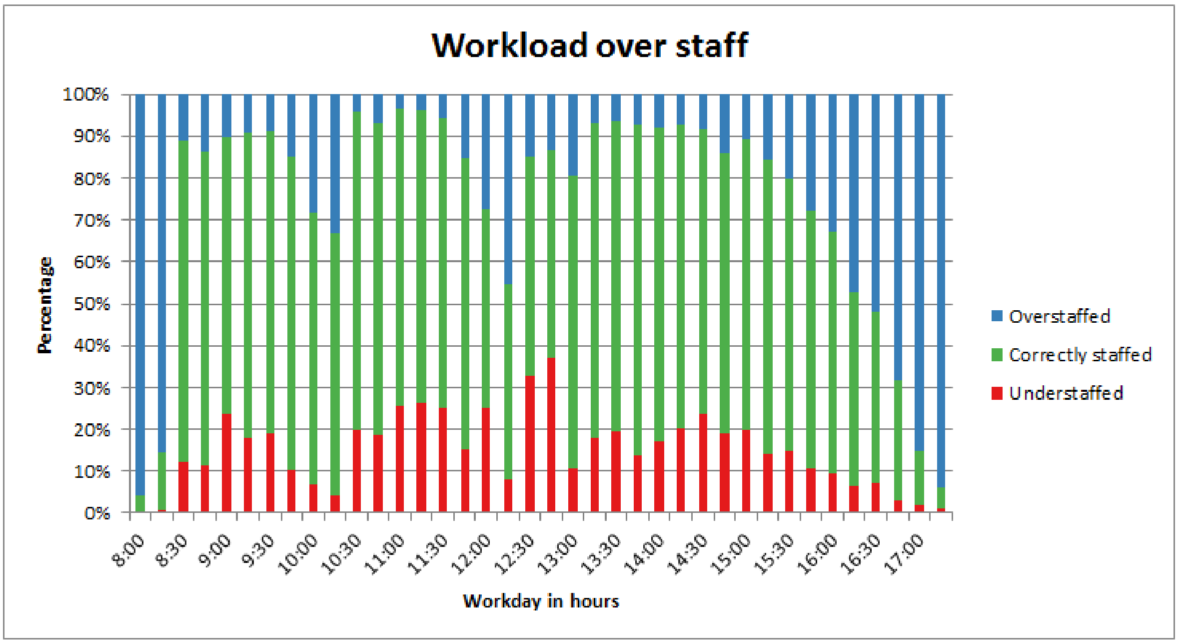

Figure 3.5: Relative workload per day, N=12840, data set complete; data from July 2015 to December 2016

Table 3.2: Percentage overtime for 2015 and 2016, N=386, data set complete; data from July 2015 to December 2016

Year	Number of days not in overtime	Number of days total	% $No\,overtime$
2015	130	132	98.5%
2016	253	254	99.6%

To calculate overtime we need to know when the last appointment of that day ended. With the appointment time and planned appointment length we calculate the departure time of all patients, and find the last ended appointment for each day. When this end time does not exceed the closing time of 18:00, the day is marked as not worked in overtime. For 2015 we only have the data from July to December. For 2016 we have the data for the entire year. Since we use the appointment time and planned appointment length the data set for the overtime is complete.

Overtime occurrence is rare, on average in the past year and a half only 3 days are worked in overtime. Table 3.2 shows the results per year. It shows that in 99.3% of the days there is no overtime.

We conclude that the average overtime over all days is 0.14 minutes and the average overtime over the days there was overtime is 18.3 minutes.

Appointment length

We want to know what percentage of appointments is estimated correctly with not more than 10% deviation, and how many appointments are overestimated and underestimated. For this calculation we need to know the planned appointment length and we need to calculate the actual appointment length. The actual appointment length can be calculated with the call in time and departure time. We have 50% missing data for the actual appointment length. Furthermore, a correction for appointment length is done. 7% of data is not taken into account in line with this correct. So the data set for the appointment length contains 8118 appointments.

Figure 3.6 shows the percentage of correctly estimated, overestimated, and underestimated appointments per month. We see that the distribution does not differ per month, which means that each month is equally poorly estimated as only 17% of the appointments is correctly estimated. We are interested if there is a difference between the groups of planned appointment lengths. Therefore Figure 3.7 gives the percentage correctly estimated, overestimated, and underestimated appointments per planned appointment group. The distribution over the appointment length does differ. Where the 100 minutes group is highly overestimated, and 75 minutes is much more likely to be correctly estimated. To give even more insight in the distribution

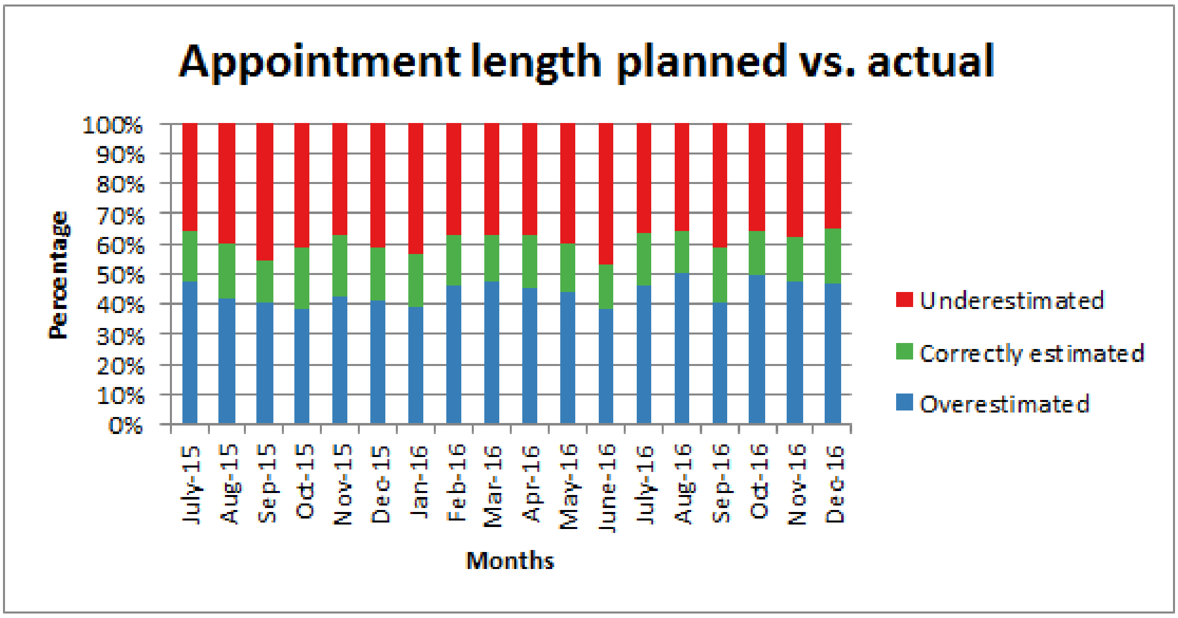

Figure 3.6: Appointment length estimation per month, N=8118, 57% of data not available; data from July 2015 to December 2016

of estimating the appointments, the box plot, with 99% and 1% percentile to correct for outliers, are given. Figure 3.8 gives the box plot for planned appointment lengths that are used in the plaster room for more than four times. For almost all appointment lengths we see a high deviation, the 99th percentile and the 1st percentile are widely spread over the y-axe. This means that even though an appointment is estimated and planned for a certain length, it can deviate a lot from this estimation. We also see that for 65, 100, and 105 minutes 75% of the appointments do not require this amount of time.

The overall deviation of the planned appointment lengths and actual appointment lengths is interesting. We use the same data set as for the estimation. If the overall deviation is small it means that even though not many appointments are correctly estimated, the appointment lengths that are overestimated and underestimated compensate each other. The sum of $L_{estimated} = 288,910$ minutes and the sum of $L_{actual} = 309,515$ minutes. Therefore the overall deviation is -7%. This means that in reality we plan 7% less for all appointments in 1.5 years.

The appointment lengths are not well estimated, when we define correct with a deviation of 10%, only 16.9% of the appointments is correctly estimated. Overall we estimate 7% less time than actual needed appointment length.

Hours worked

For the calculation of the hours worked, we need the target for hours worked from

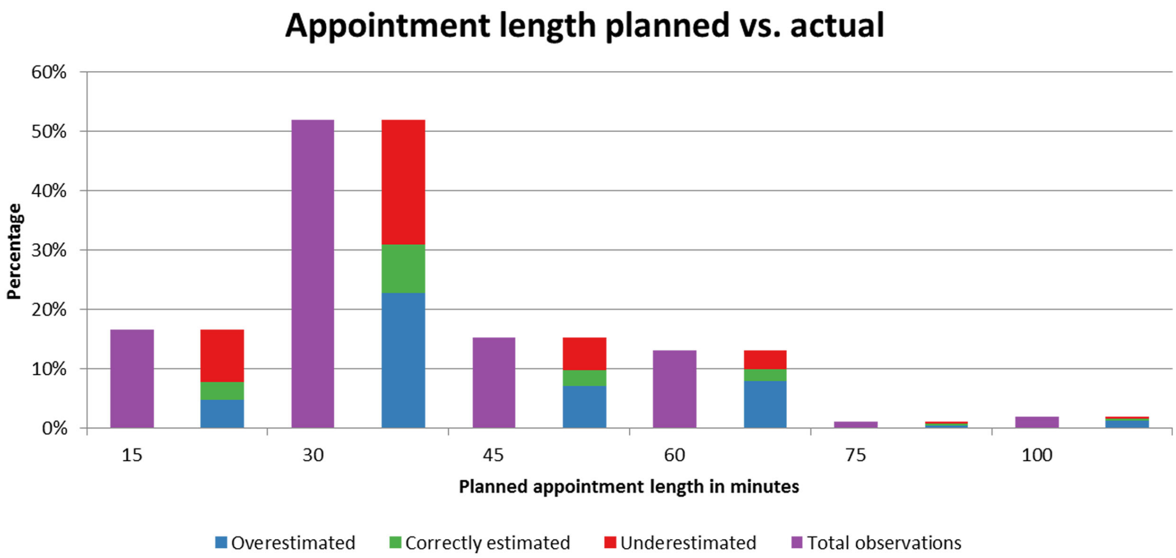

Figure 3.7: Appointment length estimation per group, N=8118, 57% of data not available; data from July 2015 to December 2016

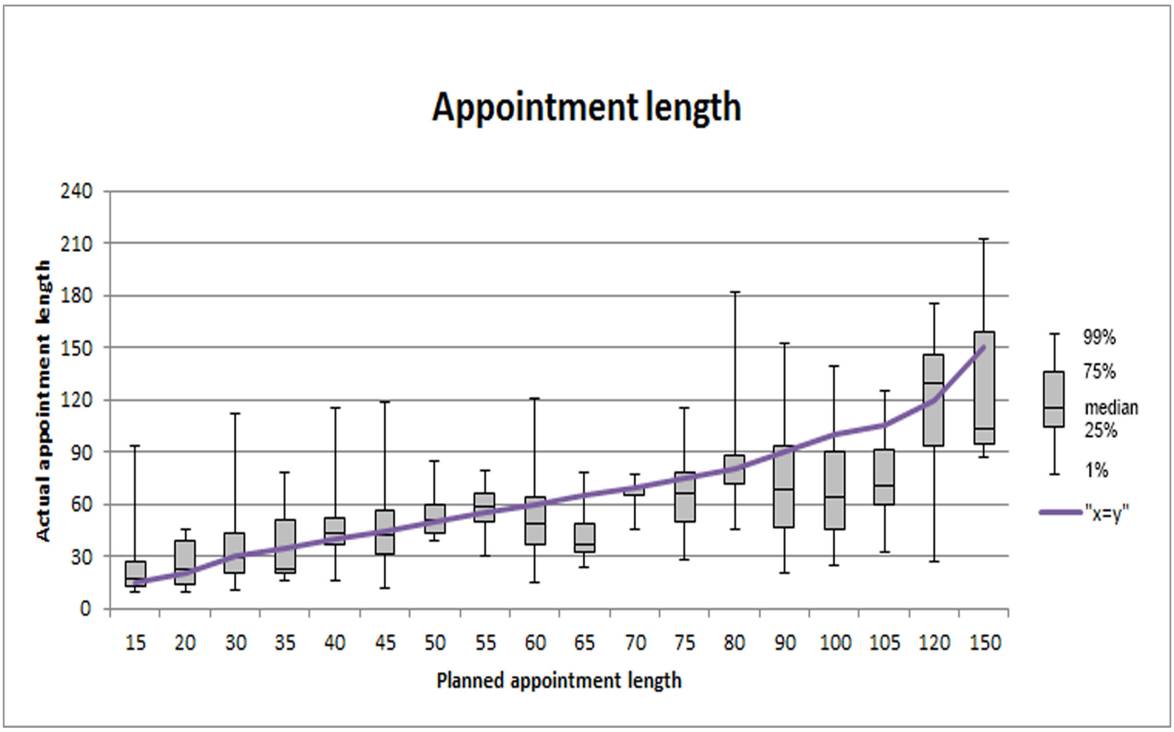

Figure 3.8: Box plot appointment length, N=8118, 57% of data not available; data from July 2015 to December 2016

the hospital and we need the personnel roster. From the personnel roster we calculate the staff capacity, this includes workdays in the plaster room in Boxmeer and Klimmendaal. Each FTE represents 1530 hours per year. On average the plaster room has 7.7 FTE available, this does not include planning staff, medical specialists, and the head of the department. We calculate this percentage for one year, since the personnel roster is only available for 2016.

