Optimization of MST Plaster Rooms

A Simulation Study

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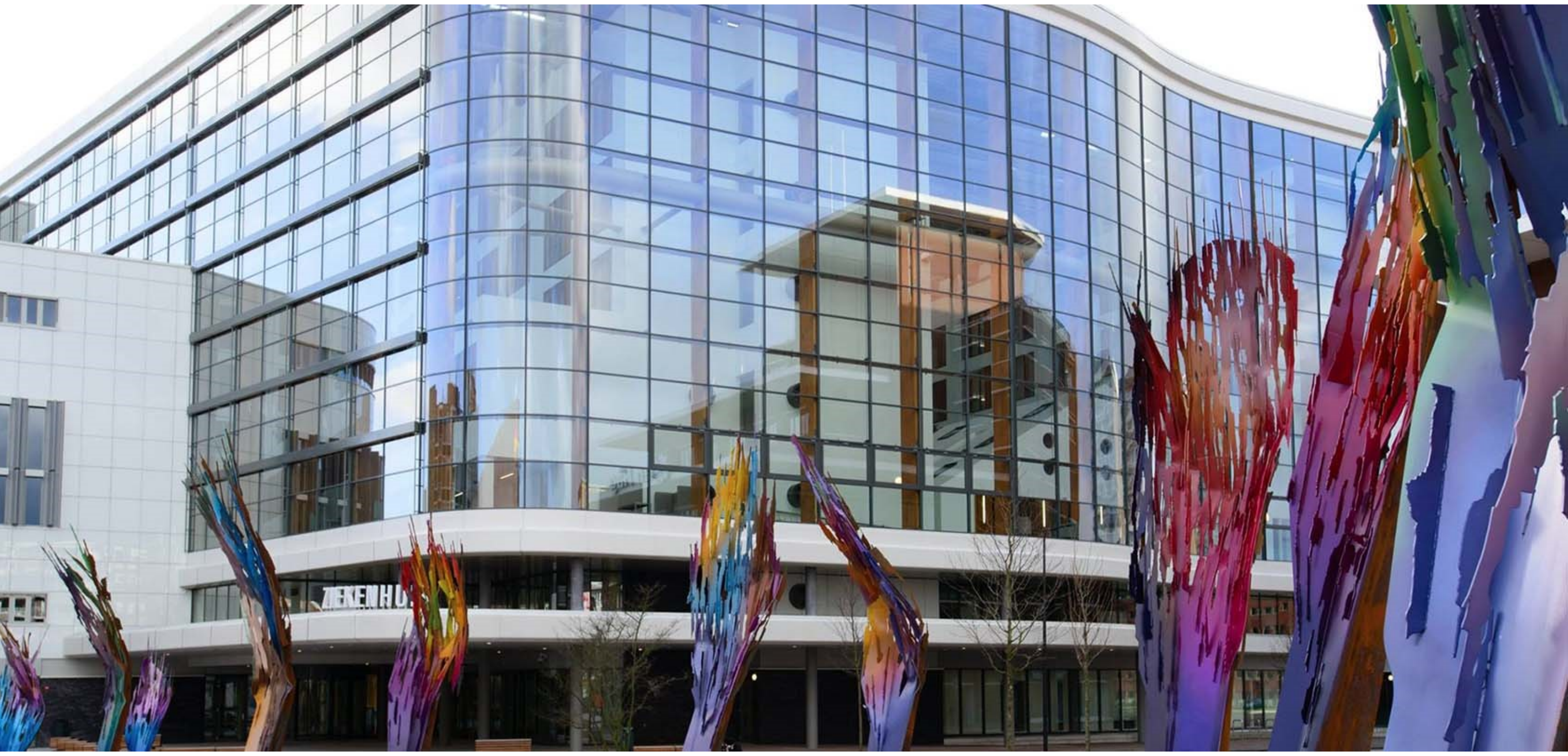

Management Summary

The Hospital & Research Motivation

We conduct this research for, and in cooperation with, Medisch Spectrum Twente (MST). MST is a hospital with its main location in Enschede. The department for which we perform this research is the emergency room (ER), or more specifically, the plaster rooms (which are a part of the department ER). Currently, there are three plaster rooms in Enschede. One of these is for emergency patients and two are for elective patients. There is also one plaster room in Oldenzaal with two tables where patients can be treated. On Wednesdays there are two plaster technicians in Oldenzaal and on the other days there is only one. The problem that MST experiences is that the plaster rooms are often overbooked. This in turn leads to high waiting time for patients and overtime for plaster technicians on the days that have many overbooked appointments.

Research Objective

We have a main goal and a secondary goal that we want to achieve with our research. The main goal is:

"*The number of overbooked appointments should be lower than 10 per week".*

Currently there are about 14 per week, if not counting overbooked appointments in Oldenzaal on Wednesdays because they overbook on purpose on that day.

The secondary goal is:

"*The amount of waiting time for patients and the amount of overtime for plaster technicians should decrease"*

Our key performance indicators (KPIs) are therefore:

- Number of overbooked appointments
- Amount of waiting time for patients
- Amount of overtime for plaster technicians

In our research we try to achieve our main goal. We try to achieve our second goal in the process, but we do not compromise on our main goal to benefit our secondary goal. Also, by achieving the main goal, the KPIs in our secondary goal also improve.

Current Situation

In this report we analyse the current situation at MST. The core problem for the current situation is the way of scheduling. The current scheduling method does not spread appointments over the day and week well. This results in a lot of overbooked appointments and in turn waiting time and overtime. We depict the process of patients flowing through the plaster rooms in a flow chart. Also, we depict the process that a patient goes through during a single appointment. These processes were not graphically represented before and these flow charts may be useful to researchers in the future. There are two main types of appointments that are important to us: surgical appointments and orthopaedic appointments. In Enschede, MST only schedules surgical appointments in the morning and orthopaedic appointments in the afternoon. For orthopaedic appointments, appointments from Children's Orthopaedics are the most troublesome. For surgical appointments, appointments from WEC (Wond Expertise Centrum, or in English, Wound Expertise Centre) are the most troublesome. These appointments are long and often run late.

Experimentation Through Simulation

We aspire to achieve a higher performance on our KPIs by finding a scheduling method that decreases the number of overbooked appointments. While doing this, we also want to find some changes that decrease the amount of waiting time and overtime. It is very hard to say how a change in the current system changes the performance on the KPIs. Experimentation is the best way to see how a change in the system results in a change in performance. However, experimenting in real life in this situation is not desirable since it takes a very long time to see how a certain intervention performs and it is also not preferable to experiment with real life patients. This is why we use simulation as a tool for experimentation. This way we get results fast and we do not have to experiment with real patients. We describe the current situation in the flow charts, which make up our conceptual model. We translate this to a simulation model. For this we need a lot of data and we need knowledge on how to translate that data to the simulation model and its input. After validation the result is a base line simulation model describing the current situation.

We experiment with multiple interventions, defined in consultation with MST. We test these interventions in the simulation by altering the base line simulation model to represent these interventions and running the simulation. To get valid results this model has a run length of a year plus a warm up period of 18 days. This is replicated 18 times with different random input values and averaged to get statistically accurate output data.

Results and Recommendations

The results of the experiments are in Chapter 6. These results show that it is mainly preferable for MST if the plaster technicians give patients a range of days on which the secretaries can schedule these patients. Also, scheduling surgical and orthopaedic appointments in Enschede over the entire day, instead of separated on the morning and afternoon, would be a substantial improvement. If this is done it is also desirable to schedule patients based on whether the city that they live is closer to MST in Enschede or Oldenzaal, but only if the surgical and orthopaedic appointments are mixed. Providing the plaster rooms in Enschede with an extra room where a patient that is waiting for a specialist can wait, substantially decreases the amount of waiting time for patients and also decreases the amount of overtime for plaster technicians. Finally, splitting WEC appointments in two short appointments in between which the patient goes to the WEC instead of the specialist coming to the plaster room, decreases the amount of waiting time for surgical appointments. It also slightly decreases the number of overbooked appointments for surgical appointments.

We mainly recommend MST to implement the following three interventions:

- *Give patients a range of days for their appointment to be scheduled*
- *Mix surgical and orthopaedic appointments and spread appointments over Enschede and Oldenzaal based on which is closest to the city where the patient lives*
- *Provide an extra room in Enschede where patients can wait for specialist*

If MST can make these changes happen, the performance on the KPIs will substantially increase. For instance, the number of overbooked appointments may decrease by more than 80%. Chapter 6 shows more improvements, but the aforementioned interventions show the highest performance. We also want to recommend MST to look into some of the changes that we could not test, because these might as well be improvements for higher performance on our KPIs. These changes are:

- *Scheduling appointments in the schedule of a specialist when we know that specialists are needed so they approximately know when they are needed.*
- *Let plaster technicians go to the patient at the other department instead of having a specialist come to the plaster room.*

Preface

This thesis marks the end of my period as a bachelor's student at the University of Twente and marks the beginning of my period as a master's student. Months of hard work went into this report and I am proud to present it to you as a result of not only these months, but as a product of all that I have learned in my entire student career, as well as in my time at MST. I am also proud and glad that I was chosen to do this assignment and that I was privileged to work in such an interesting environment with such nice people.

I would like to take this opportunity to thank some of the people that helped me get to this point. First of all, I would like to thank Monique Poessé-Vennevertloo, my supervisor at MST. It was great to work with you and I felt greatly supported by the fact that you were always ready to help me with anything. To all the other people at MST that helped me, and in particular the plaster technicians, I would like to thank you for being so enormously helpful and welcoming. Also, I would like to thank Marco Schutten, my supervisor at the University of Twente, for supporting me and providing me with the knowledge to guide me towards my graduation. Finally, I would like to give a special thanks to my loving family and friends for always supporting me and, when needed, distracting me.

Milan Westerink, August 2018

Content

Chapter 1: Introduction

In this first chapter, we start by introducing MST and the problems that we discovered at the plaster rooms. In Section 1.1 we introduce MST and our places of interest, the plaster rooms. We then discuss the motivation for this research in Section 1.2. We thoroughly analyse the problems that we observe in Section 1.3. In turn we translate these problems to goals that we want to reach, and knowledge that we want to obtain, with this research in Section 1.4. In Section 1.5 we draw conclusions from this chapter.

1.1. Introduction of MST

Medisch Spectrum Twente (MST) is a hospital with its main location in Enschede. The organisation is one of the biggest non-academic hospitals of the Netherlands. The hospital has a license for 1070 beds and they have over 200 medical specialists and about 4000 total employees. MST also has a location in the town of Oldenzaal.