$Capacity_{staff}$ = 10450 hours
$Hours\,worked_{planned}$ = 12713 hours
$Hours\,worked_{target}$ = 1530 * 7.7 = 11739 hours

$$\begin{aligned} Hours\,worked &= \{0.9 * 11739, 1.1 * 11739\} \\ &= \{10565, 12912\} \end{aligned}$$

In 2016 the hours worked is within 10% of the target.

Utilization

For the calculation of the utilization we take the staff capacity from Nijmegen, this includes the head of department when she works as an OCT and includes another staff member that works in the plaster room, but is not accounted for in FTE. We also calculate the given care. The direct care is the appointment lengths summed up for the entire year, the indirect care we assume is 25% of this time. We calculate this percentage for one year, since the staff capacity is only available for 2016.

$Care_{direct}$ = 6966 hours
$Care_{given}$ = 9288 hours
$Capacity_{Nijmegen}$ = 11425 hours

In 2016 the percentage utilization is 81.3%, this means the plaster room works efficient according to this measurement.

3.4 Conclusion

In this chapter we define KPIs to measure the current performance, as we want to identify problem areas in the performance. Table 3.3 shows the baseline measure for each KPI. We discuss the most important results.

We determine that the performance on workload balance and the performance on estimation of appointment lengths are the problem areas of the plaster room. The

Table 3.3: Overview of the key performance indicators

Group	KPI	Result
Patient	Service level $T_{waiting}$ walk-in	95.4%
	Service level $T_{waiting}$ planned	93.0%
	Average waiting time walk-in and planned patients	9.4 minutes and 3.8 minutes
Personnel	Balanced workload in percentage of “understaffed”, “correctly staffed”, and “overstaffed”	**15.0%**, **59.2%**, and **25.8%**
	% No overtime	99.3%
	Average over all days and days in overtime	0.14 minutes and 18.3 minutes
	Estimation of appointment length in percentage “correct”, “overestimated”, and “underestimated”	**16.9%**, **44.3%**, and **38.8%**
	Overall deviation	-7%
Management	Hours worked	In agreement with the target
	Utilization	81.3%

workload is not balanced, as on average only 59.2% of the day is correctly staffed. In the current system only 17% of the appointments are correctly estimated, for every month this measure is about the same. We should keep in mind that correctly estimated means that the actual appointment length only differ 10% from the estimated appointment length, which for the most often occurring appointments, those of 30 minutes, means that they may only deviate 3 minutes. The overall deviation shows that we plan 288,910 minutes, but the total appointment duration is 309,515 minutes. Therefore we plan 7% less time than needed.

We conclude that the current performance on the waiting time and overtime is good. 94.3% of all patients wait less than the target and on average patients wait 5.6 minutes. No overtime occurs in 99.3% of the days, and the average overtime per day is 0.14 minutes.

The hours worked and utilization performances are also within the target. Hence we determine that waiting time, overtime, hours worked and utilization are not problem areas of the plaster room.

To improve the performance on workload balance and correctly estimating appointment lengths we propose interventions, the literature and management will provide interventions. In the next chapter the literature review will provide the found interventions.

Chapter 4

Literature Review

From the performance analysis in Chapter 3 we conclude that the performance with respect to the workload balance and estimation of appointment lengths are the areas where improvement is possible. In this chapter we search the literature for possible solutions in the form of interventions that improve the performance on these areas. We perform a literature review on plaster rooms, from there we find that appointment scheduling gives interesting interventions which could improve workload balance. We conclude this chapter with previously used models for similar research. Appendix A provides an outline of the search strategy.

4.1 Solutions in plaster rooms

Plaster rooms are not commonly researched in terms of operations or appointment scheduling. Van de Vrugt (2016) and Hoogwout (2010) both study plaster rooms and aim to improve the workload.

Van de Vrugt (2016) investigates appointments versus walk-ins at the plaster room. The author states that with a system where more than half of the patients arrive with an appointment, a strongly varying workload indicated an inefficient appointment schedule. Hence, the focus of the study is to design appointment schedules that balance the workload throughout each day. Van de Vrugt (2016) uses a simulation model to evaluate the different appointment schedules and concludes that even with implementation of different appointment rules there still are exceptionally busy days and/or times, therefore the appointment rules cannot prevent extreme waiting and overtime. For the investigated system it is found that easy implementable rules are chosen over best results, where the implementation is difficult. This appointment rule, A10m, needs a central scheduler. As the SMK has a central scheduler we take a closer look at this appointment rule.

The best practice rule in the study of Van de Vrugt includes an outside-in schedule, where patients alternately take the first or last available appointment slot. Appointment slots are ten minutes long and are available from 8:00 until 16:40, the opening hours are from 8:00 until 17:00. Working with ten minutes slots is an option in this study as the average treatment length is 15.3 minutes and there are two or three OCTs available. By scheduling outside-in the appointments are scheduled in the least busy times regarding the walk-in patients.

We cannot adopt this rule without adjustments. In the current situation of the SMK the average treatment length is more than double, 38.1 minutes. Also the treatment lengths vary more. The idea of scheduling patients around the busy times of the walk-in patients is a good idea, which we will try to implement.

Hoogwout (2010) studies organizational interventions to improve the service level, to minimize the average patient waiting time, to minimize the overtime of the OCT and to balance the workload. The organizational interventions are increasingly invasive starting with removing delay in the plaster room process, going on with redesigning the agenda system and ending with adjustments in the capacity and establishing the first interventions. Hoogwout also uses a simulation model to analyse the current and interventions performance.

The best case scenario includes introducing a 10 minute agenda slot, low variance at the beginning of the shift rule, no-show adjustments, no planned slack, elimination of OCT unavailability, elimination of disturbance during patient treatment, reduce specialists' waiting time, and limited or extensive use of a medical assistant (Hoogwout, 2010). Some of these interventions are applicable for the SMK, such as the low variance at the beginning of the shift rule, which tries to minimize the waiting times for patients with a low variance treatment. The other interventions do not apply for the SMK. The treatment lengths in the SMK begin at 15 minutes, so a 10 minute agenda slot is not useful as the smallest treatment length does not fit. No-show occurrence is low and slack is already unplanned. Disturbance during treatment and OCT unavailability are not a problem in the SMK. The SMK does not use a medical assistant in the plaster room. The waiting time before a specialist arrives is a problem in the SMK, but this issue is out of scope for this research, as we cannot influence the specialist's behaviour.

From these conducted studies in plaster room operations, we now know that appointment schedules are the way to balance the workload. Therefore we investigate the literature for appointment schedules in similar settings.

4.2 General solutions in appointment scheduling

The plaster rooms characteristics are similar to more often studied outpatient clinics (Anderson, Zheng, Yoon & Khasawneh, 2015; Baril, Gascon & Cartier, 2014; Cayirli & Veral, 2003; El-Sharo, Zheng, Yoon & Khasawneh, 2015; Morikawa & Takahashi, 2016). Appointment scheduling in the plaster room is dynamic, as appointment requests arrive dynamically over time instead of knowing the appointments for each shift beforehand.

Cayirli and Veral (2003) state that effective scheduling systems have the goal of matching demand with capacity so that resources are better utilized and patient waiting times are minimized. Cayirli and Veral (2003) describe three decisions regarding the appointment system: the appointment rule, the use of patient classification and the adjustment made to reduce effects of walk-ins, no-shows, and/or emergency patients (Cayirli & Veral, 2003).

Reduce effects of walk-ins, no-shows and/or emergency patients

There are multiple studies on appointment scheduling for no-shows (Anderson et al., 2015; Cayirli, Yang & Quek, 2012; El-Sharo et al., 2015), however in our research this is not a problem, nor are emergency patients. We experience a high number of walk-ins. Morikawa and Takahashi (2016) schedule specific for walk-ins and use workload as main measure to assign an appointment time. For each walk-in patient an appointment time is determined at arrival. The assignment of the walk-in patient in an appointment slot is done on a workload-based scheduling (Morikawa & Takahashi, 2016). The SMK uses a similar manner of scheduling walk-in patients, we schedule walk-in patients at a time we expect less workload or when an OCT is available right now the walk-in patient is scheduled for this appointment slot.

Cayirli et al. (2012) develop a procedure to minimize the effect of no shows and walk-ins. They use the expected probabilities of no-shows and walk-ins in a time frame. They propose that if we want to treat a certain number of patients in this time frame, we should decrease the number of scheduled patients with the probability of the walk-in. For the SMK this is an interesting procedure, in the current situation capacity for walk-in patients is reserved(Cayirli et al., 2012). However this is done statically while the number of walk-in patients fluctuates during the day. Now we know the historic probability of walk-in patients, we can use this for future reservations following Cayirli et al. (2012) procedure.

Use of patient classification

Van de Vrugt (2016) investigates the use of patient classification. While both planned and walk-in patients are in the waiting room, the planned patients have priority over walk-in patients. However in the system most patients are treated immediately at arrival, this type of prioritizing does not change the waiting times for the patients. We decide not to investigate this further, as in our situation the majority of patients are also treated on arrival.

Appointment rule

Bhattacharjee and Ray (2016) try combinations of sequencing and appointment rules. They found that the sequencing rule “increasing order of mean service time” performs the best. In their setting, an Individual Block, Variable Interval appointment rule performs the best. This means scheduling a single patient at a time with inter-appointment times adjusted to mean service time of patient class (Bhattacharjee & Ray, 2016). We want to treat multiple patients at a time and already use a variable interval size to plan our appointments. Furthermore before implementing rules with low variance or mean service time, the treatment lengths should be correctly approximated which is not the case in the SMK. We therefore do not implement these rules.

Cayirli et al. (2012) develop a universal, “Dome”, appointment rule. The appointment rule is based on a two-step procedure. It uses a wide set of clinic parameters that are major factors affecting the choice and the performance of appointment systems. The “Dome” rule is called this way because the appointment intervals look like a dome. The appointment intervals are small at first, then increase and decrease toward the end of the session. This means that at the beginning and end of the day more appointments start. The aim is to minimize the waiting time and idle time, which will also balance the workload (Cayirli et al., 2012). Gupta and Denton (2008) describe why appointment scheduling can be complex in hospital settings, they also find innovative procedures and point out the “Dome” shape. We judge that the idea of the “Dome” rule is interesting to implement in the SMK setting, so we implement an intervention which has more appointments at the beginning and end of the day.

4.3 Available models

In literature two main approaches for optimization can be distinguished, one is using a simulation model (Baril et al., 2014; Bhattacharjee & Ray, 2016; Cayirli & Veral, 2003; Cayirli et al., 2012; Groothuis, van Merode & Hasman, 2001; Morikawa & Takahashi, 2016; Samorani & LaGanga, 2015) and the other is using analytical models (Cayirli & Veral, 2003; Cayirli et al., 2012; Kortbeek et al., 2014; Samorani &

LaGanga, 2015).

Simulation models aim to simulate real processes very accurately. They allow experimentation with an imitation of the actual system as it progresses through time. Even though it is simplified, the model can be programmed as complex as needed. It can handle a many input characteristics, and is able to handle variability. A simulation model requires a lot of (historic) data before the model is a valid representation of the real system. Seeing that a simulation model loops through time, as does in the actual situation, it is easy to understand what the model does and therefore is easy to communicate with the management. This accomplishes a greater acceptance of the results.

Analytical models are suitable in cases with low complexity and allow variability in arrival patterns as well as service durations. They are useful for evaluation for simple relationships to obtain an exact solution. However, analytical models require restrictive assumptions to simplify the actual situation in terms of the steady state behaviour. An analytical model, for example, assumes a fixed arrival rate for any day. Furthermore analytical models are not transparent, nor easy to understand for outsiders, such as the management of the plaster room, as the set of mathematical equations may be a struggle to understand.

As the plaster room is a complex system, a model to evaluate the interventions is necessary. Not only do experiments in reality take too long, they can also be hazardous to the well-being of the patient. We find that for similar situations analytical models and simulation models are used, described above are some advantages and disadvantages. We conclude that because of the need of a representation of a complex system where a lot of data is available, that has the acceptance of the management, and correctly processes the high variability of the plaster room processes, asks for a simulation model.

4.4 Conclusion

The following proposed interventions from literature are taken into account when trying to improve the workload balance:

1. Appointment rules that increase the number of appointments at the beginning and end of the day.
2. Reducing the effect of walk-in patients by:
    - Scheduling walk-in patients at a later time.

- Planning fewer appointments at times the probability for walk-in patients is high.

Other interventions are elaborated in Section 5.3.1.

We will use a simulation model to test the interventions, as a simulation model can mimic a complex system, maintain the high variability, and can be easier understood by management.

The next chapter will provide the simulation model and experiments, with which we assess the formulated interventions and the interventions from the plaster room management.

Chapter 5

Model

In this research we identify and assess interventions that can improve the current performance in terms of workload of the plaster room. To do this we develop a model, do experiments with the interventions, and find practical solutions. This chapter describes the model, and experiments.

As the plaster room is an operational system, where experiments in reality take too long, and analytical models are limited to restrictive assumptions, we choose to design a simulation model. A simulation model can imitate a complex system, as it simulates the reality, has less restrictive assumptions, maintains high variability, is easier to explain, which increases the reliance in the results of the model, and increases the probability of implementing the solutions.

The opening hours of the plaster room, no steady state occurrence, and the fact that the process is altered by occurrence of events are reasons for the use of discrete event simulation.

5.1 Conceptual model

Before we start building the simulation model, we design a conceptual model. This conceptual model is a non-software specific description of the model, and describes the objective, overview of the model, and the required input.

5.1.1 Objectives

The objectives of the model give the specific purpose of this model:

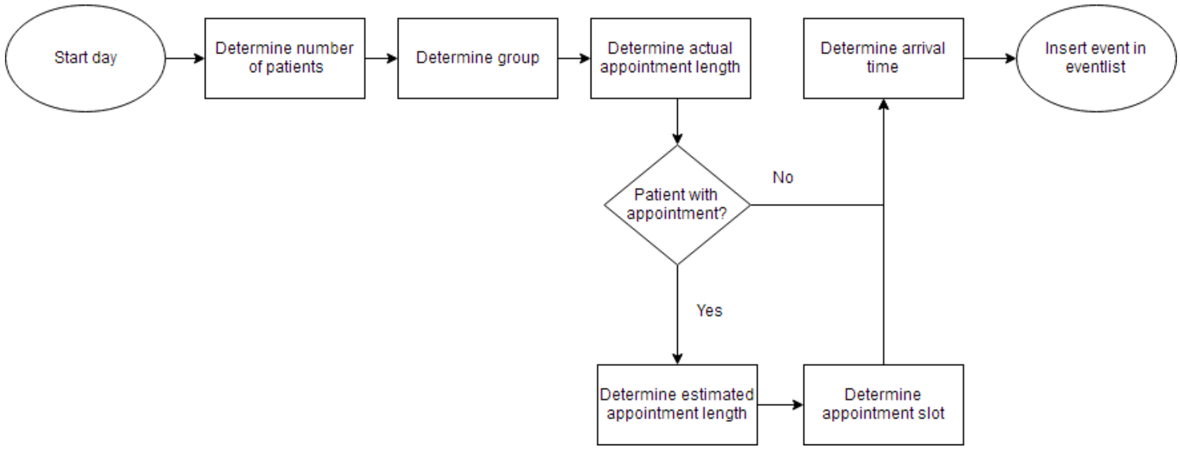

Figure 5.1: Model initialisation

1. The model simulates the current process in the plaster room.
2. The model is suitable to implement interventions (decision variables).
3. The model measures output in terms of patient waiting time, service level of waiting time, workload of OCT, and overtime per day for the OCT.

5.1.2 Overview of the model

With this model we mimic the current process of the plaster room. Therefore the model needs to simulate days and includes the difference between appointments and walk-ins. The appointments are scheduled before the day starts, throughout the day walk-ins occur. For each run of the model the number of OCTs is constant. The OCTs treat one patient at a time. The OCTs are available for nine hours, then overtime starts. Appointments are scheduled following the agenda slots.

The model starts with an initialisation of all patients for this day, including the arrivals of the patients. After all arrivals for this day are determined, the day starts executing the first arrival.

Initialisation Figure B.4 shows the initialisation of the day. Before simulating the day, the model creates patients which, according to their group, receive a service length, representing the actual treatment length. When the patient has an appointment, the model determines the estimated treatment length, the appointment slot, and the arrival time. When the patient is a walk-in the model only determines the arrival time. Figure 5.1 shows all patient characteristics which the model determines, and in short how they are determined.

OCT available After determining the patient characteristics, the OCTs are made

Table 5.1: Patient characteristics

Appointment type	Scheduled	Walk-in
Patient group	1 to 13	0
Estimated treatment length	random variable from distribution	-
Actual treatment length	random variable from distribution	random variable from distribution
Appointment slot	determined by appointment rule	-
Arrival time	varies from appointment slot with distribution	distribution throughout the day

available. As long as an OCT is available treatment can start for the patient, otherwise the patient is placed in a virtual queue.

Arrival of patient Each time a patient arrives, the procedure to check OCT availability is called. When an OCT is available this OCT starts the treatment and is busy with this patient until the treatment ends. This end is determined by the earlier set treatment length. When no OCT is available the patient waits until an OCT becomes available.

Departure of patient After each finished treatment, the procedure to start with the next patient is triggered. When there is no patient in the waiting room, the OCT is idle until a new patient arrives.

Break Each OCT has the right to a lunch break, starting from 12:00 and when there are no patients in the waiting, each OCT takes a 30 minute break. After this break the OCT is available again, and the procedure to start with the next patient is triggered. When all OCTs are busy at 12:00, the procedure for the break is initialised again after the treatment finishes.

Figure 5.2 shows these procedures of the model, and in summary it shows how the model steps through these procedures.

5.1.3 Required input

From the conceptual model, we find input characteristics that are required to define the model.

Arrival pattern It is necessary to know how many patients arrive and at what time the patients enter the plaster room. This might depend on patient type, patient group,

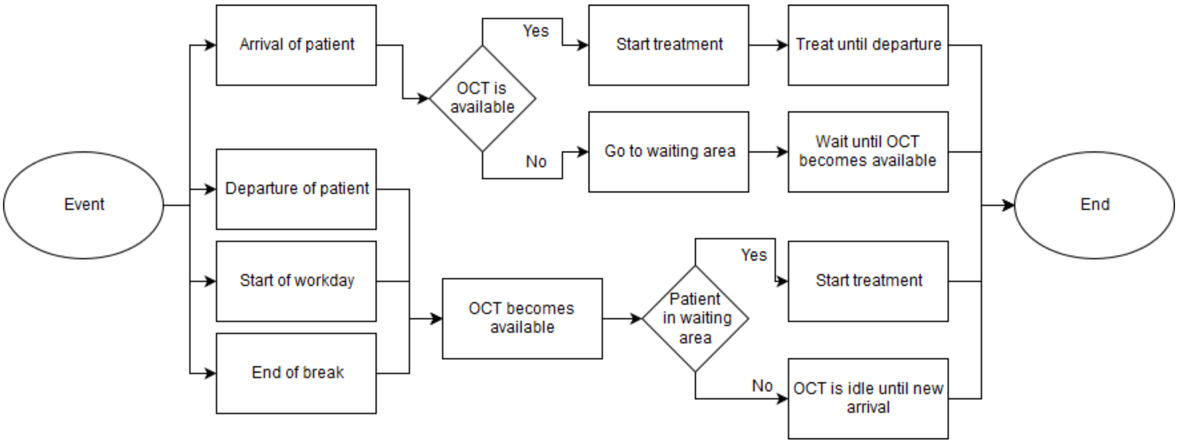

Figure 5.2: Procedures in model

or day of the week.

Patient group The patient type and patient group determine the next steps of the model and are therefore necessary to know. We distinguish two types, namely scheduled patients and walk-in patients. We have 13 patient groups, which determine the estimated and actual appointment length.

Actual treatment length The actual treatment length is the duration of the treatment, so it determines how long the patient is treated and how long the OCT is occupied with this patient. The actual treatment length may depend on patient type, patient group, or other factors.

Estimated treatment length The estimated treatment length is necessary for determining the appointment slots that will be occupied by this patient. In practice we estimate the treatment length and schedule the appointment so that the appointment length equals the estimated treatment length. The estimated treatment length depends on patient type or patient group.

Appointment slot For planned appointments we need appointment slots in where we can plan them. We need multiple agendas with appointment slots and need to determine agenda's for the interventions.

5.2 Simulation model

As stated in the literature study, there are similar studies conducted in other plaster rooms. We extend the model of Van de Vrugt (2016). As this basic model is programmed in C++, our model is as well. We use Microsoft Visual Studio as software to build, run, and analyze the model. The model is a discrete-event simulation, consisting of independent days. The system is cleared at the end of the day, making it a terminating simulation. The end of the day is the terminating event, as we do not carry patients from one day to another. Details of the basic model can be read in Van de Vrugt (2016) and Appendix C provides a detailed description of the extended model.

5.2.1 Input

For each input required data is gathered and fitted to theoretical distributions. If no fit can be established, an empirical distribution is constructed based on the historical data. Appendix B shows the gathered data in detail.

Distribution fitting is done using EasyFit, an Excel extension. For continuous data we try to fit Uniform, Normal, Chi-Squared, Exponential, Gamma, Log-Normal, and Weibull distribution. We assess goodness of fit with the Kolmogorov Smirnov test. For discrete data we investigated Binomial and Poisson. We assess goodness of fit with the Chi-Square test.

In this section we mention the used distributions. Appendix C shows the parameters and p-values from the used distribution, as well as a detailed description of the used empirical distributions.

Time and day The model keeps track of the simulation time. A day starts at simulation time 0 and runs until the simulation time of the last event. The model also tracks the day number.

Number of patients The number of patients for each day is determined as a random variable stemming from a theoretical distribution. The model creates exactly this number of patients at the start of the day.

The number of patients fit a Poisson distribution. We determine that we have busy days and quiet days, however these fluctuations all are representative for the fitted Poisson distribution.

Patient group For the distribution over the patient groups one empirical distribution is constructed from historic data.

Actual treatment length The actual treatment length is determined, depending on patient group, by theoretical distributions, which are bound as in historic data.

For the patient groups 0, 1, 2, 3, 4, 5, 6, 7, 10, 11, and 12 Log-Normal distributions are fitted. For the patient groups 8 and 9 Gamma distributions fit. A normal distribution fits the best with the actual treatment length of group 13.

Estimated treatment length As walk-in patients do not receive an estimated treatment length in the model, we do not fit them to a distribution. None of the estimated treatment length distributions can be fitted to a theoretical distribution. For each groups an empirical distribution is constructed, resulting in thirteen empirical distributions.

Appointment slot The appointment slots are determined through expert opinion.

Arrival time The arrival time for walk-in patients is fitted to an empirical distribution. The arrival time of planned patients depends on their appointment slot, they arrive around the appointment time with a certain distribution. This punctuality of planned patient fits a normal distribution.

5.2.2 Output

Output of the simulation is given in three tables. The first output table contains one row for each day and shows the number of patients, total waiting time, total overtime, total idle time, total treatment time, and number of OCTs. The second table shows the workload per 15 minute time bracket. The last table shows the patient type, and waiting time. This output resembles the historic data.

These tables record the output per experiment and serve to calculate the KPIs. In the model we focus on the following KPIs: service level of patient waiting time (waiting less than 15 or 30 minutes, respectively for planned or walk-in patients), average waiting time per patient, percentage balanced workload over the day, percentage understaffed workload over the day, percentage overstaffed workload over the day, percentage days no overtime, and average overtime overall worked days.

5.2.3 Warm-up, number of runs and common random numbers

Warm-up time

A simulation model needs to reach a steady-state. Some models need a warm-up period to reach this steady-state as they are transient in the beginning. The data of the warm-up period is deleted so that only the steady-state is analysed (Law, 2007). However, this model is simulated with independent days without inventory (patients) remaining for another day, therefore no warm-up period is needed.

Number of runs

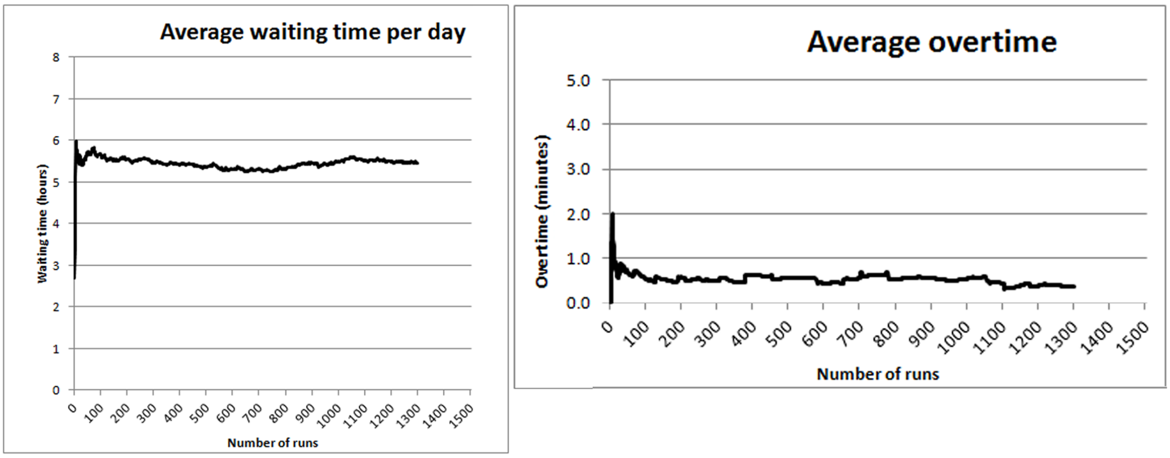

Figure 5.3: Welch's graphical procedure to determine necessary number of runs

Each day is an independent run of the model. In order to accurately evaluate the model the number of runs needs to be specified. We use Welch's graphical procedure to assess the number of runs. As we determine that the days do not differ, each day is the same for the input and we only need to determine the number of runs. Figure 5.3 presents the results of this method. We conclude that we need 500 runs, so a simulation length of minimal of 500 days is required.