The department for which we perform this research is the emergency room (ER), or more specifically, the plaster rooms (which are a part of the department ER). Currently, there are 3 plaster rooms in Enschede. One of these is for emergency patients and 2 are for elective patients. There is also 1 plaster room in Oldenzaal with 2 tables where patients can be treated. On Wednesdays there are two plaster technicians in Oldenzaal, but on the other days there is only one.

1.2. Research Motivation

The initial problem sketched by MST was that the plaster rooms were often overbooked. Also, MST stated that appointments from WEC (Wond Expertise Centrum or Wound Expertise Centre in English) and Children's Orthopaedics needed specific attention. These departments send a lot of patients to the plaster rooms and the treatments for these patients is often more complex and longer than the treatment for the average patient. At MST they want to have better knowledge of what the current capacity of the plaster rooms is and if it is high enough for the number of appointments.

1.3. Problem Definition

We define the problem in two parts. First, we state all problems that we observe at MST and then we need to determine what our core problem is. We do this be putting the problems that we encounter at MST in a problem cluster from which we deduct our core problem in Section 1.3.1. Then we analyse our core problem, which we focus on in most of our research, in Section 1.3.2.

1.3.1. Problem Cluster

To properly define the problem, we use observations and conversations at MST and also a full interview with the head of ER (the main contact at MST). This uncovered a lot of different problems, which are in the problem cluster in Figure 1. The problem that MST stated is that the plaster rooms are often overbooked. This is caused by the combination of the limited number of plaster rooms and the incapability to handle the elective flow of patients. The plaster rooms have two major distinctive flows of patients: The emergency flow and the elective flow. Emergency patients come in without having an appointment and must be treated as soon as possible. Elective patients on the other hand, are patients that have an appointment that is scheduled beforehand. At the plaster rooms they currently do not know how to handle the elective flow because the current method of scheduling is not working well, which is our core problem. We discuss this in Section 1.3.2. We describe why the current way of scheduling is insufficient in Chapter 2. The current scheduling method contributes to the fact that appointments often take longer than expected or are delayed. Also, the plaster rooms in

Oldenzaal are supposedly not considered enough in the scheduling process. This all leads to the fact that there are often not enough plaster rooms to fit the number of appointments scheduled on a day.

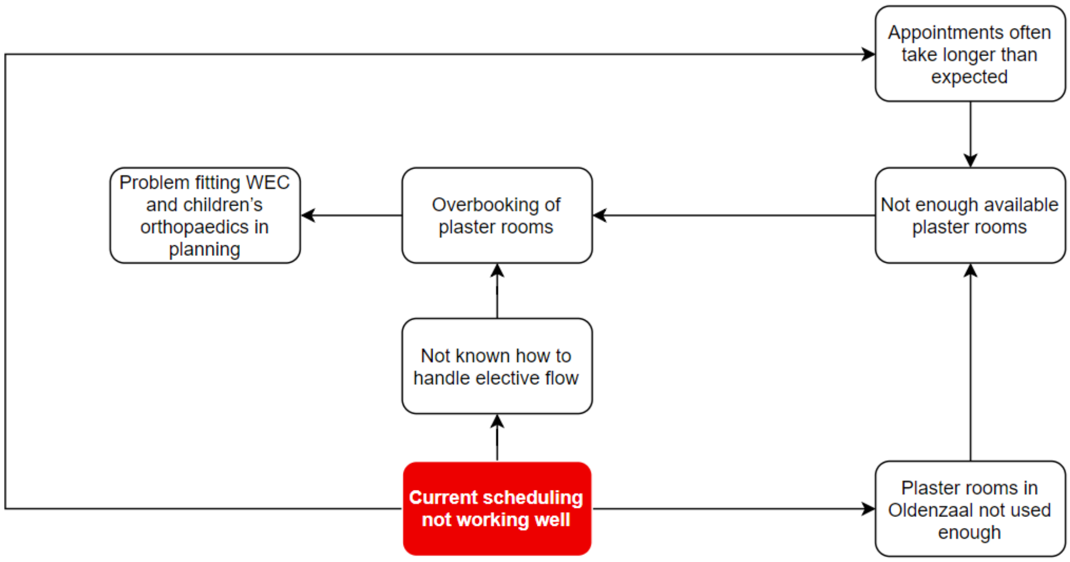

Figure 1: Problem Cluster

1.3.2. Core Problem

The problems depicted in the problem cluster are the main problems that we have established with the people at MST (list of all problems in Appendix 1). During the conversations at MST and while making the problem cluster, it became clear that the core problem is that the current scheduling method is not working well. This is the problem that affects the other problems the most. MST has pointed out from the first moment that they were mainly having trouble with the elective flow of patients and not the emergency flow. They stated that they could predict the emergency flow better than the elective flow, which seems very strange as elective patients can be scheduled. A cause for this is that the way of scheduling causes substantial deviations in the spread of appointments over the day and week. The focus of this study is therefore mainly on the elective flow of patients.

Since MST is now operating from a relatively new hospital, they have not had a lot of time to see which scheduling method works well and they would like to try other methods. The current scheduling results in an irregular distribution of appointments over the week (some days far too busy, other days time to spare). Fridays are often the busiest. This irregularity is the cause of most of the problems in the problem cluster. The ineffective scheduling results in the inability to handle the elective flow and schedules too few appointments in Oldenzaal. The current scheduling results in a lot of overbooked appointments. These overbooked appointments all need to be compensated by treating patients faster. However, treatments often take longer than expected, which leads to a lot of waiting time for patients and overtime for plaster technicians. MST desires to have these performance indicators decreased

WEC (Wond-Expertise Centrum) and Children's Orthopaedics are departments that need special attention. These are prioritized because appointments from these departments are special cases that can only be planned on a few days per week, and currently scheduling appointments for these departments is troublesome. These appointments can only be planned on one or two days per week and they are also longer and more variable in duration than the average appointment. The consequence of this problem is that the overtime for plaster technicians and waiting time for patients are too high, which are the key performance indicators (KPIs) for our action problem along with the number of overbooked appointments. In this research we attempt to find ways of improving these KPIs. We provide scheduling methods to spread appointments in the schedule better and therefore limit the number of overbooked appointments. Also, we look for ways to decrease the amount of waiting time for patients and overtime for the plaster technicians.

1.4. Research Problem

A problem can be defined as a discrepancy between a norm and reality (Heerkens, 2012). To solve our problem, we therefore need to first determine our norm, which we do in Section 1.4.1. We then translate this norm to a knowledge problem that we need to solve in order to achieve our objective. In Section 1.4.2 we define our research questions, which we need to answer to obtain the knowledge needed for our knowledge problem. Finally, we delineate the scope of our research in Section 1.4.3.

1.4.1. Objective

Together with MST we determine the norm of what they want to achieve with this research. In consultation with the supervisor at MST we establish the following norm:

"The number of overbooked appointments should be lower than 10 per week, while maintaining low waiting time for patients and overtime for plaster technicians"

In a perfect situation the number of overbooked appointments would be 0, but of course some situations occur where overbooking takes place, so that is why the norm is lower than 10 per week. The supervisor at MST thought this goal would be a good balance between improvement and achievability. Our norm can be split in a main goal and a secondary goal. The main goal is:

"*We want the number of overbooked appointments to be lower than 10 per week"*

The secondary goal is:

"*We want to decrease the amount of waiting time for patients and the amount of overtime for plaster technicians"*

Our main goal is the aim of this research. While working to achieve that goal we also aspire to achieve our secondary goal, but the focus of the research stays on our main objective. We desire to lower the number of overbooked appointments but not at the expense of waiting time and overtime, hence we state our secondary goal. This secondary goal is not specific because we see any improvement on those KPI's (Key Performance Indicators) as an extra. In 2017 there were 1006 overbooked appointments. This means 19.35 per week. However, in Oldenzaal a lot of appointments are overbooked on purpose because on Wednesdays they work with two people. Therefore, the real number is lower. If we do not take the Wednesday in Oldenzaal into account then there are 703 overbooked appointments in 2017, 13.52 per week. Figure 2 shows the distribution of appointments over the week per type of appointment. We do not count the overbookings on Wednesdays in Oldenzaal as real overbooked appointments, because on Wednesdays two plaster technicians work there and appointments are overbooked on purpose because of that. For this reason, we leave the overbooked appointments in Oldenzaal on Wednesday out of Figure 2. HCH means surgical appointments in Enschede (Haaksbergerstraat, Chirurgie) and HBP means orthopaedic appointments in Enschede (Haaksbergerstraat, Behandelpoli). OCH and OBP are the respective types of appointments in Oldenzaal.

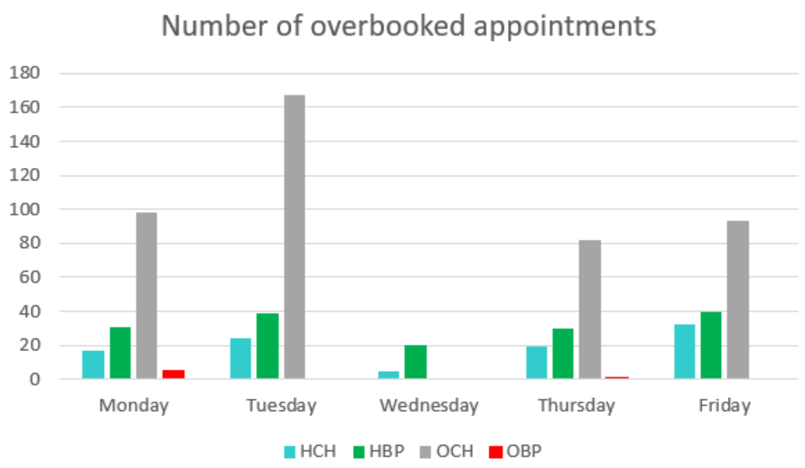

Figure 2: Number of overbooked appointments per day of week and session in 2017

As we see, most of the overbooked appointments are in Oldenzaal. This is because they have the extra table in Oldenzaal, which allows them to treat a new patient when another patient is waiting for a specialist. Overbooked appointments are therefore not as much of a problem in Oldenzaal as they are in Enschede. Because of this, overbooked appointments are not always avoided.

The main knowledge problem that we need to solve in order to solve the problems mentioned is:

"Which scheduling method, which can be applied at MST, results in the lowest number of overbooked appointments for the plaster rooms and what effect does this have on the overtime for plaster technicians and waiting time for patients?"

We define scheduling as: *"a term used in planning and control to indicate the detailed timetable of what work should be done, when it should be done and where it should be done"* (Slack, 2013). We define overtime as: *"the amount of time plaster technicians need to keep working after their official working hours"*. We see waiting time for patients as: *"the time between the scheduled starting time of an appointment and the actual start of the appointment"* (if an appointment starts before the scheduled time, the waiting time is registered as 0, so it cannot be negative). We express overbooked appointments as: *"the amount of appointments in the schedule in which there is overlap between two appointments in one plaster room"*. If we can lower these indicators it will lead to less stress for the personnel, lower expenses for MST, higher patient satisfaction and higher treatment capacity (more patients could be treated on one day without as much issues), which is why it is important that we solve this problem.