Common random numbers

We compare more than two alternative configurations of the model. To facilitate this comparison we need similar controlled experimental conditions. Therefore we pick the same seed for each experiment. This seed generates common random numbers. In the C++ model implementation of two header files (MersenneTwister and Random) provide the common random numbers.

5.2.4 Verification and validation

Verification We verify the conceptual model with the plaster room management and supervisors. The simulation model is also verified by discussing model mechanisms.

Validation

We validate model inputs for correct implementation of theoretical and empirical distributions. The minimal number of runs, determined with Welch's graphical procedure, is 500. We use runs of 1500 days to validate our model as this is sufficiently above the minimal number of runs.

As a component validation we followed patients, entities, moving through the system.

Table 5.2: Output model and baseline measure of the output

Output	Baseline measure	Model output
Service level patient	94.3%	89.7%
Average waiting time	5.6 minutes	6.4 minutes
Workload over the day (percentage correctly staffed, overstaffed, understaffed)	(59.8%, 29.4%, 10.8%)	(61.7%, 22.7%, 15.6%)
No overtime	99.3%	98.7%
Average overtime	0.14 minutes	0.24 minutes

To validate output data, we compare the results of the KPIs. Table 5.2 shows the results of the model, in comparison with the baseline measurement from the historic data. Figure 5.4 shows the workload output of the model on the right in comparison with the current practice on the left. We can conclude that the result mimics the current practice.

5.3 Experiment design

This section outlines which interventions are tested and which experiments we perform.

5.3.1 Interventions

The performance analysis shows that the number of OCTs fluctuate each day. To assess the influence of a constant number of OCTs we experiment with this number. We expect that this can give an indication whether four, five, or six OCTs are necessary each day.

During the performance analysis we find that the appointment lengths are not correctly estimated. Therefore we are interested in how the performance improves as we do estimate the appointment lengths correctly.

During this research the plaster room's management informs us about the upcoming changes in opening hours. We assess the extended opening hours in the intervention "opening hours".

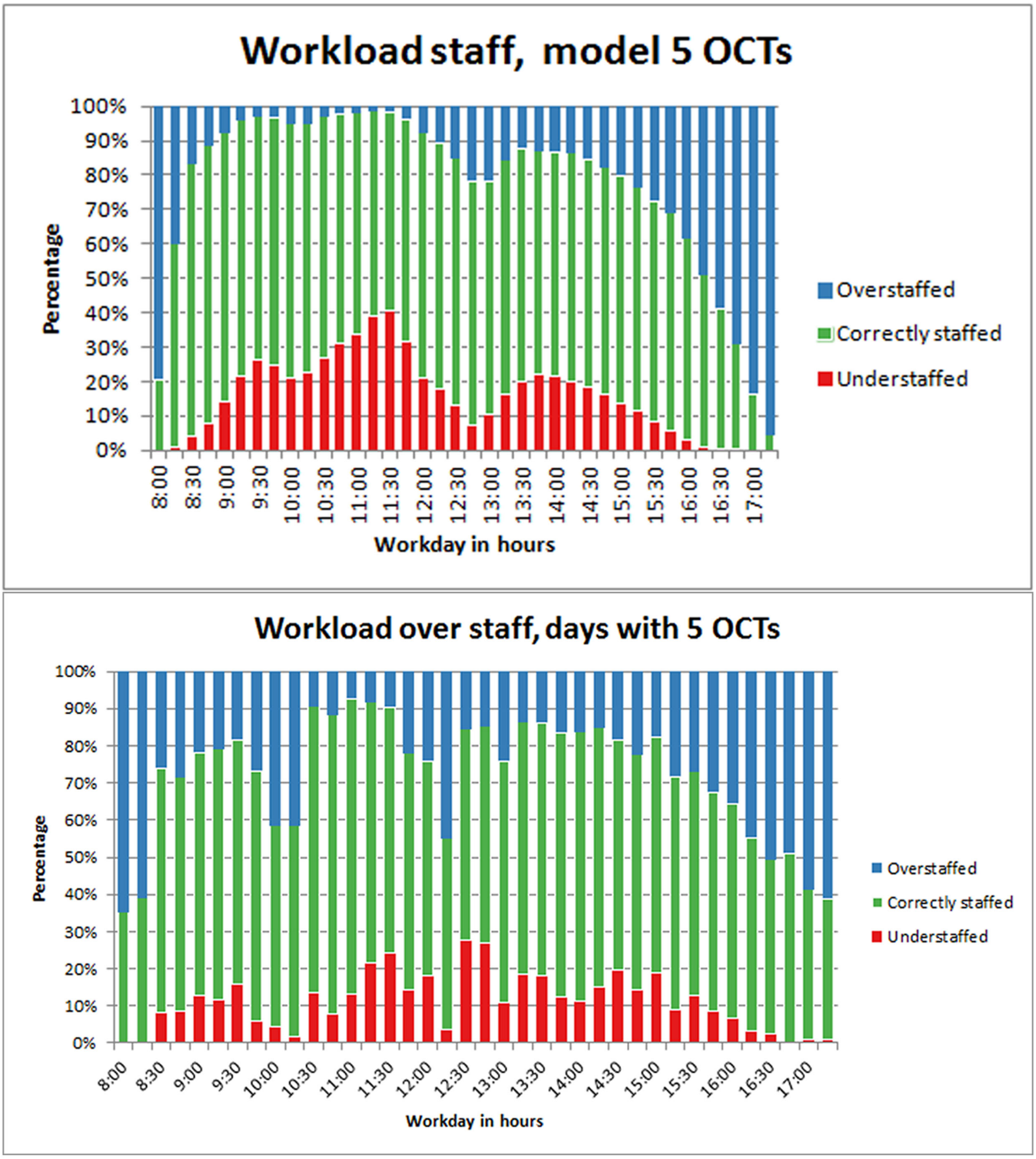

Figure 5.4: Relative workload per day, model for 5 OCTs

Table 5.3: Experiment

Number	Intervention
I	Number of OCTs
II	Estimation appointment lengths
III	Opening hours
IV	Appointment schedule
V	Capacity reservation

In the literature we find the following interventions interesting for the plaster room of the SMK: "Dome" rule and reduce effect of walk-ins.

The "Dome" rule is a type of appointment scheduling rule. With this rule more appointments are scheduled at the start and end of the day. The aim is to minimize the waiting time and idle time, we expect that the workload balance improves. This is the "appointment schedule" intervention.

The proposed intervention which reduces the effect of walk-ins we call "capacity reservation". The walk-in patients represent an unknown demand until they arrival. The effect is that waiting times can increase is that the arrival and need for an appointment The procedure states that the number of scheduled patients should be decreased with the probability of walk-ins. We like to achieve this by a dynamic capacity reservation. We expect that the workload improves.

We set up five sets of experiments. In each we assess an intervention. Table 5.3 shows the set of experiments.

5.3.2 Intervention I

In the first set of experiments we change the number of OCTs. We expect that busy days require six OCTs to ensure the performance and that quiet days can be handled with four OCTs. We perform three experiments.

5.3.3 Intervention II

We expect that estimating the appointment lengths correctly influences the appointment schedule drastically, and decreases waiting time. Currently the actual appointment length can be five times longer than estimated. This means that when an appointment is estimated for a length of 15 minutes, it might take longer than 75 minutes. The appointment planning is based on the estimated appointment length.

An appointment that takes five times longer than expected influences the planning. The next appointment cannot begin in time; waiting time increases. We assess this intervention by gradually changing the ratio between the estimated appointment length and the actual appointment length from five to two times, where in the current system a ratio of five times off might occur. We perform four experiments. When the estimated appointment length is not within the ratio, we change this estimation.

5.3.4 Intervention III

We change the opening hours from 8:00 to 17:30, to 8:00 to 20:00. This expansion is necessary to provide an OCT for the extra operations performed after 17:30. One OCT is available from 10:00 to 20:00. We expect that with the current arrival rate the extra hours are not used efficiently. Therefore we also experiment with an increased rate of operations. We perform three experiments.

5.3.5 Intervention IV

We change the appointment schedule from list scheduling to an “outside-in” schedule. We expect that the effect of walk-in patients is less disruptive, as we plan patients at the end and start of the day. It is expected that the overtime occurrence is higher. However we expect a positive influence on the balance of the workload.

5.3.6 Intervention V

We change the capacity reservation. In the hours where historically the amount of walk-in patients is high, we plan fewer appointments. We expect that this has a positive influence on the balance of the workload.

For each experiment we measure the KPIs: average waiting time per patient, service level (percentage patient waiting less than the target), percentage correctly staffed, overstaffed, and understaffed workload, percentage no overtime occurrence, and average overtime per day.

5.4 Conclusion

This chapter describes the conceptual model and the simulation model. We present the input parameters and we perform verification and validation. Furthermore we elaborate on the experimental settings.

We perform five sets of experiments, in each set we implement one intervention. We assess the effect of the number of OCTs, correctly estimating the appointment lengths, extension of the opening hours, and multiple experiments on the effect of fewer appointments during the busy hours of the walk-in patients.

The next chapter provides the results of the sets of experiments.

Chapter 6

Results

This chapter presents and discusses the results of the experiments. We conclude with the most effective intervention.

Table 6.1 shows the sets of experiments and the implemented intervention. Appendix E provides a complete overview of all results.

The current system of the plaster room works more efficiently than the model could perform. The difference between the performance measure of the current system and performance of the model is taken as a not statistical difference. Therefore, as we discuss the results on the performance of the sets of experiments we only mention the results that differ statistically.

6.1 Intervention I

Experiments with the number of OCTs show that having the same number of OCTs every day does not result in a balanced workload. Table 6.2 shows the results of this set of experiments. We determine that with six OCTs the average waiting time decreases, however the performance on correctly staffed and overstaffed workload

Table 6.1: Experiment

Number	Intervention
I	Number of OCTs
II	Estimation appointment lengths
III	Opening hours
IV	Appointment schedule
V	Capacity reservation

Table 6.2: Output model intervention I

Output	Model output 5 OCTs	6 OCTs	4 OCTs
Service level patient	89.7%	98.0%	61.3%
Average waiting time	6.4 minutes	1.9 minutes	22.9 minutes
Workload over the day (Percentage correctly staffed, overstaffed, understaffed)	(61.7%, 22.7%, 15.6%)	(54.6%, 37.7%, 7.7%)	(49.7%, 24.2%, 26.1%)
No overtime	98.7%	99.8%	89.3%
Average overtime	0.24 minutes	0.02 minutes	9.81 minutes

declines. We conclude that the performance with six OCTs on average waiting time improves, but the workload does not and on average there is more staff than necessary.

In the experiment with four OCTs each day the waiting time, overtime, and understaffed performance deteriorate. This result is what you would expect as busy days are handled with fewer staff members.

We conclude that on busy days four OCTs cannot retain the performance. Therefore the number of OCTs should match the demand of the day. If done correctly the waiting times decrease, workload is better balanced, and overtime is reduced. However, in practice it is difficult to estimate the demand correctly, so we recommend further research.

6.2 Intervention II

Table 6.3 shows the results of this set of experiments. Gradually estimating the appointment lengths improves the correctly staffed performance. However it deteriorates the overtime performance.

The appointment planning is determined at the estimated appointment length, the better this complies with the actual appointment length the better the planning will be. We expect the waiting time to decrease and the workload to be more balanced.

The results do not show a decrease in waiting time, but show an increase in overtime. This can be explained by the model mechanisms for planning on the estimated appointment length. As the estimation is better the appointments are scheduled later in the afternoon, but the appointment can still take longer than expected. As an appointment starts late and takes longer than expected, it is more likely to cause

Table 6.3: Output model intervention II

Output	Current ratio 5 times	Ratio 2 times
Service level patient	89.7%	92.2%
Average waiting time	6.4 minutes	5.4 minutes
Workload over the day (Percentage correctly staffed, overstaffed, understaffed)	(61.7%, 22.7%, 15.6%)	(62.2%, 23.5%, 14.2%)
No overtime	98.7%	97.7%
Average overtime	0.24 minutes	1.39 minutes

overtime. Therefore better estimation of appointment length increases the risk of overtime.

We expect a change in the performance after the appointment lengths are better estimated. We find that, in our model, only 6% of the estimated appointment lengths are not within the two times ratio of the actual appointment length. So in our experiment 6% of the estimated appointment lengths is altered. Together with the fact that the estimated appointment length may still differ from the actual appointment length this explains the minor improvement we see.

As the results show a better balance of workload, estimating appointment lengths better is a promising intervention for the plaster room. However, the overtime increases and planning staff should keep this in mind when determining the planning in the afternoon.

6.3 Intervention III

In set III the experiments focus on extended opening hours. It is likely that this intervention will be implemented in September 2017 as the SMK starts operating from 17:30 to 20:00.