The challenging thing about this situation is that it is impossible to know exactly how a scheduling method influences the indicators (overbooked appointments etc.), which is why performing lots of different experiments works best. In real life this would cost a lot of time and effort and it would be necessary to effectively experiment with patients. This is why, for this research, we choose to use simulation to model the current situation and try different scheduling methods and other interventions to see what delivers the best performance. We explain this in more detail in Chapter 5.

1.4.2. Research Questions

The knowledge that is missing for this research needs to be obtained somehow. To clarify what information we need to solve the main knowledge problem, we divide it in different research questions (each of these is an individual knowledge problem). In Appendix 2 we divide these research questions in multiple subquestions to clarify how we want to answer the research questions. Appendix 2 also contains argumentation as to why these questions are important to answer. Since this is a simulation study, some research questions are oriented toward simulation. The research questions are:

Research question 1: What is the process of scheduling and performing an appointment?

As we mentioned in Section 1.4.1, simulation is the most useful tool for this research since it overcomes a lot of issues that real life experimentation has. To build this simulation model, we need a precise flow chart of the process and the right data must be available. To get valid simulation results, it should be known how MST currently schedules appointments for the plaster rooms. This way we know where changes can be made. We answer this research question in Chapter 2.

Research question 2: What interventions should we test in the simulation?

We need to test multiple scheduling methods to see which one fits MST's situation best. There are many changes we can make on scheduling, and we must research which ones can be used. Also, we need to research which other improvements are possible for our secondary goal. In Chapter 4, we list our possible interventions and decide which ones we test.

Research question 3: What is the necessary input data for our simulation model?

It is important to know which data we need, how to obtain it and which probability distributions we can extract from this data. All this information provides the building blocks to construct a simulation model, which we use for experimenting. We research this in Chapter 3 and implement it in Chapter 5.

Research question 4: Which intervention would be most suitable for use at MST?

We test all interventions from RQ2 in the simulation model and from the performance on the KPIs we deduce what works best and eventually we base our advice to MST on these KPIs. We show the experiment results in Chapter 6 and draw conclusions in Chapter 7.

1.4.3. Research Scope

The scope of this research is limited by three aspects. The first one is lack of medical knowledge. This prevents us from being able to research the actual casting process. Therefore, only the scheduling and other technical aspects is researched. This includes a range of scheduling methods and some ways to decrease the time that patients spend in the plaster room.

Second, since it can take a long time before our findings can be implemented, and because we do not have a lot of time for this research, we are not implementing and evaluating our findings in the real-life situation. When our research is done MST will have to decide if they want to implement what we recommend in this research. We expect the improvements are not too complex to implement for MST and that MST does not require any help from a third party.

The third aspect is the emergency flow of patients. There are currently no problems with the emergency flow of patients. The real problems arise when looking at the elective flow of patients, as we discussed before. Therefore, the scope of this research only includes the elective flow of patients.

1.5. Conclusion

The core problem we found is that the current method of scheduling appointments is not performing well. The main goal we set for this research is: "*We want the number of overbooked appointments to be lower than 10 per week".* We also have a secondary goal: "*We want to decrease the amount of waiting time for patients and the amount of overtime for plaster* *technicians".* The main knowledge problem that we need to solve in order to reach these goals is: *"Which scheduling method, which can be applied at MST, results in the lowest number of overbooked appointments for the plaster rooms and what effect does this have on the overtime for plaster technicians and waiting time for patients?".*

Chapter 2: Current Situation Analysis

In this chapter, we analyse the current situation at MST. To try to improve on the current situation, it is important to first have an understanding of what the current process looks like. In Section 2.1 we use process flow charts and other techniques to describe the process of patients flowing through the plaster rooms. We also take a closer look at the individual process of scheduling in Section 2.2 and the appointment process in Section 2.3. After this we establish what the problem areas that we focus on later in our solution design are in Section 2.4. We state the conclusions of this chapter in Section 2.5.

2.1. Process Flow Chart

Before we think of possible solutions to our problem we need to have a good understanding of what the process looks like. By interviewing multiple people at MST and by visiting the plaster rooms in Oldenzaal and Enschede we get a better view of the current situation. Appointments can come from a lot of different departments that request appointments for patients at the plaster rooms. MST schedules this patient in Enschede or in Oldenzaal if they prefer. At the day of the appointment the patient goes to the designated location. Sometimes patients have to go to another department during the appointment and come back. After the appointment the secretary schedules a new appointment if necessary. We depict this by using the flow chart in Figure 3. This flow chart effectively answers our first research question: “What does the process look like?”.

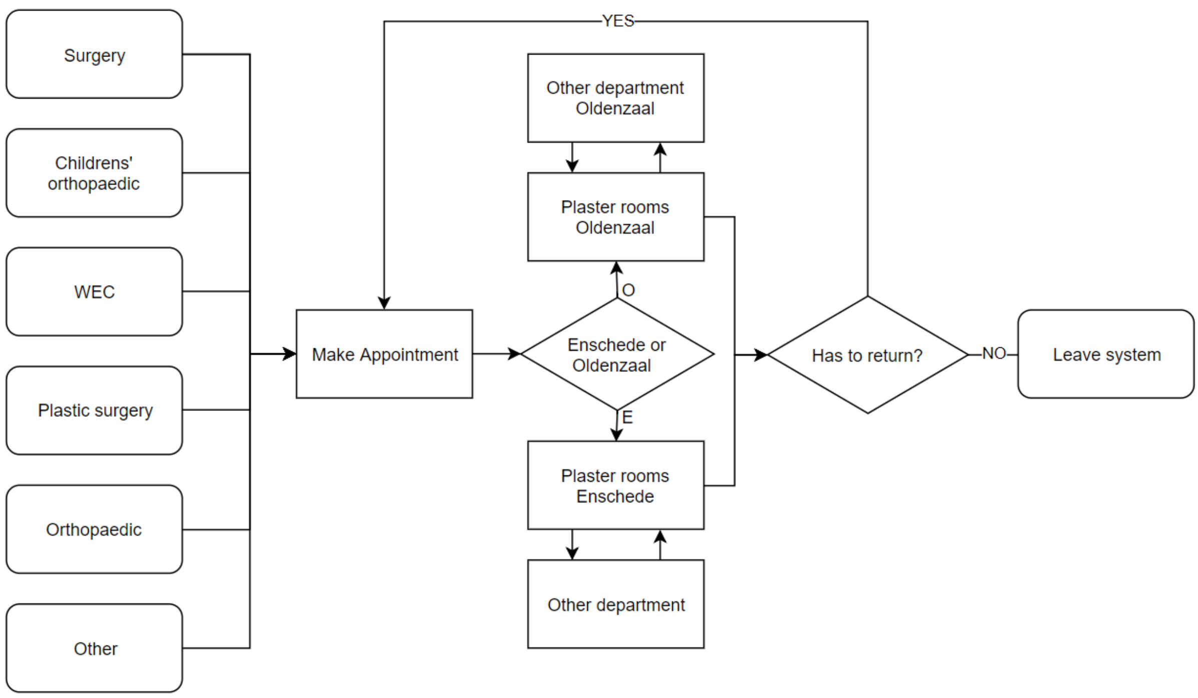

Figure 3: Process Flow Chart of Patient Flow in Plaster Rooms

Patients come in through a lot of different departments, of which some only have consultation a few days per week. Appointments for departments that only have consultation a few days per week have to be simultaneous to these consultation times. While making the appointments, patients indicate if they want to go to Oldenzaal instead of Enschede. During the appointment, patients sometimes need to go to another department and come back later. This normally is to go to Radiology. Then, sometimes patients have follow-up appointments. The plaster technician tells the patient to come back in a certain number of days (often one or two weeks). Another appointment will then be scheduled on that exact day, which causes some problems, as we discuss in Section 2.4.

2.2. Scheduling

In this section we answer our second research question about how appointments are scheduled. The secretaries schedule appointments at the plaster rooms or on the phone. They schedule a time, day and place for the appointments and immediately put these appointments in the schedule (This is not to be changed). Patients are often given a certain day to come to the plaster room by the plaster technicians. The patient will be planned on that day. Appointments are either seen as orthopaedic appointments or surgical appointments (depending on which department they come from). In Enschede, orthopaedic appointments are scheduled in the afternoon (13:30-16:00) and surgical appointments are scheduled in the morning (8:15-12:15). In Oldenzaal, both these types of appointments can be done at any time of the day. However, in 2017 only 12.6% of the appointments in Oldenzaal was orthopaedic, whereas overall in 2017 31.4% of all appointments was orthopaedic and 68.6% came from surgery. Enschede is the higher capacity location. In 2017 MST sent 67.3% of plaster room patients to Enschede.

2.3. Appointment Process

When the patient goes to the plaster room, a process happens that is also important to our simulation. Our goal is to find a scheduling method that decreases the number of overbooked appointments. While doing this, we also try to decrease the waiting time and overtime. By looking closely at what happens when patients go to the plaster rooms, we can find some possibilities for improvement to reduce waiting time and overtime. To depict this process, we have a detailed process flow chart in Figure 4, which shows the process of an appointment at the plaster room.

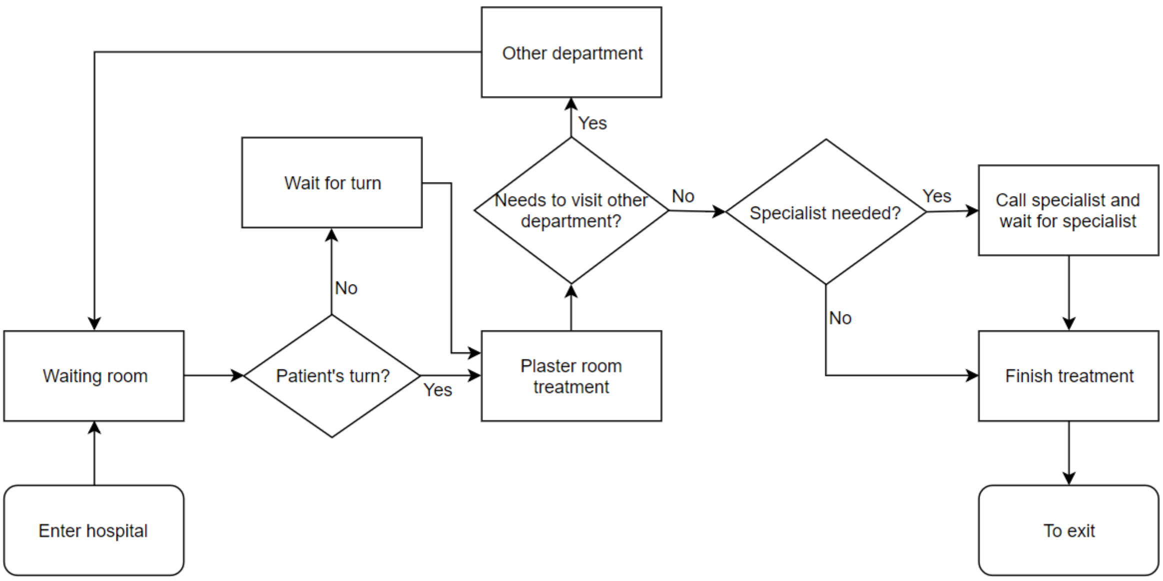

Figure 4: Process Flow Chart of Patient Flow During One Appointment

The most important things to notice are that patients sometimes need to go to other departments during their appointments and that a specialist is sometimes needed. These are occurrences that take a lot of time and there are improvements possible in these scenarios. In our simulation, we try various ways of treating patients that need to go to other departments or those that need specialists.