Operating after regular workdays means that at least one OCT should be present to assist during operations. As we do not know the demand we experiment with the current demand rate and an increased demand rate, as we expect more operations. For these experiments we have one OCT present from 18:00 to 20:00. Appointments, and thus operations, are scheduled from first to last slot; during quiet days

Table 6.4: Output model intervention III

Output	Model output current opening hours	Extended hours, current rate	Extended hours, rate +25%
Service level patient	89.7%	85.3%	84.1%
Average waiting time	6.4 minutes	8.4 minutes	9.1 minutes
Workload over the day (Percentage correctly staffed, overstaffed, understaffed)	(61.7%, 22.7%, 15.6%)	(47.1%, 38.7%, 14.2%)	(47.5%, 37.7%, 14.8%)
No overtime	98.7%	99.9%	99.8%
Average overtime	0.24 minutes	0.09 minutes	0.10 minutes

the extra opening hours will not be used. We do not expect walk-in patients during the extended opening hours.

Table 6.4 shows the results for the current rate and an expected rate of 25% more operations. We conclude that the waiting time performance, the correctly staffed, and the overstaffed performance deteriorate. For the current modelling inputs this result can be expected. Only one OCT works from 10:00 to 20:00, so when demand is high waiting times increase. On the other hand when there are no appointments from 18:00 to 20:00 the OCT is overstaffed.

We encourage the plaster room to investigate the expected demand between 18:00 and 20:00 in terms of operations and maybe even walk-in patients before implementing this intervention. It is necessary to determine whether an OCT needs to be present during these hours or if it might be sufficient to have an OCT available on call.

When the right number of appointments takes place in the evening hours, the OCT can be correctly staffed and this intervention can ease workload during the day.

6.4 Intervention IV

We implement an “outside-in” appointment schedule, expecting a more balanced workload and fewer appointments in the middle of the day.

Table 6.5 shows the results of the appointment schedule and the dynamic capacity, implemented in the next set. We conclude that the results do not show a significant

Table 6.5: Output model interventions IV & V

Output	Model output current practice	Outside-in	Dynamic capacity
Service level patient	89.7%	91.3%	92.9%
Average waiting time	6.4 minutes	5.5 minutes	5.0 minutes
Workload over the day (Percentage correctly staffed, overstaffed, understaffed)	(61.7%, 22.7%, 15.6%)	(61.3%, 24.7%, 14.0%)	(63.2%, 23.0%, 13.8%)
No overtime	98.7%	88.4%	98.5%
Average overtime	0.24 minutes	2.66 minutes	0.35 minutes

difference in the performance, except for the overtime performance which worsens. This is the result of planning more appointments in the afternoon.

The intervention of scheduling “outside-in” is not able to reduce the effect of walk-in patients in practice, moreover it is likely to cause more overtime.

6.5 Intervention V

In the last set of experiments we implement a dynamic capacity reservation. We expect that the effect of walk-in patients will be reduced, as fewer appointments are scheduled during hours where high numbers of walk-in patients are expected.

Table 6.5 shows the results of the experiment with a dynamic capacity reservation. We conclude that this intervention results in a better workload balance, the correctly staffed performance improves. The average overtime is slightly longer, as a little more appointments are scheduled in the afternoon. We conclude that the results of the overtime performance are still very good.

The intervention of dynamic capacity reservation performs the best on balancing the workload and maintaining the other performances.

6.6 Conclusion

This chapter presents the results of the assessment of the selected interventions. We can now establish which intervention improves the performance. We start this

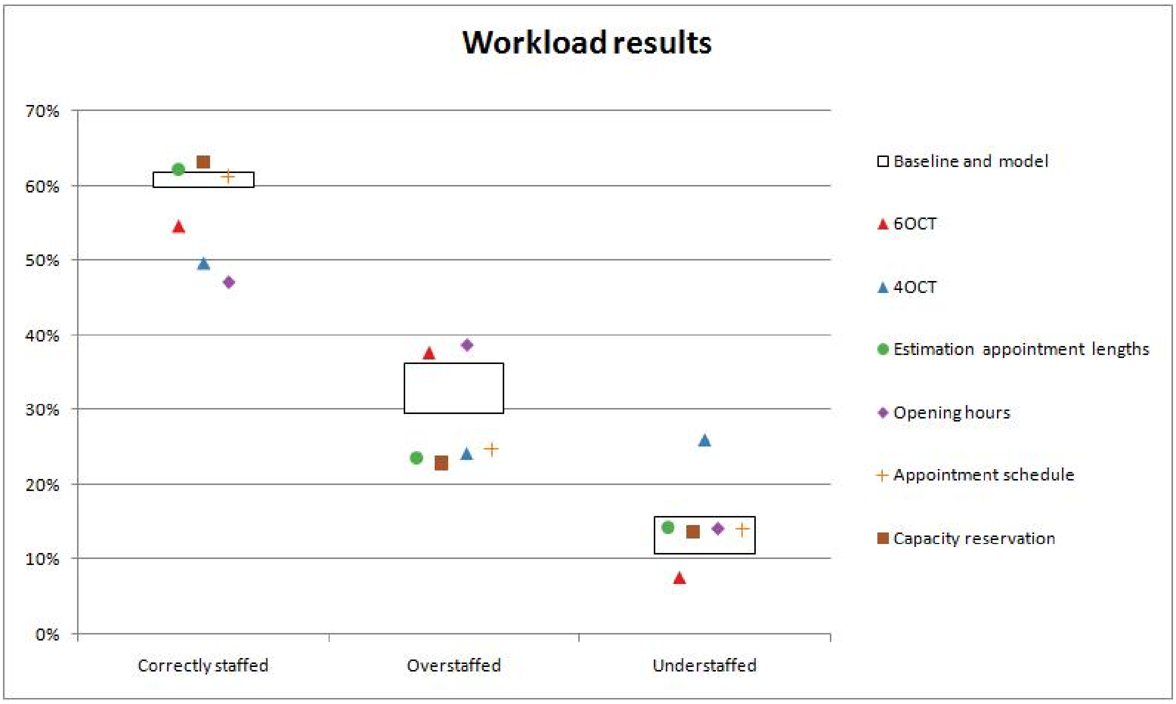

Figure 6.1: Results of all experiments on workload performance

section with a limitation of the model; the model performs worse than practice.

The model does not statistically differ from the baseline measure. As we discuss the results on the performance of the sets of experiments we only mention the results that make a statistical significant impact on performance.

Figure 6.1 shows the results of the experiments on the workload performance. We conclude that the interventions estimation appointment lengths and capacity reservation improve the performance in terms of correctly staffed workload. The interventions on changing the number of OCTs and extending the opening hours all deteriorate this performance. For the overstaffed performance we see that six OCTs and extending the opening hours deteriorate the performance. The understaffed performance is reduced by implementing four OCTs.

We did not find an intervention that improves all performance measures. The best performing intervention, dynamic capacity reservation, improves the correctly staffed performance to 63.2% and deteriorates the average overtime slightly to an average per day of 0.35 minutes.

Having a constant the number of OCTs per day does not increase the performance, four OCTs decline all performance measures. The correctly staffed performance drops by 10.1%. Six OCTs decline the correctly staffed performance by 5.2%, but decrease the average waiting by 3.7 minutes. It is important to balance the number of OCTs to the demand, a busy day requires six OCTs while a quiet day requires four OCTs. An “outside-in” schedule declines the “no overtime” occurrence by 10.9% and the average overtime increase by 2.52 minutes.

Estimating appointment lengths correctly will improve the workload; it increases to 62.2%. However this increases the no overtime occurrence by 1.6%. Extending the opening hours requires more data and should not be implemented without establishing rules for the availability of an OCT during these extended hours, otherwise the overstaffed performance deteriorates considerably; by 12.7%.

The results show that dynamic capacity reservation performs the best and is, with the now collected data, easy to implement. The correctly staffed performance improves to 63.2%.

Chapter 7

Conclusions

This chapter provides the conclusions and recommendations of this research. Section 7.1 discusses the limitations. Section 7.2 provides the conclusions. Section 7.3 provides the recommendations for the SMK. We conclude with directions for future research.

7.1 Discussion

The primary goal of this research is to provide information on current processes and performance in the plaster room, and to identify and assess interventions that improve the performance in terms of patient waiting times and balance of workload.

At the start of this research the scope is chosen to provide insight in the current processes and performance, as there is a lack of management information. We focus on the processes in the plaster room, thereby leaving out all other processes in the hospital that influence this process. For example we did not focus on the staff planning, or how to improve the staff planning, nor did we try to improve medical specialists' availability, or communication between the outpatient clinic and the plaster room.

We also did not take the influence from the schedule of outpatient clinic into account, which influences the number of walk-in patients per day. Nor did we investigate how to estimate the demand per day in advance. We suggest further investigation into these processes, as we expect possibilities for more improvement in them.

During the data analysis we encountered a lot of missing data, which might have led to a biased view on the performance. We argue that we did not find a relation for the missing data, it appeared to be random. There is one exception, for all occasions of assistance there is no data available, as to when the assistance started or ended. We advise the staff to register the time spent giving treatment and especially when assisting. The data from this registration can be used to determine the average length of assisting, and can be applied in the model.

Furthermore we found performance indicators which we could not measure, because the necessary data is not available and we could not generate it. We expect that performance on access time is interesting. This tells us how many patients have an appointment during their preferred time frame, which can inform us if we reserve enough capacity for all patients.

Modelling the current situation of the plaster room proved to be a challenge as the appointment rules are not always strictly followed. The expertise of the planning staff of when to avoid certain appointment slots is hard to implement. The differences between the model results and baseline measure of the historic data is seen as not a statistical difference. The results of the experiments should differ statistically from the baseline measure to improve or deteriorate the performance.

The most promising intervention is dynamic capacity reservation, which improves the correctly staffed performance with 3.4%. Implementation of this intervention is easy, as we have now analysed the distribution of walk-in patients.

The intervention of extended opening hours is likely to be implemented in September 2017. We simulated this intervention, with the following rules: there is always one OCT present in the plaster room during the extended hours, appointments are scheduled from first slot to the last slot, and no walk-in patients occur during the extended hours. These rules influence the results of the experiment. Most days do not have appointments scheduled during the extended hours and some days there are multiple appointments scheduled. Having no appointments scheduled causes the extended hours to be overstaffed for most days, while having multiple appointments scheduled causes long waiting times for the patients. We conclude that the plaster room' management should investigate the expected demand for the extended hours and plan staff accordingly. Another solution might be an OCT on call base during the extended hours.

We investigated all interventions individually. As the improvement on the performance is limited, a combination of interventions might improve more. We recommend for further research to research the combination of estimating appointments better and using a dynamic capacity reservation. We expect that estimating appointments better and using a dynamic capacity reservation improves the performance, as both interventions individually improve the correctly staffed performance. Also other interventions as mentioned out of scope for this project can be combined with a dynamic capacity reservation. When the plaster room can predict the demand more precise, dynamic capacity reservation will be even more promising as the reservation is made on the estimation of necessary demand.

7.2 Conclusion

This research succeeds in analysing the current process and performance in terms of waiting times, balance of workload, overtime, hours worked, and utilization. The defined performance measures (KPIs) can be used in further research concerning the plaster room performance. They are set according to SMK standards. A baseline measurement with these KPIs is performed, and problem areas are determined. We review the literature on plaster rooms, appointment schedules, and available models. We propose interventions, which we test with a model. Therefore a simulation model is constructed. The model simulates the current system of the plaster room, is able to assess interventions, and measures the output in similar terms as the baseline measure. Several interventions are implemented and the output is assessed to determine the most promising intervention.

The baseline measures of the performance show a well performing system. Patient wait on average 5.6 minutes, 94.3% of the patients waits less than the target. In 99.3% of the days no overtime occurs; overtime occurs rarely. The target for ”hours worked” is met and the utilization is 81.3%, which shows that the plaster room works efficiently. We find that the balance of workload is low, 41.8% of the times the workload is not correctly staffed. The performance on estimating the appointments is only 17%.

The most promising intervention is dynamic capacity reservation. The ”correctly staffed” workload improves and increases to 63.2%. Furthermore this intervention does only decrease the average overtime slightly to an average of 0.35 minutes. All other performances remain the same.

7.3 Recommendations

Based on the discussion and conclusion as well as observations made while performing this research, several recommendations for the SMK can be made. We also give recommendations for further research.

The results show that the most promising intervention is the dynamic capacity reservation. We recommend testing this intervention in practice. This intervention involves another manner of reserving the capacity. The hours with expected few walk-in patients should not be reserved for walk-in patients. Historically busy hours in terms of walk-in patients should be more reserved for walk-in patients. During historically busy hours in terms of both walk-in and planned patients the optimum of reservation for walk-in patients should be found.

Furthermore, the results show that extending the opening hours and always having one OCT present does not lead to a balance of workload during these extended hours. We advise the plaster room's management to investigate the expected demand during the extended hours, and plan staff accordingly. Otherwise, implementing the extended hours only worsens the performance of the plaster room.

We strongly advice further research into prediction of the demand. The dynamic or even static, capacity reservation is depended on the prediction of demand per appointment slot. In the current situation planning staff estimates the demand on scheduled outpatient consults. In the model this is done based on the historical data. The next step is an accurate prediction of the demand beforehand, the SMK is developing a model for such prediction.

The data from the hospital information system is not complete. In the information system the patient appears in a field. Each field represents a part of the plaster room, the patient can be in the waiting room, in a treatment room or the treatment is finished. The change of a field triggers the system to save the time and these times are linked to the arrival, start treatment, and departure time. The OCTs must change the field each time they start the treatment and as the treatment is finished. We notice a lot of missing data, during the data analysis. More data creates a more representative view of the situation in the plaster room. We advice the OCTs to pay more attention to changing the fields each time.