2.4. Problem Areas

The most probable cause of the large number of overbooked appointments is the lack of equal distribution of appointments over the day and over the week. The fact that MST only schedules appointments on the exact day the plaster technicians indicate that the patient should come back, makes for a bad distribution over the week. The plaster technicians say that it would not be a problem for patients to come a day sooner or later. In some cases, it might be possible to take an even bigger number of days, but the patient cannot come to soon, because they might not have healed enough, and making patients come later is often unpleasant for the patient. The distribution of appointments over the day is also not optimal, since in Enschede only mornings or afternoons can be used, depending on what type of appointment it is. This uneven distribution causes a lot of overbooked appointments when it is busy, since those appointments are not moved to the morning or the afternoon (in Enschede) or another day.

The appointments that take longer than expected most frequently are the appointments from WEC and those from Children's Orthopaedics. These appointments can only be scheduled on one or two days per week and they vary a lot in length. This is a nearly weekly recurring problem, which we need to look at to reduce the amount of waiting time and overtime.

During appointments a specialist is often needed. Also, patients often have to go to other departments. These two occurrences cause an appointment to take more time and can disrupt a day's schedule. It is therefore important to see if there are any improvements possible in this area.

2.5. Conclusion

In this chapter, we answered our first research question: "*What does the process of scheduling and performing an appointment look like?".* We depict this in Figures 3 and 4. We also defined the main problem areas at the plaster rooms. These are: Lack of equal distribution of appointments over the day and week, appointments from WEC and Children's Orthopaedics, the need for a specialist and the need for a patient to move to another department.

Chapter 3: Literature Review

This research is a simulation study, which means that we use simulation as a tool to perform experiments. Therefore, it is important to know how to perform a simulation study correctly. We introduce some literary sources to help us understand more about how we construct and use our model. In Section 3.1 we explain the theoretical framework of how a simulation study is performed. We then also pay some extra attention to one of the most important aspects of this framework and thus our research. This is the aspect of data collection and analysis. To understand and depict the current situation we need data. To use simulation as a tool to perform our experiments we need large quantities of data to accurately represent reality in a computer model. That is why it is important to pay some special attention to the theoretical side of obtaining data and analysing it. We do this before explaining the simulation model in Chapter 5, because this theoretical perspective provides some background knowledge to understand how the historic data and simulation model are related. We pay attention to four different aspects of data collection and analysis in our research: data requirements, obtaining data, representing unpredictable variability and selecting statistical distributions, as discussed in Robinson (2014). We discuss these aspects in Sections 3.2 to 3.5 respectively. We research possible interventions that we find in reports from CHOIR (Centre for Healthcare Operations Improvement & Research), which we can use in our situation, in Section 3.6. In Section 3.7 we state this chapter's conclusions.

3.1. Theoretical Framework

We use simulation as a tool to perform our experiments because it provides a lot more possibilities as to what can be tested in comparison to reality and it is lot faster than experimenting in reality. Also, we take away the necessity to use patients in the experiments, which could have caused some ethical issues. There is a lot of literature on how to perform a simulation study. Robinson (2014) is our main source of information for this. Figure 5 shows a graphical representation of the process of setting up a simulation study, consisting of steps that in turn consist of tasks (Law, 2007). We follow this process in our research as well. In Chapter 1 we treat step 1 of this process. In Chapter 2 we perform the first two tasks of step 2 for our current situation, which is what the experiments are based on (the tasks marked by 2. and 3.). Chapter 5 describes our process in tasks 4 to 6 for the current situation. As the figure shows step 2 to 6 is an iteration because it is necessary to check the validity of the model and make changes accordingly multiple times. The simulation model we made was subject to such iterations to ensure validity, but we do not describe this process in this report to limit the length of the report and because we believe it is not relevant to the reader. We treat task 7 to 10 in Chapter 6. Step 7 is a model construction step on its own for each experiment since we experiment with different interventions, which we introduce in Chapter 4. This means constructing a slightly different model for each intervention where we repeat tasks 2 to 6, though not as elaborately as we did for the current situation since we are only making minor changes.

Not all tasks in the figure are relevant for the reader, which is why we do not explicitly describe how we perform all tasks in Figure 5. Also, for the sake of readability, the structure of our report is not strictly in line with these tasks. To perform step 2 and 3 of the framework we need knowledge on how we construct a model, and for this we need to be able to translate historic data to input data to construct our model with. We describe how we can do this in Sections 3.2 to 3.5, based on literature and the knowledge that we already have. Apart from the three steps depicted in Figure 5, some literature suggests there is also a fourth step. This step is implementation (Robinson, 2014), but this step is not performed in every simulation study (e.g.

we do not perform implementation in this study, but we leave this to MST). Arguably, it is also not necessarily part of the simulation study, but more of a step following the simulation study.

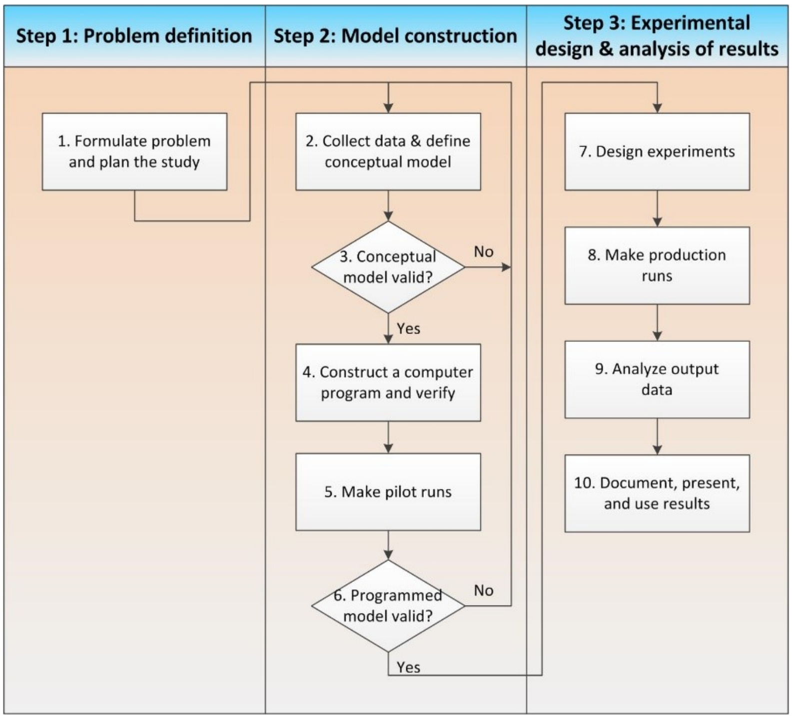

Figure 5: Simulation study setup (Law, 2007)

3.2. Data Requirements

We require data in many different aspects of our research. From assimilating an understanding of the current situation to experimentation, it is imperative that we obtain and analyse data accurately. In almost every task in the framework in Section 3.1 we need to do this. For our type of research (simulation study), there are three types of data requirements (Pidd, 2009). The first is contextual data. We use this data to better understand and describe our problem situation. In Chapters 1 and 2 we mainly use contextual data to describe the current situation. This type of data requirement mostly contains qualitative data. The second type of data requirement is the data required for model realisation. When moving from a contextual model to a simulation model, we need this data. We need it to, for instance, describe the number of appointments coming in, what attributes these appointments have, processing times in the plaster rooms, etc. We discuss this in more detail in Chapter 5 and Appendix 5 shows how we process this type of data. Third, data is required for model validation. It is important to validate our model to see if it represents the real-world system accurately. We do this in more detail in Chapter 5. This data consists of data from our model as well as from reality. Often these are compared to each other for validation.

3.3. Obtaining Data

In Section 3.2 we discussed various types of data requirements. The data to fulfil these data requirements can be of different categories that describe the obtainability (Robinson, 2014). Table 1 shows these categories.

Category	Availability and collectability
Category A	Available
Category B	Not Available but collectable
Category C	Not available and not collectable

Table 1: Categories of data availability and collectability (Robinson, 2014)

Our first data requirement, contextual data, is satisfied by category B data. There are no reports on the plaster rooms that mention anything about the process or scheduling. We had to collect this information. The data that we need for the second data requirement is mainly category A data from the MST database. We extract most of the necessary information from the database using a database analysis and reporting tool called Web Intelligence Rich Client by SAP. However, some of the data that we need for our second data requirement is not available and has to be collected. The limited time for our research means we could only collect data for a week. We need to do this for the arrival times of patients, the actual appointment duration, the frequency of needing a specialist and the frequency of a patient moving to another department during the appointment. We document the arrival times by making observations for a few days. For the remaining type B data, we compose a form, which the plaster technicians fill in after each appointment for a week (Appendix 4 shows this form). Category C data occurs when we search data for model validation. For instance, in Oldenzaal in the current situation schedulers do not always try to prevent overbooked appointments. In our model we do because it is better for performance comparison with our experiment interventions. There is no information on how Oldenzaal would perform if they always try to prevent overbooked appointments, so the model cannot truly be validated for that aspect. We come across more category C data in the experimental interventions that we introduce in Chapter 4, which is why we exclude some of these possible interventions from our study.

3.4. Representing Unpredictable Variability

In data that represents the real world there is always variability. Processing times, arrival times etc., are examples of these variable values, since we never exactly know them beforehand. We need to establish how these values are distributed to mimic reality according to historical data in our simulation model. Specifically, in the 5th task of Law's framework and for us also sometimes in the 7th task (because we tweak our simulation model to experiment) we need to find probability distributions. To statistically establish how these values are distributed there are various methods. There are three basic options to represent variability. These options are: traces, empirical distributions and statistical distributions (Robinson, 2014). A trace is a stream of data that describes a sequence of events. This is predefined, so the resulting value does not alter from the sequence. In this research we only use empirical distributions and statistical distributions.