In the data, the distinction between patients that are visited by a OCT in the ward and patients that are staying overnight but visit the plaster room are not clear. Both are indicated as inpatients. The difference is whether or not a treatment room in the plaster room is being occupied. The same is noted for ordering an orthosis or fitting the orthosis while the patient is physically present. A generic code should be in place for these instances, as the data can then accurately represent the use of the plaster rooms. Assessment of the use of plaster room can be made, which is of interest for management.

The agenda system of the SMK is based on the number of treatment rooms, while the limiting resource of the plaster room is the number of OCTs. Therefore it can happen that the agenda system does not show a problem, while in reality the plaster room is understaffed. Currently the planning staff tries to prevent this by reserving more capacity for walk-in. We recommend a system where the limiting resource is leading in the planning.

Our research shows that some treatment codes are regularly not correctly estimated. We recommend changing the expectations for treatment codes that are now estimated at 60, 75, 90, and 100 minutes.

For further research we recommend to research the access time of patients. Patients prefer a treatment on a certain date, how many of them do, and how many of them do not. And how much does it deviates. There is no historic data from the hospital. This should be acquired before this research starts.

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Appendix A

Literature search

Search methods

We use search engines and search terms to find a number of scientific articles. Furthermore, we find several articles as references in other work. For the simulation study we use the book Simulation Modeling and Analysis by (Law, 2007).

Search engines

The literature search is conducted using the ScienceDirect search engine (`http://www.sciencedirect.com`). For references found in other work we use the Google Scholar engine (`https://scholar.google.nl`). Furthermore, we use the database of graduation reports by the CHOIR group and the database of the University of Twente.

Search terms

For literature on plaster rooms we use the following search term *(plaster or cast) room AND healthcare*, *(plaster or cast) room AND logistics*, and *(plaster or cast) room AND scheduling*. We find a large number of research, but non apply to our research. In the CHOIR and University database we find multiple researches on this topic.

On outpatient clinics and appointment scheduling we find literature with the term *appointment AND scheduling AND outpatient*. For simulation or analytical models the terms *AND simulation* or *AND analytical* are added.

For specific literature on walk-in patients we search with *walkin AND appointment*.

Selection and exclusion

Literature is selected based on title, abstract, and the relation to this research project. We exclude literature when the content is not related to this research project.

Appendix B

Results of data analysis for model

For each group of patients we count the number of instances. We exclude an instance when the actual length of the appointment could not be measured or when the actual length is less then 10 minutes. Table B.1 shows the number of instances per group. For patient group 6 there is no available data on the actual length, we use the instances of the estimated appointment length instead.

Table B.1: Included instances of appointment length per group

Patient group	Total measured	Included instances
Total	18873	12530
0	8957	4046
1	3767	3102
2	1627	1149
3	978	949
4	924	830
5	665	636
6	483	483
7	397	390
8	385	368
9	325	244
10	127	114
11	121	111
12	105	96
13	12	12

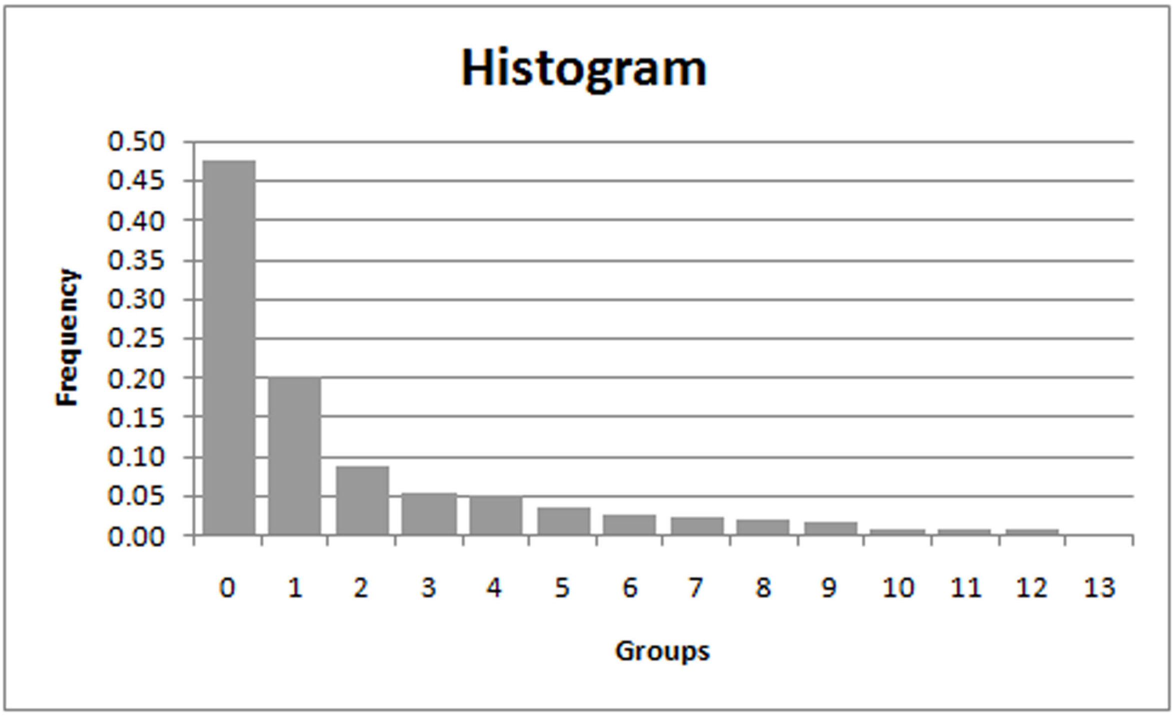

Figure B.1: Histogram instances per group, N=18873, data set complete

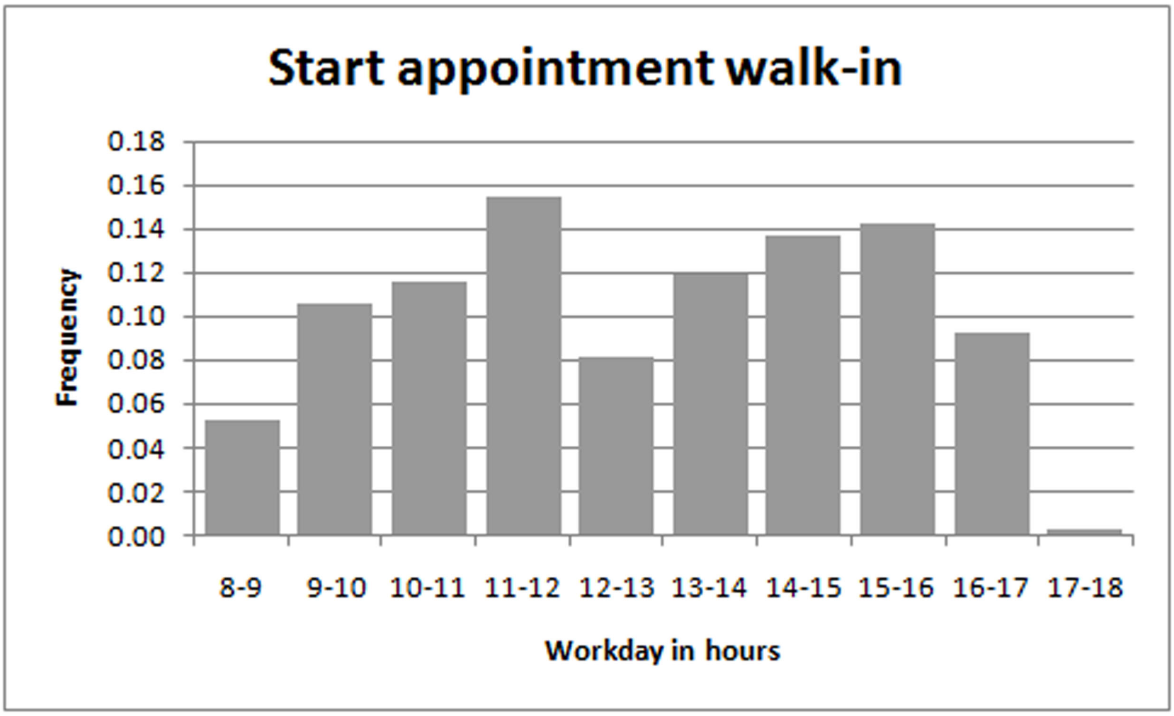

Figure B.2: Histogram walk-in appointments started over the workday, N=8957, data set complete