An empirical distribution shows the frequency with which data values, or ranges of data values, occur. Values from this distribution are randomly sampled based on how often they occur in the historical data. On average the sampled values show the same frequency of occurrence as is indicated in the empirical distribution. For example, when looking at Figure 6, the empirical distribution will have the same distribution as the historical data has (bar charts). The drawback of this type of distribution is that it can only take values that we find in the data, so it somewhat copies what happened in the past with a random aspect to it. Statistical distributions are defined by a mathematical function or probability density function. A lot of statistical distributions exist with known characteristics. These can be divided in discrete and continuous distributions. Discrete distributions can only take specific values, such as integers or non-numeric values. Continuous distributions can take any value across a certain range, which can for instance be used for processing times. When it is possible we use statistical distributions, because these are not limited to historic data and are the way of describing a distribution that acts most similar to reality. When data does not follow a statistical distribution, we use an empirical distribution. In Figure 6 we see how a statistical distribution can represent historical data, in this case being the frequency of appointments in certain intervals of appointment duration. In this figure we compare the expected frequency of appointments in intervals of duration for the gamma distribution, (line graph) which we found from the historical data, to the frequencies in the historical data (bar chart) and we see that they fit well together. There are also approximate distributions, used when little to no data is available. Appendix 5 contains information on what distributions we used to represent real situation.

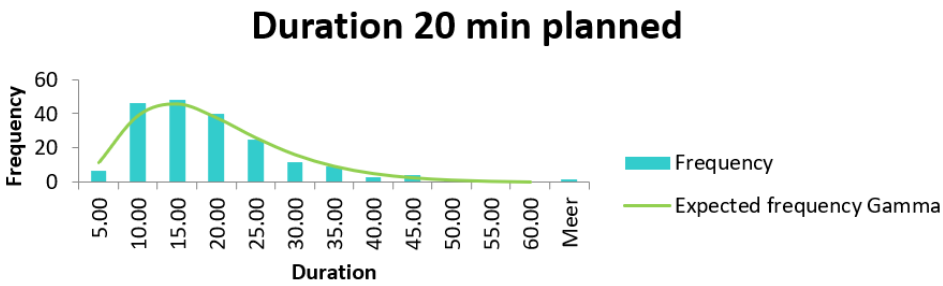

Figure 6: Duration of appointments scheduled for 20 minutes (expected frequencies for the resulting gamma distribution compared to frequencies of occurrences in historical data)

3.5. Selecting Statistical Distributions

Every part of the process where there is variability has to be described by a distribution for the simulation model, which we need to in task 5 and 7 of Law's framework. To do this we need to make sure that the necessary empirical data is available. In Section 3.3 we discussed how we do this. For some processes it is possible to select a distribution based on its properties. For instance, the times at which appointments come in can be assumed to be random and, in this case, we could use a negative exponential distribution for the time between appointments coming in. Processes with similar properties often follow the same type of distribution and this is helpful because it takes away some time searching the right type of distribution. Table 2 lists some of the most useful distributions for different properties (Robinson, 2014). However, we still need to assess the fit in this situation. When it is less clear what statistical distribution the data follows we need to fit a distribution based on empirical data. We do this in three steps, which we demonstrate below (Robinson, 2014):

1) Select a distribution
2) Determine the parameters
3) Test the goodness of fit

Property to be modelled	Dsitributions
Arrivals	Negative exponential: arrivals at random
	Erlang
Activity time	Erlang
	Log-normal: especially for repair time
	Triangular, uniform: for approximate modelling
Time between failure	Negative exponential: no ageing effect
	Weibull: ageing effect
Success/failure in trials	Binomial
Error values e.g. weight, size	Normal

Table 2: Selection of distribution for modelling system properties (Robinson, 2014)

If the distribution does not fit the data we should go through these steps for another distribution or we use an empirical distribution, which is the best option in some cases. To illustrate how this is done we use the duration of appointments that have 20 minutes in the schedule. In Figure 6 we see how the frequencies of occurrences in duration intervals are distributed and we see that it resembles a gamma distribution (similar shape). We therefore select this distribution and establish the parameters. Using methods of estimating these parameters from a lecture by Mes (2017), we find the parameters k and θ (theta). However, by graphically comparing the distribution with these parameters we saw that the distribution with these parameters did not fit well. This might be due to the relatively small number of observations (200), which makes the estimation approach less accurate. Normally, with historical data, there is a lot of data, but because we had to collect this data by recording it for a week there is not as much data as we would normally have. The average value of the gamma distribution is the product of the two parameters k and θ. By trial and error, we found better values for these parameters, by changing the parameters while making sure $k * \theta$ stays the same, because the average should stay the same. Figure 6 shows the gamma distribution with these graphically estimated parameters. Table 3 lists which calculations we make to try to find our parameters. Instead of using the estimations we calculated, we graphically estimate more accurate parameters by trial and error. Every type of distribution has a different approach as to how to find the parameters.

Properties	Values	Calculation
Average	17.10	Average of sample data
Variance	109.76	Variance of sample data
Coefficient of variation	0.61	Variance^0.5/Average
Median	2.04	Average(Error^3)/var^1.5
Standard deviation	10.48	Variance^0.5
k estimate	0.96	(2/Median)^2
theta estimate	17.77	Average/k
k graphical	3.00	Trial and error
theta graphical	5.70	Trial and error
k scaled to seconds	3.00	Same as k graphical
theta scaled to seconds	341.92	Theta graphical * 60

Table 3: Finding parameters for the gamma distribution

Validation of these distributions is done by testing the goodness-of-fit. We can do this graphically or using statistical tests. Using statistical tests is more accurate though much more time-consuming. That is why do not statistically test everything. In Appendix 6 we show how we perform a statistical test of the gamma distribution for 20-minute appointment durations that we just discussed. The test that we used is the Chi-square test, which is probably the best-known goodness-of-fit test (Robinson, 2014). The chi-squared test is used to determine whether there is a significant difference between the expected frequencies and the observed frequencies in one or more “bins” of what in our case are appointment durations. In our case, the bins are 0-5 minutes, 5-10 minutes, …, 55-60 minutes. Based on the level of significance, which in our case is 5% (typical for this kind of research), the test either accepts or rejects the hypothesis that the distribution fits the data. A study's defined significance level, α, is the probability of the study rejecting the null hypothesis, given that it were true (Dalgaard, 2008).

3.6. CHOIR literature review

CHOIR (Centre for Healthcare Operations Improvements & Research) is a research centre within the University of Twente (UT). It is currently one of the most active and productive research groups in the field of Operations Research and Management in Healthcare. We review publications from this research group to try to find interventions that are also applicable in our case. We search in publications from CHOIR because they have a lot of publications that are publicly available and because they are specialized in healthcare.

Furthermore, we believe CHOIR is a trustworthy source since we have been introduced to their work several times in the past at the University of Twente.

We look for publications that are about scheduling since that is what we mainly want to improve at the plaster rooms. There are over 100 publications by CHOIR and after a first selection by title we find six papers that seem of interest to us. However, when reading the publications, it soon shows that these publications are often too specific and too theoretical to apply at MST. Most of them contain mathematical models for that specific situation and others suggest very complex methods and algorithms for general use. They usually do not show practical interventions.

CHOIR also provides a lot of bachelor and master assignments, which they make public. These are usually case studies at hospitals and they often contain more practical interventions that we might be able to use as well. However, we do not find any interventions that are applicable on the MST plaster rooms. The reason for this is because our main goal is to decrease the number of overbooked appointments which is a rare KPI. For instance, CHOIR has a report that suggests providing extra slack between appointments to reduce waiting time (Knoeff, 2010), but this would increase the number of overbooked appointments. Also, there are not many studies on plaster rooms by CHOIR. Other departments could also have similar scheduling interventions but after a lot of searching we were not able to find one that fits our situation and is possible of improving performance.

3.7. Conclusion

In this chapter we describe the framework for conducting a simulation study and we provide the knowledge that we need for our third research question: *"What is the necessary input data for our simulation model?".* In chapter 5 we answer this research question based on the knowledge we obtained in this chapter. For our research we have three data requirements:

- Contextual data
- Data required for model realisation
- Data required for model validation

We satisfy these requirements by obtaining the necessary data. This data is of category A, B or C, which are in order of obtainability, with A being the most obtainable. We obtain category A data from the MST database. We collect category B data by making observations and by providing the plaster technicians with a form to fill in after every appointment for a week. Category C data needs to be estimated. To represent the data and unpredictable variability in the data we use empirical distributions and statistical distributions. Statistical distributions are the most desirable and can be determined in three steps:

1) Select a distribution
2) Determine the parameters
3) Test the goodness of fit

However, data does often not follow a statistical distribution, which is why we often use empirical distributions. These are less desirable because they only mimic the frequencies of occurrences in the data and cannot take new values.

Chapter 4: Experimental Design

In this chapter we discuss what interventions we want to test. We list the interventions we came up with in consultation with MST in Section 4.1. In this section, we also state which one of those we want to and are able to model and the reasoning behind the decisions. We conclude this chapter in Section 4.2.

4.1. Experiment Interventions

The problem areas that we noticed are: the insufficient distribution of appointments over the day and over the week, appointments from WEC and Children's Orthopaedics and that the need for a specialist during appointments costs a lot of time. Based on this and in consultation with the head of ER and a member of the secretariat we defined a couple of interventions that we want to test. Some of these do not correspond to the problem areas that we discussed in Section 2.4 but are still desirable to test since they have a possibility of improving one or more of our performance indicators (overbooked appointments, waiting time, overtime). In the following list of interventions, we denote the interventions that we actually test with a green dot and we denote the interventions that we do not test with a red dot. The list of interventions, established in consultation with MST, with argumentation why we do or do not test the intervention, is as follows:

- Letting orthopaedic appointments and surgical appointments in Enschede be planned in the morning as well as in the afternoon (mix them).

  This intervention may improve the spread of appointments over the day. It takes away the restriction of having to plan only in the morning or afternoon. It is also nice for the patient to have the possibility to go in the afternoon as well as in the morning. This is therefore one of the interventions to experiment.

- More orthopaedics appointments in Oldenzaal and better spread of appointments over Enschede and Oldenzaal.

  MST does not schedule enough appointments in Oldenzaal according to the plaster technicians. Mainly orthopaedics appointments are scarce in Oldenzaal and in Enschede this causes the most overbooked appointments. A better spread of appointments over the two locations is therefore desirable and that is why we choose to model this intervention.