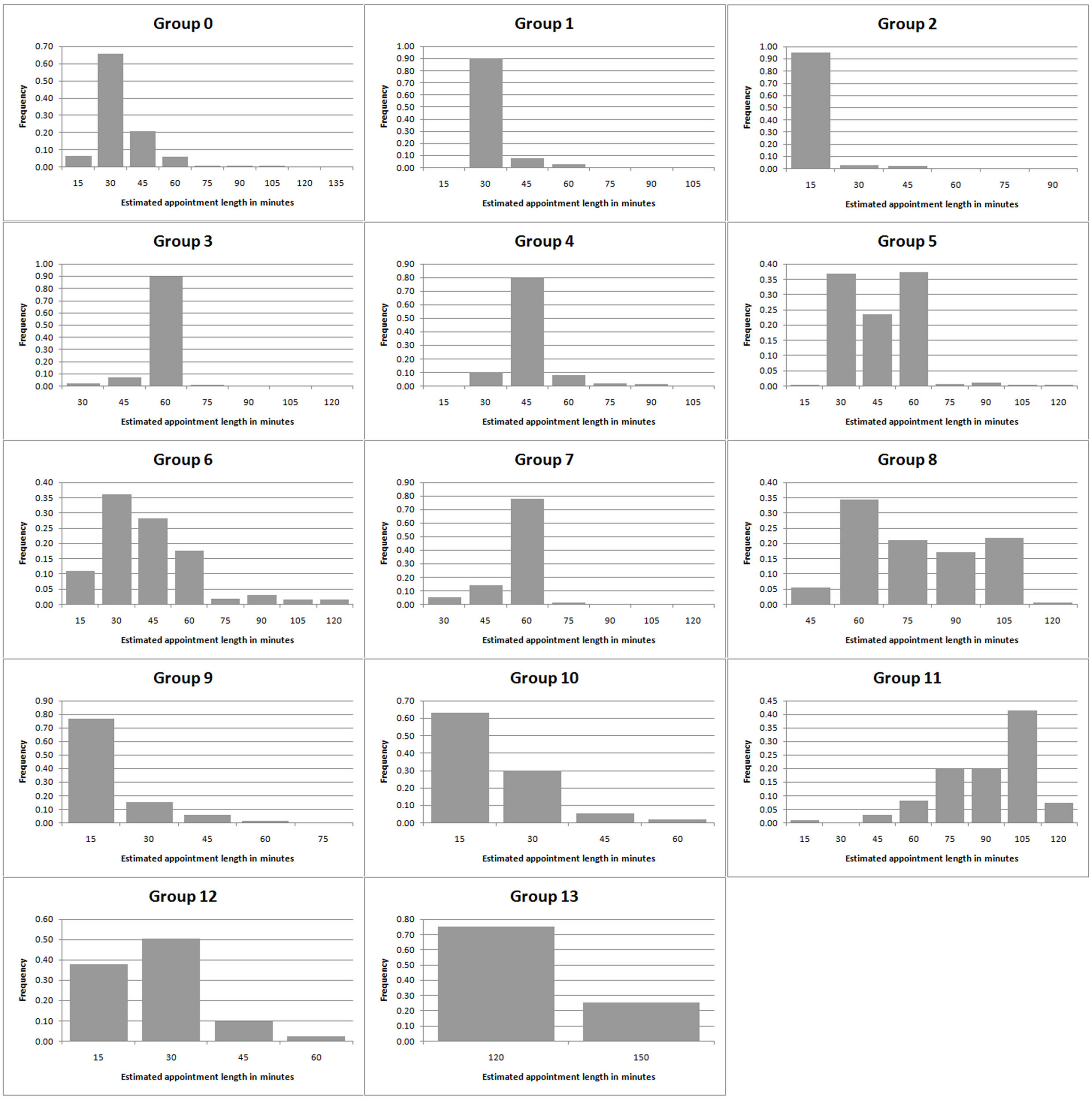

Figure B.3: Histogram estimated appointment length per group, N=12530

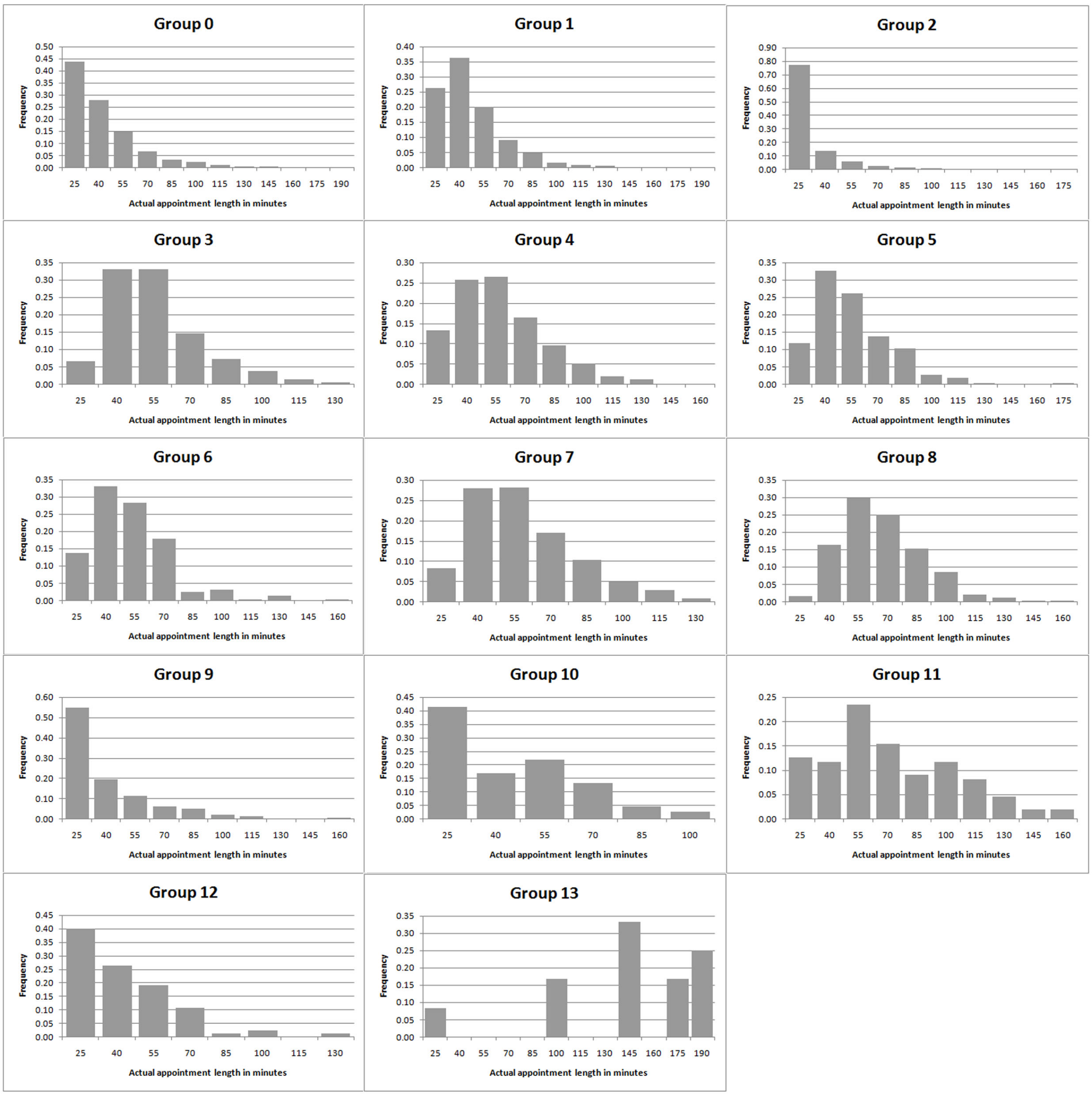

Figure B.4: Histogram actual appointment length per group, N=12530

Appendix C

Detailed description of the simulation model

Input

Time and day

The model keeps track of the simulation time. A day starts at simulation time 0 and runs until the simulation time of the last event. The next day is triggered as all events of the previous day are finished.

Number of patients

We determine that the number of patients follow a Poisson distribution, which is independent on the day of the week. The model draws a random variable from this distribution to determine the number of patients at the start of the day. We use a Poisson distribution, with λ 48.9 and a p-value of 0.11.

Patient group

For the distribution over the patient groups one empirical distribution is constructed from historic data. Table C.1 shows this distribution.

Actual treatment length

The actual treatment length is determined, depending on patient group, by theoretical distributions, which are bound as in historic data.

Table C.1: Distribution patient group

Patient group	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Frequency	0.474	0.200	0.086	0.0528	0.049	.035	0.026	0.021	0.020	0.017	0.007	0.006	0.006	0.001

Table C.2: Distributions actual treatment length

Patient group	Distribution
0	Log-Normal distribution (μ = 3.3607, σ = 0.5744, p = 0.05)
1	Log-Normal distribution (μ = 2.9291, σ = 0.5012, p = 0.14)
2	Log-Normal distribution (μ = 3.5305, σ = 0.5065, p = 0.04)
3	Log-Normal distribution (μ = 3.8041, σ = 0.4069, p = 0.04)
4	Log-Normal distribution (μ = 3.8021, σ = 0.5003, p = 0.04)
5	Log-Normal distribution (μ = 3.7654, σ = 0.4738, p = 0.03)
6	Log-Normal distribution (μ = 3.6348, σ = 0.4836, p = 0.18)
7	Log-Normal distribution (μ = 3.8564, σ = 0.4528, p = 0.03)
8	Gamma distribution (α = 4.8906, β = 11.376, p = 0.03)
9	Gamma distribution (α = 2.9193, β = 15.301, p = 0.04)
10	Log-Normal distribution (μ = 3.5114, σ = 0.5507, p = 0.10)
11	Log-Normal distribution (μ = 4.0734, σ = 0.5926, p = 0.06)
12	Log-Normal distribution (μ = 3.4019, σ = 0.5698, p = 0.08)
13	Normal distribution (μ = 144.25, σ = 59.833, p = 0.16)

For the patient groups 0, 1, 2, 3, 4, 5, 6, 7, 10, 11, and 12 Log-Normal distributions are fitted. For the patient groups 8 and 9 gamma distributions fit. A normal distribution fits the best with the actual treatment length of group 13. Table C.2 shows the used distributions, their parameters and the p-value for the goodness of fit test.

Estimated treatment length

As walk-in patients do not receive an estimated treatment length in the model, we do not fit them to a distribution. None of the estimated treatment length distributions can be fitted to a theoretical distribution. For each groups an empirical distribution is constructed, resulting in thirteen empirical distributions. Table C.3 shows the empirical distributions for the estimated treatment length per patient group.

Appointment slot The appointment slots are determined through expert opinion. The appointment slots are 15 minutes long. Appointment slots are available from three agendas and every fifteen minutes there is appointment slot. The agendas are created so that multiple appointments are planned at once, while the treatment length is taken into account. Table C.4 shows the appointment slots in the static capacity reservation and the dynamic capacity reservation.

Arrival time

The arrival time for walk-in patients is fitted to an empirical distribution. The arrival time of planned patients depends on their appointment slot, they arrive around the

Table C.3: Empirical distributions for estimated treatment length per group

	Estimated treatment length in minutes								
Patient group	15	30	45	60	75	90	105	120	150
0	0.063	0.656	0.207	0.056	0.006	0.005	0.006	0.001	0.000
1	0.002	0.900	0.072	0.022	0.001	0.001	0.000		
2	0.951	0.023	0.021	0.003		0.001			
3		0.022	0.066	0.898	0.009	0.003		0.001	
4	0.001	0.099	0.793	0.080	0.016	0.009	0.002		
5	0.003	0.368	0.234	0.373	0.005	0.011	0.003	0.003	
6	0.108	0.360	0.282	0.176	0.017	0.029	0.014	0.010	0.004
7		0.054	0.138	0.779	0.015	0.005	0.003	0.005	
8			0.054	0.342	0.209	0.171	0.217	0.005	
9	0.766	0.156	0.057	0.016	0.004				
10	0.632	0.298	0.053	0.018					
11	0.009		0.027	0.081	0.198	0.198	0.414	0.063	0.009
12	0.375	0.500	0.094	0.021					
13						0.083		0.583	0.333

Table C.4: Appointment slots for the static (current) capacity reservation and the dynamic capacity reservation

Agenda	Current	Dynamic
1	8:00-11:45, 12:30-16:45	8:00-11:45, 12:30-16:45
2	8:30-11:45, 13:15-15:45	8:30-9:45, 10:30-11:15, 13:00-13:15, 14:00-14:15, 15:00-15:15
3	8:30-11:45, 13:30-15:45	8:30-9:45, 10:30-10:45, 11:30-11:45, 13:30-13:45, 14:30-14:45, 15:30-15:45

Table C.5: Distributions arrival time walk-in patients

Workday in hours	Distribution
8-9	0.052
9-10	0.106
10-11	0.115
11-12	0.154
12-13	0.081
13-14	0.119
14-15	0.137
15-16	0.142
16-17	0.092
17-18	0.002

appointment time with a certain distribution. This punctuality of planned patient fits a normal distribution. The Normal distribution with μ = -7.3968, σ = 26.949, and a p-value of 0.16 describes the punctuality.

Output

Output of the simulation is given in three tables. The first output table contains one row for each day and shows the number of patients, total waiting time in hours, total overtime in hours, total idle time in hours, total treatment time in hours, and number of OCTs. The second table shows also contains a row for each day. The row shows the workload per 15 minute time bracket. The last table shows the patient type, and waiting time. This output resembles the historic data.

These tables record the output per experiment and serve to calculate the KPIs. The output can easily be exported to Excel where the calculations for the KPIs can be performed. In the model we focus on the following KPIs: service level of patient waiting time (waiting less than 15 or 30 minutes, respectively for planned or walk-in patients), average waiting time per patient, percentage balanced workload over the day, percentage understaffed workload over the day, percentage overstaffed workload over the day, percentage days no overtime, and average overtime overall worked days.

Model elements

The model consist of the following elements: main, initialise, make patients, and simulation.

main

The main function sets up the experiments is in this run. The number of days are determined, the method *Initialise* is called, and next the *simulation* is executed here. After executing the simulation overtime calculation is done and the memory is cleared.

Initialise

The method Initialise makes an initialisation for the simulation. It creates the number of OCTs, gives the OCTs an available status, and triggers the *begin break* event so that the OCTs can have a break. This method also sets up the calculation for the workload, which will be executed as an event. Then the method *Make patients* is called.

Make patients

The method Make patients consists of two parts. First, the patients are created and the patient group, actual treatment length, and estimated treatment length are determined. Second the appointment planning is made.

After determining the number of patients, the patient attributes are determined. For all patients this includes the patient group and the actual treatment length. For the planned patients this also includes the estimated treatment length.

The appointment planning for walk-in patients includes determination of the arrival time, which is determined by the arrival rate. An event is inserted at the arrival time.

For planned patients we first need to determine the appointment time. After determination of the appointment time the arrival time is set. The arrival time is normally distributed around the appointment time. The appointment slots that are now taken by this appointment are deleted. At last the event is inserted at the arrival time.

The appointment time is determined by loading all available appointment slots, calculating the remaining time in the agendas, and determining the first available slot. When the estimated treatment length fits the remaining time of an agenda the appointment is planned at that time. If there is more than one agenda large enough to fit the appointment the first available slot is chosen. When the estimated treatment length does not fit the remaining time of one of the agendas the appointment is planned in the agenda with the most remaining time at the first available slot.

Simulation

After the method *Make patients* all starting events are initialised. The simulation can now start. All events are executed.

Arrival event Executing an arrival triggers a check for an available OCT. When an OCT is available the idle time is determined, the departure time is determined, and a new event is set at the departure time. When an OCT is not available the patient is placed in the queue.

Departure event Executing a departure triggers the method which checks whether there is a patient in the queue. If there is a patient in the queue this patients treatment starts. The waiting time for the patient is determined, we do not count voluntary waiting time. A new event is inserted at the departure time. When there is no patient in the queue there is a check whether the OCT can take a break, after 12:00, or can end his shift.

Begin break event The *begin break* method executes the break. This can mean ending an shift or starting a lunch break. Ending an shift can only happen after 17:00 and when there are two or more OCTs still working. A lunch break triggers a break for half an hour. The *end break* event is inserted half an hour from now. The break event triggers a status change for the OCT, he becomes unavailable to treat a patient.

End break event This event ensures that the OCT is available again, his status changes, and triggers a check for a new OCT to go on a break.

Workload calculation event This calculation is triggered every fifteen minutes. It calculates the number of OCTs available and the number of patients that are available. The latest includes patients waiting for treatment, as waiting indicates an unbalanced workload.

Appendix D

Treatment codes

This appendix gives an overview of the treatment codes that are used in the plaster room. The treatment codes are given in their Dutch abbreviation and with the English explanation. We give the frequency per code and in which patient group it belongs. Table D.1 shows the treatment codes.