- Instead of giving patients a certain day for their appointment, give them a range of days from which the secretary can decide which is best.

  The insufficient spread of appointments over the week is one of the main causes for overbooked appointments. By giving patients a range of days where their appointments can be scheduled, the spread should improve. This should decrease the number of overbooked appointments, which is why this is also one of the interventions that we test.

- When the plaster technicians already know that a specialist needs to come, schedule the appointment in the schedule of a specialist so he/she can anticipate on this.

  According to the plaster technicians, this intervention has a positive effect on the amount of the time they have to wait for a specialist in Oldenzaal, where they sometimes apply this already. The shorter time waiting for the specialist means a shorter waiting time for the next patient, which we desire. However, there is no way for us to determine the effect of doing this, since it is not documented in Oldenzaal and not done in Enschede. The result is that there is no data to base a simulation on. We therefore leave this intervention out of consideration, but we still recommend MST to look into this possibility. If the specialist is at the plaster room sooner on average, it is preferable for the plaster technicians that MST applies this method. It is probably also desirable for the specialist to be able to anticipate.

- Provide the plaster rooms in Enschede with a room where a patient can wait for a specialist during the appointment.

Waiting for a specialist is a bottleneck in the process at the plaster rooms. In Oldenzaal they have the extra table where they can treat another patient while a patient is waiting for a specialist. This decreases the waiting time for patients. In Enschede the rooms are not big enough for another table and there is no room for a patient to wait during the appointment. Plaster technicians do not want to put patients back in the waiting room during the treatment because these patients often have their cast cut off already. If there would be a room at the plaster rooms in Enschede where a patient can wait for a specialist, MST can decrease the waiting time, so this is an intervention that we are going to test.

- Schedule appointments using the estimated treatment times according to the treatment codes of the treatments that the plaster technicians expect to perform.

MST currently schedules appointments with a standard time of 20 minutes and for special appointments it can be longer or shorter. All treatments have codes and a standard time that is needed to perform it. The head of ER wants to plan appointments based on the code list and the estimated treatments that will be performed. This is why we test this intervention as well. The deviation between the scheduled length and actual length of the appointment might vary less as well if MST uses this method of scheduling. However, we cannot verify this since we have no actual data of how much time individual treatments take (notice the distinction between treatments and appointments; in an appointment, multiple treatments can be performed). With this experiment we can therefore only see what the effect on the schedule is. The performance on waiting time and overtime are not correct because the average durations are based on the average of appointment lengths with the normal way of scheduling appointments where a 20-minute appointment is the standard.

- Structurally spreading appointments over the day using a template.

We want to achieve spread of appointments over the week and over the day. A template assures the spread of longer appointments over the day so there is a lower chance for these appointments, that are more variable in length, to be placed after each other. This might lower waiting times when an appointment causes a delay. However, research shows the best sequencing rule is to allocate all low variance patients at the beginning of the session and high variance patients toward the end, to strike a balance between waiting time and idle time (Klassen & Rohleder, 1996). A template to spread appointments over the day would therefore not make sense. Also, keeping to a template is an extra restriction, which only increases the number of overbooked appointments, because 20-minute appointments are not planned in these slots. Modelling the simulation to follow the template is also very time-consuming. This, in combination with the expected higher number of overbooked appointments and that there might be no gain in waiting time (Klassen & Rohleder, 1996), is the reason that we do not model this intervention.

- Let plaster technicians go to the patient at the other department instead of having a specialist come to the plaster room.

Applying this method would be good for the plaster rooms, since the time that the plaster room is occupied would be decreased and the plaster technician would save some time on the appointment. However, this would lead to higher occupation of the other departments. Still it is worth researching, but the problem is that MST does often not know beforehand if a specialist needs to come or not. We also do not know for what percentage of appointments it is known beforehand that a specialist needs to be there since they do not document this. There is also no data to suggest how much time it would take for a plaster technician to go to another department and treat a patient there. All these unknowns make simulating this situation infeasible for us. This is something that might be interesting for MST research in another way.

- Use the emergency table in Enschede as an extra table to place patients waiting for specialist when the emergency table is not busy.

This intervention is a trade-off between decreasing waiting times (and with that overtime) and occupation of what is meant to be an emergency table. Using the table when the emergency table is not busy, decreases waiting time for patients. If we schedule elective appointments on the emergency table, the number of overbooked appointments obviously also decreases. However, in Appendix 9 we have two figures showing that the busiest days for the emergency table and for plaster rooms 1 and 2 in Enschede coincide. This means, when the emergency room is not busy, the elective plaster rooms are also not busy and there is less need for the extra table. Also, since the emergency table was left out of the scope of the research, we do not have this table in the simulation model, as we discuss in Chapter 5. If we would incorporate the emergency table in the model, this would mean rebuilding the entire model and this would be too time-consuming. These arguments combined with the fact that it is simply not very desirable for MST to have elective patients on the emergency table are why we do not test this intervention.

- Split WEC appointments in two appointments where patient goes to specialist in between.

Currently, the appointments from the WEC cause trouble, since they are longer and more varying in length than normal appointments. Almost half of the WEC appointments needs a specialist, which is what partially causes the problem. These patients often wait a long time, and this causes a lot of delay. If we split these WEC appointments in two parts and let the patient go to the specialist instead of the other way around, we would cut the time waiting for the specialist and the time that the patient is examined by the specialist. This is why we also test this intervention.

4.2. Conclusion

The interventions that we test are:

- Letting orthopaedic appointments and surgical appointments in Enschede be planned in the morning as well as in the afternoon (mix them).
- More orthopaedics appointments in Oldenzaal and better spread of appointments over Enschede and Oldenzaal.
- Instead of giving patients a certain day for their appointment, give them a range of days from which the secretary can decide which is best.
- Provide the plaster rooms in Enschede with a room where they can store a patient that is waiting for a specialist.

- Schedule appointments using the estimated treatment times according to the treatment codes of the treatments that they expect to perform.
- Split WEC appointments in two appointments where patient goes to specialist in between.

This answers our second research question: "*What interventions should we test in the simulation?".* We describe how we test these interventions in Chapter 5. How we design these experiments and the results of the experiments are in Chapter 6.

Chapter 5: The Simulation Model

As a tool to perform our experiments we use simulation. This chapter is therefore devoted to this important part of our research. In Section 5.1 we describe how we construct a simulation model based on the information in Chapters 1 to 3. After this we describe what input data we need to run the model in Section 5.2 and we describe the output data that the model delivers in Section 5.3. We discuss the assumptions and simplifications that we made to build the model in Section 5.4. We then thoroughly research the validity of our model in Section 5.5. We state the conclusions of this chapter in Section 5.6. It is useful to remember our theoretical framework (Law, 2007) for conducting a simulation study that we introduced in Section 3.1. We perform task 4 (constructing a computer model and verify) from this framework in Section 5.1, 5.2, 5.3 and 5.4 and task 6 (validation) in Section 5.5.

5.1. From Conceptual Model to Simulation Model

To get to a simulation model for experimentation, we need to make a conceptual model to understand the process and simulate it. After this, the conceptual model needs to be converted to a working simulation model. The program we use for this is Tecnomatix Plant Simulation by Siemens PLM Software. For our research the conceptual model is depicted as the process flow charts describing the current situation (Figure 3 and Figure 4). Figure 4 is most representative for our model. In the simulation model we model objects called MUs (moving units), which flow through the model. In our case there is one type of MU and that is an appointment (we give these MUs multiple attributes, which describe what type of appointment it is). The reason we look at appointments instead of patients, is because MST does not document if a patient is there for the first time in their treatment or if they are there for a second time, a third time, etc. for instance, to have check-ups. We describe how the model works using a figure showing a part of the resulting simulation model in Figure 7 (this also gives a picture of what the model looks like). Appendix 3 shows a zoomed-out version of Figure 7 and explains our complete model in more detail.

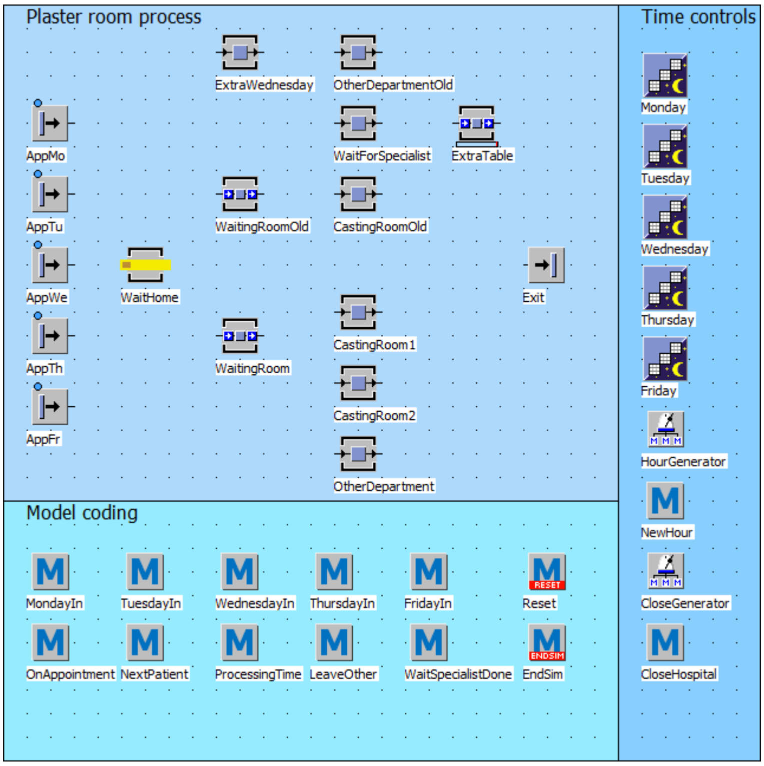

Figure 7: Simulation model

We split the layout in parts with distinct functions in the coloured blocks. The top left area is where the process happens in which we make appointments and send them to the plaster rooms etc. (this is where our MUs flow through the model) and the rest of the model controls this process or contains the necessary statistics. The bottom left contains all the “methods”. These contain code that controls how we schedule and perform appointments. This is where we model the various experiment interventions that concern the scheduling of appointments. The column on the right contains the controls how time influences the system. For instance, when the hospital closes and opens.

The top left is the direct result of converting the conceptual model to a simulation model. The MUs (appointments) move around from event to event. In Oldenzaal there is a plaster room, an extra table and the possibility to go to another department. In Enschede there are two plaster rooms and the other departments that patients can go to. We simplify the other departments in Enschede and Oldenzaal to one object per location, as we explain in Section 5.3. The event that a specialist is needed happens in the plaster room itself and we model this in the model coding part (bottom left).