Table D.1: Treatment codes with associated group in model

Dutch Treatment code	Frequency in percentage	English explanation	Patient group
ORPF	18.93	prefabricated orthosis	1
ASSG	16.44	assistance	6
OBGI	11.62	lower leg plaster	1
ORVV	8.48	orthosis not prefabricated	4
WCUI	6.10	extensive wound consult	1
GVGI	5.98	plaster removal	2
OBGWHV	4.57	lower leg plaster renewed and remove stitches	3
VCGI30	3.17	follow-up 30 minutes	1
OBGWVC	3.12	lower leg plaster renewed and follow-up	5
VCGI	2.98	follow up 15 minutes	9
OAGI	2.44	lower arm plaster	1
OBGWWC	2.24	lower leg plaster renewed and wound consult	7
GVGIVS	2.03	plaster removal and consult	2
TCGI	1.77	follow-up via telephone	2
VATH	1.63	vacuum therapy	8
CONO	1.22	normal consult	3
GVGIGK	1.19	plaster renewed	2
WCNO	0.82	normal wound consult	10
COUI	0.75	extensive consult	11
BAGI	0.72	upper arm plaster	4
BBGI	0.68	upper leg plaster	5
OBGWVA	0.63	lower leg plaster renewed and vacuum therapy	8
HVGI	0.58	remove stitches	12
VCGI45	0.53	follow-up 45 minutes	4
GVGIHS	0.51	plaster removal and remove stitches	9
OAGWHV	0.30	lower arm plaster renewed and remove stitches	5
VCGI60	0.14	follow-up 60 minutes	7
KVGI	0.12	remove K-wires	10
OAGWVC	0.11	lower arm plaster renewed and follow-up	5
DYSP	0.07	dynamic splint	13
BRAA	0.06	fitting brace	1
BRCO	0.03	consult brace	1
OBGWPO	0.03	lower leg plaster renewed assisted by POM	4
GVGIKS	0.01	plaster removal and consult children	2

Appendix E

Results of simulation

This appendix gives a complete overview of the results from the experiments performed in the simulation model.

Figure E.4 shows all results. Significant improvements are shown in green, significant deteriorations are shown in red, and small changes are shown in orange. Figure E.1 shows the results on the workload performance. Figure E.2 shows the results on the average waiting time and the average overtime. Figure E.3 shows the results on the service level of the waiting time and the percentage no overtime. The boxes represent the baseline measure and the model measure. Every point outside the box is significant.

The experiment with six OCTs improves the average waiting time by 3.7 minutes, and shows a small improvement in average overtime, improving it by 0.12 minutes. Furthermore, it shows deterioration in correctly staffed and overstaffed workload. The experiment with four OCTs deteriorates almost all performance measures.

Better estimating the appointment length shows an improvement in correctly staffed and increases to 62.2%. It decreases the performance on both overtime measures.

Extending the opening hours with the rules implemented in the model does not deliver good performance measures. The performance on waiting time and workload deteriorate. The service level performance drops by 9.0% (or more) and the workload correctly staffed deteriorates by 12.3% (or more).

The experiment with an “outside-in” appointment schedule performs badly on both overtime measures. The chance on overtime increases by 10.9%.

The dynamic capacity reservation is the most promising intervention as this results show an improvement on correctly staffed workload and only a small deterioration of the average overtime of 0.21 minutes. The correctly staffed workload increases

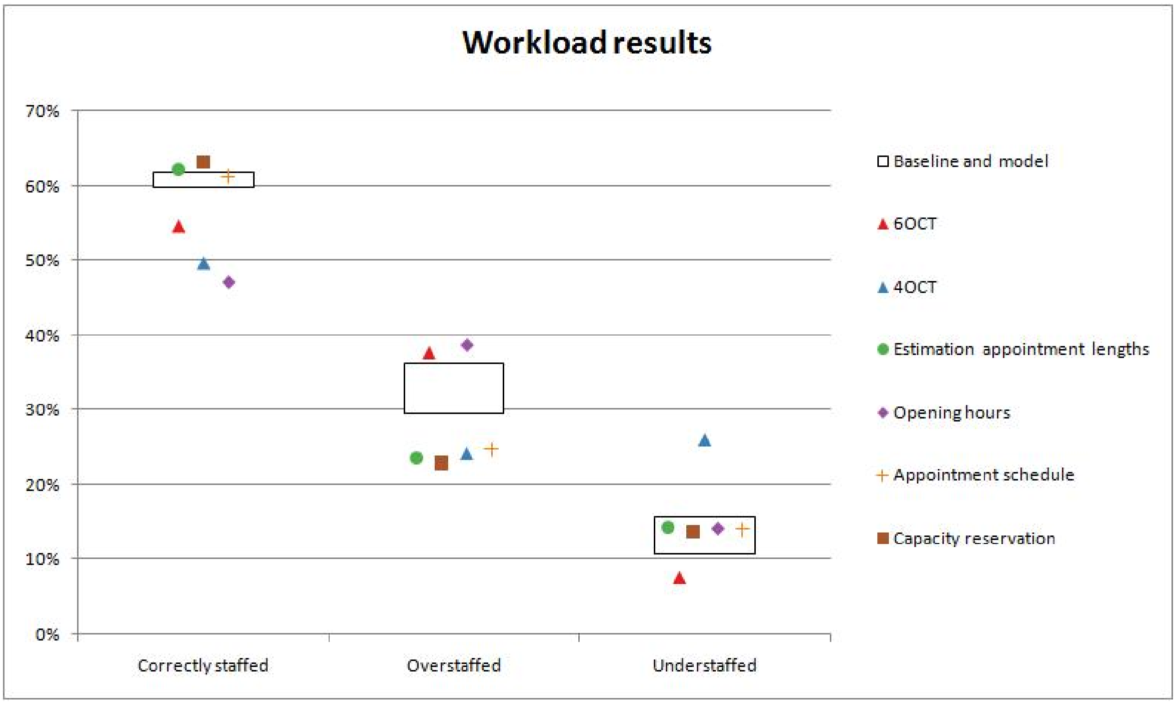

Figure E.1: Results of all experiments on workload performance

to 63.2%.

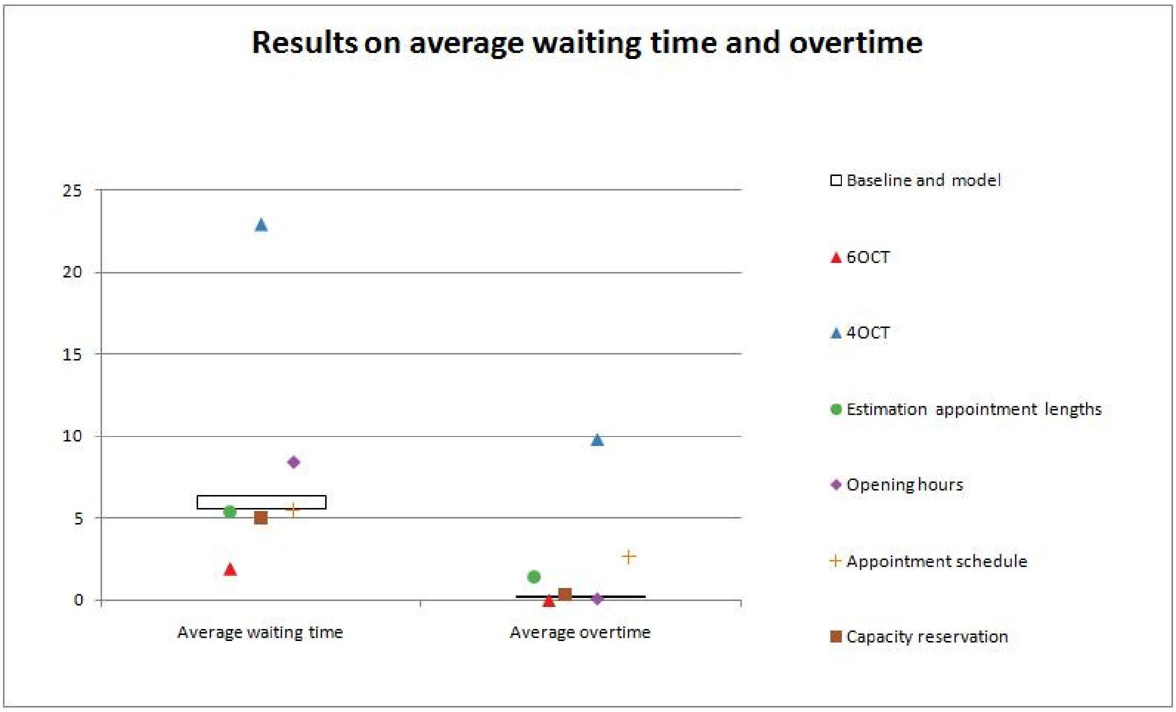

Figure E.2: Results of all experiments on waiting time and overtime performance

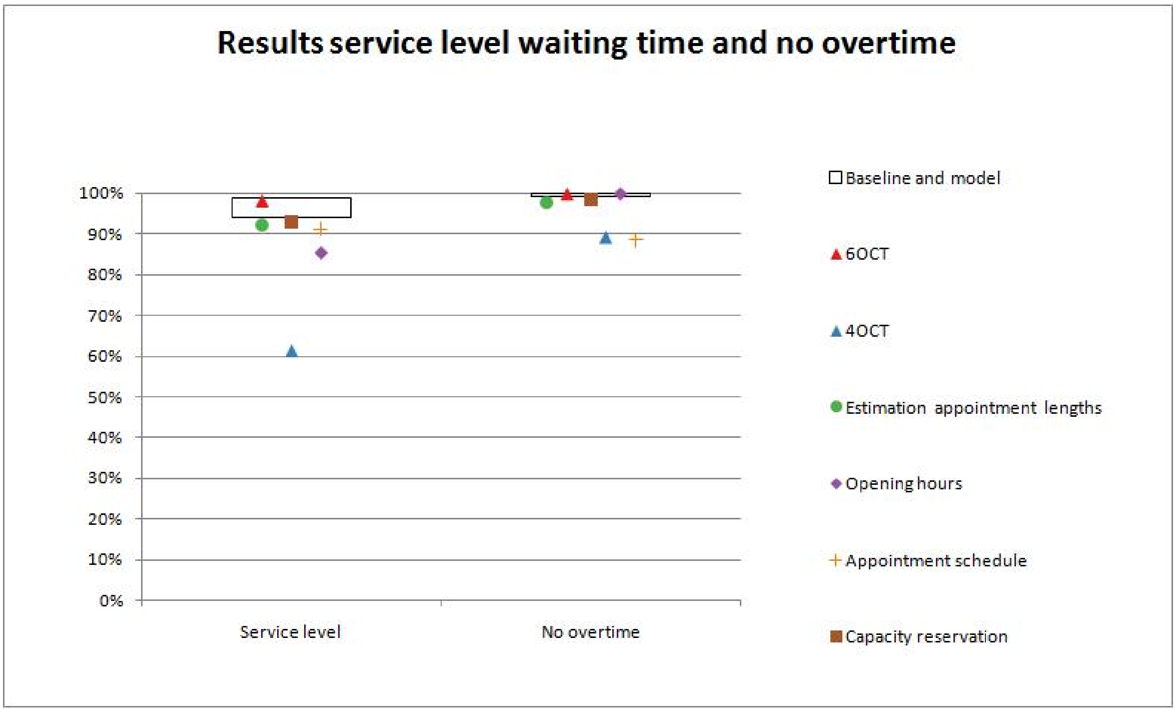

Figure E.3: Results of all experiments on service level and percentage no overtime performance

Results		Service level	Average waiting time	Workload			% No overtime	Average overtime
				Correct	Overstaffed	Understaffed		
Baseline		94.3%	5.6	59.8%	29.4%	10.8%	99.3%	0.14
Model		89.7%	6.4	61.7%	22.7%	15.6%	98.7%	0.24
Difference		-4.6%	0.8	-1.9%	-6.7%	4.8%	-0.6%	0.10
Set I	6OCT	98.0%	1.9	54.6%	37.7%	7.9%	99.8%	0.02
		3.7%	-3.7	-5.2%	8.3%	-3.1%	0.5%	-0.12
	4OCT	61.3%	22.9	49.7%	24.2%	26.0%	89.3%	9.81
		-33.0%	17.3	-10.1%	-5.2%	15.3%	-10.0%	9.67
Set II	2times	92.2%	5.4	62.2%	23.5%	14.2%	97.7%	1.39
		-2.1%	-0.2	2.4%	-5.9%	3.5%	-1.6%	1.25
	3times	90.2%	6.2	60.4%	24.5%	15.1%	98.5%	0.29
		-4.1%	0.6	0.6%	-4.9%	4.3%	-0.8%	0.15
	4times	89.8%	6.4	60.3%	24.6%	15.2%	98.7%	0.26
		-4.5%	0.8	0.5%	-4.8%	4.4%	-0.6%	0.12
Set III	Extended opening	85.3%	8.4	47.1%	38.7%	14.2%	99.9%	0.09
		-9.0%	2.8	-12.7%	9.3%	3.4%	0.6%	-0.05
	Rate +10%	85.2%	8.5	47.3%	38.3%	14.4%	99.8%	0.11
		-9.1%	2.9	-12.5%	8.9%	3.6%	0.5%	-0.03
	Rate +20%	84.3%	9	47.4%	37.9%	14.6%	99.9%	0.07
		-10.0%	3.4	-12.4%	8.5%	3.9%	0.6%	-0.07
	Rate +25%	84.1%	9.1	47.5%	37.7%	14.8%	99.8%	0.10
		-10.2%	3.5	-12.3%	8.3%	4.0%	0.5%	-0.04
Set IV	Outside - in	91.3%	5.5	61.3%	24.7%	14.0%	88.4%	2.66
		-3.0%	-0.1	1.5%	-4.7%	3.2%	10.9%	2.52
Set V	Capacity	92.9%	5	63.2%	23.0%	13.8%	98.5%	0.35
		-1.4%	-0.6	3.4%	-6.5%	3.0%	-0.8%	0.21

Legend:	
	significant improvement
	significant deterioration
	small significant improvement
	small significant deterioration

Figure E.4: Overview results of all experiments