5.2. Input Data

To make this model work, a lot of input data is needed. First, we need to replicate the current situation in our simulation to get a baseline for reference. To achieve this, we will extract the input data from last year’s data at MST. We need the following distributions:

- Number of appointments coming in per day of the week
- Ratio orthopaedic appointments and surgical appointments
- Ratio Oldenzaal/Enschede
- Number of days between the moment of scheduling and the start of the appointment per day of the week
- Arrival times (number of minutes early or late)
- Planned durations of appointments per day of week
- Actual duration of appointments linked to what is planned
- Probability of needing a specialist
- Probability of moving to another department
- Additional duration because of specialist or move to another department

Most of these distributions can be extracted from data from the MST database. However, MST does not document actual durations of appointments. Also, arrival times of patients in the waiting room are not documented and it is not possible to see if patients needed a specialist or needed to move to another department during an appointment. This data had to be collected. We kept track of the arrival time of patients for one week. Also, all plaster technicians agreed to collect data for this research by filling in a form after each appointment for a week. This form can be seen in Appendix 4. These forms give us information on the actual duration of appointments. They also tell us if patients went to other departments or if specialists were needed and how much time was lost because of it.

To extract these distributions, we used the methods from “Simulation: The Practice of Model Development of Use” (Robinson, 2014) and lecture slides on data collection and analysis & output analysis (Mes, 2017). The resulting distributions can be found in Appendix 5.

5.3. Output Data

The input data is needed to make this model accurately represent the current situation at MST. Our goal however, is to get important data from our experiments to see which intervention performs best and to see where improvements are possible. Therefore, getting the right output data from the model is also very important. The output data we collect from our model is:

- Amount of waiting time for each patient
- Number of overbooked appointments, amount of waiting time and amount of overtime per location
- Number of overbooked appointments, amount of waiting time and amount of overtime per day
- Number of overbooked appointments in total

This data will provide a good view of how appointments should be performed and scheduled. These output values also provide useful information to see if our model is valid and to point out faults when modelling new interventions (if an output value seems incorrect, then we know something is wrong and through this information we can find the fault in the model).

When we get to the experimentation phase, we are more interested in the overall performance of the intervention on our KPIs. With the experiments we therefore focus on our KPIs and use the output values:

- Number of overbooked appointments over the entire year
- Sum of waiting time for patients over the entire year
- Sum of overtime for all plaster rooms over the entire year

5.4. Assumptions and simplifications

Real life situations are too intricate to copy exactly, which is why assumptions and simplifications are needed. First, we discuss the difference between the two:

- Assumptions are made either when there are uncertainties or beliefs about the real world being modelled; they fill gaps in our knowledge about the real world (Slack, 2014).
- Simplifications are incorporated in the model to enable more rapid model development and use, and to improve transparency (Slack, 2014).

The assumptions that we make are:

- Appointments that MST schedules for 40, 50 or 60 minutes are so scarce that there is not enough data to extract a distribution for their duration. We assume these appointments are gamma distributed with a shape parameter (θ) of 3, because 20 and 30-minute appointments both have this shape as well. Luckily, since these appointments are so scarce, this assumption does not have a substantial impact on the model.
- The 50 and 60-minute appointments were too scarce to get a valid average duration. We therefore assume that 50-minute appointments on average last as long as a 20-minute appointment plus a 30-minute appointment. We also assume that a 60-minute appointment lasts twice as long as a 30-minute appointment. Again, this will not have a substantial impact on the model because these types of appointments scarcely occur. The resulting distribution of appointment processing times is in Appendix 5
- 50 and 60-minute appointments have the same frequency of needing a specialist and having to move the patient as 40-minute appointments.
- The rate of appointments coming in stays the same during the course of the day.

The simplifications that we make are:

- The other departments that patients go to are modelled as one object.
- Arrival times of patients are equally distributed for all appointments.
- Frequency of moving to another department is equally distributed for each appointment length.

- Additional time needed if specialist is needed is equally distributed for each type of appointment.
- The amount of time that a patient is away during a move to another department is equally distributed for all types of appointments.
- The distribution of the number of days between scheduling and the appointment is the same for all lengths of appointments.

5.5. Validity

We want to be certain that our simulation model accurately represents reality. Therefore, we want to validate the model output and the most important input distributions in our model. in Section 5.5.1 we validate some of the most important input distributions. Then, in Section 5.5.2, we determine the warmup length and in Section 5.5.3 we calculate the number of replications that we need for statistically accurate results, based on our desired run length.

5.5.1. Input Validation

The three most important distributions are the number of appointments that come in per day of the week, the number of days between scheduling the appointment and the day of the appointment, the number of minutes that are scheduled for an appointment and the actual duration of an appointment based on how many minutes are scheduled. To simulate the number of appointments coming in, the number of days between scheduling and the day of the appointment, and the number of minutes that are scheduled for an appointment, we use empirical distributions. An empirical distribution can be used for all distributions and it copies frequencies of occurrences in historical data. This will always follow the historical data and does not need to be validated. Since an empirical distribution is very accurate in simulating based on historical data, one might question why we do not use this for all input data. This is because empirical distributions merely mimic the historical data without being able to produce values that have not occurred in the historical data and without outliers that you would have in reality. Statistical distributions are known distributions that can often be found in real-life processes and, if fitted well, more realistic than an empirical distribution.

The actual duration of appointments (processing time of plaster room) are gamma distributed with a shape parameter 3 for 20 and 30-minute appointments (Appendix 5 shows how found these distributions). For the other appointment lengths there is not enough data available to establish the distribution, which is why we assume these durations are also gamma distributed with shape parameter 3. The average durations of 50 and 60-minute appointments are estimated by adding the average duration of a 20-minute and a 30-minute appointment (for 50-minute appointments) and by adding the average duration of two 30-minute appointments (for 60-minute appointments) respectively. 20-minute appointments are by far the most occurring appointments, which is why it is important to validate the fit of the distribution. We performed a chi-square test with level of significance of 5% to test if the distribution accurately represents reality. The test revealed that the distribution fits well (see Appendix 6 for results of chi-square test).

Now we have the main input data validated, we would like to see if the output data resembles reality. For this we look at the amount of overbooked appointments (MST does not document waiting time and overtime, so we cannot compare those to reality). Table 4 shows the average number of overbooked appointments over 18 replications (see Section 5.5.3 to see why we perform 18 replications) of our simulation on the left. On the right we see the values we found in the data for 2017. In the left table, the session CH1 and CH2 make up HCH (surgical), O1 and O2 make HBP (orthopaedic) and CHOld is OCH and Oold is OBP. Keep in mind that in Oldenzaal a lot of appointments are overbooked on purpose, since when plaster technicians think a specialist might need to come they can use the extra table and they can treat the other patient. In the simulation we always try to prevent overbooking. We never overbook an appointment unless there is no room left on the designated day to fit the appointment. We do this because we want to see how the current intervention could perform on number of overbooked appointments when they try. This number is therefore lower in the simulation than it was in Oldenzaal in the 2017 data. For the current situation that should show what performance could be obtained when they would always try to prevent overbooking. Unfortunately, since this is not done in reality, we cannot validate the accuracy of this value from Oldenzaal. Also notice that HBP is lower than O1+O2 and HCH is lower than CH1+CH2. This is caused by the fact that sometimes in reality they "cheat" by scheduling 20-minute appointments as 10-minute appointments to fit them in the schedule and we do not do that. This is because we want to know what performance is possible without cutting appointments short. Aside from that, it is also not possible to know how much of the 10-minute appointments are 20-minute appointments, since it is not documented. This makes it impossible for us to simulate the eventual "cheating" in such cases. Taking away these causes of deviation, these numbers seem well proportioned compared to each other in our opinion. Orthopaedic appointments in Oldenzaal have a very low number of overbooked appointments, surgical in Enschede has about 120 overbooked appointments, orthopaedic in Enschede about 180 (without cheating) and surgical in Oldenzaal 140 when always trying to prevent overbooked appointments. This will be our baseline for the other experiments to come. The most important aspect of our research is to find out how different interventions differ from this baseline simulation.

Session	Overbookings	Session	Overbookings
CH1	60.89	HCH	97
CH2	59.67		
CHOld	140.28	OCH	440
O1	93.11	HBP	160
O2	95.22		
OOld	10.67	OBP	6

Table 4: Number of overbooked appointments per appointment type and location over a year (simulation left, real data right)

5.5.2. Warmup Period

The plaster room process is non-terminating and steady state, meaning that there are always patients in our system (in the schedule) and there is no ending or beginning time to the system. However, the simulation model has a starting period where there are no appointments in the schedule. This means that at the start of the simulation there are not as many appointments as we would have on a normal day later in the year. It takes a while to get a representative amount of appointments in the schedule to produce valid output. Therefore, we need to establish what this warmup period is and exclude the output data from this period from our results. We do this by applying the MSER (Marginal Standard Error Rule) on the number of patients that are treated per day, since all our performance indicators are correlated to this value (Appendix 7 shows how we perform this procedure). Figure 8 shows how the number of patients treated per day develops over the year in our simulation. The horizontal axis of this figure represents the workdays (254 workdays) of our simulation run in 1 year, which is our run length. Run length is the amount of time that is simulated. We explain more about this in Section 5.5.3. According to the MSER, the warmup period is 12 workdays, which is 18 days with weekend days added.

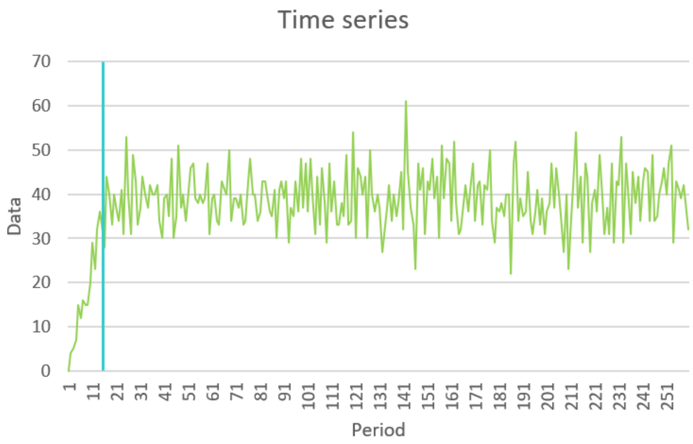

Figure 8: Warmup period

5.5.3 Replications and Run Length

To be sure that our output data is accurate, we need to establish the right run length and the right number of replications. The run length is the amount of simulated time and replications are simulation runs with different random variables. The number of replications also depends on the run length, since when the run length is longer, the variability of the output data is lower and less replications are needed. The rule of thumb for run length is that it should be at least 10 times the warm up length. Our warmup length is 18 days and thus a run length of 180 would suffice. However, for comparison to reality we would like to model a year, which is also more intuitive. Therefore, our run time is 365 days. This will decrease the number of replications we need to run.

The number of replications that we need can be found with various methods. One of these is a rule of thumb. The rule of thumb by Law and McComas (1990) is that one should perform at least 3 to 5 replications. It is also possible to use a graphical approach. A simple graphical approach is to plot the cumulative mean of the output data from a series of replications. As we perform more replications the graph should become a flat line (Robinson, 2014). A more accurate method is the confidence interval method. A confidence interval is a statistical means for giving an estimated range within which the true mean average is expected to lie (Robinson, 2014). We estimate the number of replications that we need by performing the confidence interval method in Appendix 8. The number of overbooked appointments is our most important key performance indicator, which is why we use this indicator for determining the number of replications. This method uses the number of overbooked appointments from every replication, and more and more replications are performed until the confidence interval is narrow enough to satisfy the norm. This norm is a significance level of 5%, which means that there is a 95% probability that the true mean of all replications lies within the confidence interval. The number of replications that this method provides for our simulation model is 18 (see Appendix 8 for a detailed description of this method).

5.6. Conclusion

In this chapter, we described how we constructed our simulation model and how we validated it. We also list the input data, output data, simplifications and assumptions. From our output data we stated three output variables, which describe our KPIs, that we use for experimentation:

- Number of overbooked appointments over the entire year
- Sum of waiting time for patients over the entire year

- Sum of overtime for all plaster rooms over the entire year

The part of this chapter on validation shows the warmup period, run length and number of replications that our simulation needs to produce statistically accurate output data. The warmup period is 18 days. We use a one year run length and the number of replications needed is 18.

Chapter 6: Experiments and Results

In this chapter, we discuss how we perform the experiments that we introduced in Chapter 4 and we discuss the results from these experiments. In Section 6.1 we explain how the various interventions translate to changes in the simulation model. The output values for each of these experiments are the average of the tables with statistics per location over 18 replications, which have a run length of one year. After discussing the results per experiment in Section 6.2, we analyse and compare those results in Section 6.3. In Section 6.4 we conclude this chapter.

6.1. Intervention to Simulation

In Chapter 4 we established which interventions we want to test and which ones we do not want to test or cannot test. We have not yet established how we alter the model to represent these interventions. There are six different interventions, which we represent by six slightly different models. We explain how we did this for each intervention.

Letting orthopaedic appointments and surgical appointments in Enschede be planned in the morning as well as in the afternoon (mix them):

To make the model schedule appointments spread over the day we need to make a subtle change in the scheduling code in the method (a method contains code that controls the model) for appointments coming in on Monday. We only need to change the time slots that will be used for scheduling and the time slots in which the model may not schedule because of the coffee and lunch break. Unfortunately, there is a lot of coding in this method (1636 lines of code for just the appointments that come in on Monday) and we need to change it for every type and every length of appointment in Enschede. For each day of the week we have a method that schedules appointments that come in on that day. This keeps the model simple and easy to code for different days. Once we do this for the Monday it is easy to copy the code from that method to the other days and then we only have to change a few lines to make it function as the code for another week day.

More orthopaedics appointments in Oldenzaal and better spread of appointments over Enschede and Oldenzaal.

For this we need to first determine what appointments should go to Oldenzaal and which one to Enschede. Intuitively, we would like to have the patients that live closer to the plaster rooms in Oldenzaal to go there and the others to Enschede. From the address data, we determined what percentage of patients lives closer to Oldenzaal and what percentage lives closer to Enschede (see Appendix 10). We then used this ratio for sending patients in the model to Oldenzaal or Enschede. The address data showed that 33.4% of patients lives closer to Oldenzaal. Whether a patient is orthopaedic or surgical is equally distributed for both locations, which is, based on 2017, 31.4% orthopaedic.

Instead of giving patients a certain day for their appointment, give them a range of days from which the secretary can decide which is best.

In our normal model we have three possible steps to scheduling appointments. First, look for a slot in the designated plaster room on the designated day. If this cannot be found and if the location is Enschede then see if there is a slot in the other plaster room. If this is not the case, then overbook the appointment on random slots that are not yet overbooked. To model our new intervention, we needed to add one or two steps before the overbooking step, depending on what day the appointment is on. If it is a Monday or a Friday, we only need to look for an appointment slot a day later or sooner, respectively. On the other days we search for an appointment slot a day later, and if that day is full, a day earlier.

Provide the plaster rooms in Enschede with a room where a patient can wait for a specialist during the appointment.

In this intervention we build the same type of situation in Enschede as we have in Oldenzaal with the extra table. The patients can be put in the extra room when they are waiting for a specialist to come. We can convert a lot of the code for the extra table in Oldenzaal to what we need for the extra room in Enschede, so this was relatively simple to construct.

Schedule appointments using the estimated treatment times according to the treatment codes of the treatments that they expect to perform.

For this we needed to individually search for the treatment codes that were used for every appointment in the system for a period of a month. Based on the frequency of each combination of codes we use an empirical distribution to determine the number of slots that we need to schedule for an appointment. This distribution can be seen in Appendix 11.

Split WEC appointments in two appointments where patient goes to specialist in between.

This is an intervention that is hard to simulate. There is no way for us to know how much time will be saved by sending the patient to the other department, since this cannot be deduced from the data. From the data we obtained from the forms that the plaster technicians filled in, we could deduce the proportion of appointments that come from the WEC. We only split 30 and 40-minute WEC appointments, which are the most frequent. We split a 30-minute appointment in two 10-minute appointments and a 40-minute appointment in a 10 and 20-minute appointment, because they perform part of the appointment at the other department in this situation. However, the secretaries often schedule 10-minute appointments to fit 20-minute appointments in the schedule if the schedule is full. The duration of 10-minute appointments is affected by this and it would not be correct to assume that 10-minute appointments that we schedule for the split WEC appointments have the same average processing time as usual. That is why we use an average processing time of 10 minutes for these appointments by default.

6.2. Experiment results

In Table 5 we see the results table for all the experiments. Below table 5 we discuss each experiment individually and in Section 6.3 we compare and analyse all the results. The experiments are numbered from 1 to 8 as follows:

1. *Current situation*
2. *Give patients a range of days for their appointment to be scheduled*
3. *Spread appointments over Enschede and Oldenzaal*
4. *Mix surgical and orthopaedic appointments*
5. *Schedule according to code list*
6. *Extra room in Enschede where patient can wait for specialist during the appointment*
7. *Split WEC appointments in two appointments*
8. *Spread appointments over Enschede and Oldenzaal + mix surgical and orthopaedic appointments*

All experiments:

Experiment	Overbookings	Overtime	WaitingTime
1	459.83	94.45	1072.27
2	84.39	58.85	755.32
3	464.17	41.35	1060.35
4	275.89	48.63	911.80
5	780.17	167.78	2032.18
6	459.83	61.06	681.95
7	445.89	70.92	1014.44
8	230.78	40.37	872.33

Table 5: Performance on KPIs for all experiments

These are the statistics for all the experiments. All experiments have a run length of one year, which is replicated 18 times with other random values to assure a statistically accurate average result. We compare the results in Section 6.3. In this section we describe what we notice for each individual experiment. Table 6 shows the performance on the KPIs for the current situation. Tables 7 to 14 show the performance on the KPIs for the experiments. We repeat these numbers to make it easy for the reader to see the performance of that experiment without having to check table 5 for every experiment. In Appendix 12 there are more specific tables that show all statistics per type of appointment and location. We choose to only show the total values of our KPIs in this section, because it is easier to comprehend and compare than the more specific tables.

Current situation:

Experiment	Overbookings	Overtime	WaitingTime
1	459.83	94.45	1072.27

Table 6: Performance on KPIs for current situation

These values are the performance on the KPIs of the current situation. These values can be used for comparison to the experiments.

Instead of giving patients a certain day for their appointment, give them a range of days from which the secretary can decide which is best:

Experiment	Overbookings	Overtime	WaitingTime
2	84.39	58.85	755.32

Table 7: Performance on KPIs for scheduling in range of days

As expected, this method of scheduling appointments significantly improved the spread of appointments over the week, which is reflected by the decrease in number of overbooked appointments. Applying this in real life would mean that the plaster technicians write a range of three days on the appointment card instead of one day on which the appointment can be scheduled. This is a card that is handed to the patient who in turn hands it to the secretary to make an appointment. The lower number of overbooked appointments in turn leads to less overtime and waiting time for patients, since there are less days that are too busy.

More orthopaedics appointments in Oldenzaal and better spread of appointments over Enschede and Oldenzaal:

Experiment	Overbookings	Overtime	WaitingTime
3	464.17	41.35	1060.35

Table 8: Performance on KPIs for spreading patients over Enschede and Oldenzaal

In this intervention we spread patients over Enschede and Oldenzaal based on which location is closer to the town they live in. The problem with this situation is that the orthopaedic session in Enschede is not well utilized and the surgical session in Enschede is overloaded, which we see in Appendix 12 in the location-specific table. Using this method of scheduling would therefore result in too much issues for the surgical session in Enschede. However, if orthopaedic and surgical appointments could be planned mixed over the entire day, that would solve this problem. The total number of overbooked appointments would go from 276 (if mixing surgical and orthopaedic) to 231 as we see when comparing Table 10 with Table 14.

In this experiment we found out that scheduling patients at the location that they are closest to does not perform better than the current situation unless orthopaedic and surgical appointments would be mixed. However, it would be useful for MST to know what the optimal distribution of appointments over Enschede and Oldenzaal is. Plaster technicians indicated that they think that there are not enough orthopaedic appointments in Oldenzaal and too much in Enschede. To find out what the right distribution of orthopaedic and surgical appointments is and the corresponding distribution of number of appointments over Oldenzaal and Enschede, we perform a sensitivity analysis. In Appendix 13 we perform this sensitivity analysis and we explain what this is and how it works. From this analysis we conclude that the optimal proportions of appointments and appointment types are as depicted in Table 9. For a more detailed explanation we refer to Appendix 13.

	Number of appointments/Total	Percentage Orthopaedic at this location	Percentage Surgical at this location
Enschede	68%	34%	66%
Oldenzaal	32%	26%	74%

Table 9: Optimal proportions of appointments and appointment types in current situation

Letting orthopaedic appointments and surgical appointments in Enschede be planned in the morning as well as in the afternoon (mix them):

Experiment	Overbookings	Overtime	WaitingTime
4	275.89	48.63	911.80

Table 10: Performance on KPIs for mixing orthopaedic and surgical in Enschede

The schedule is suffering from rigidity and this intervention gives more freedom of scheduling and more spread of appointments over the day. This is not only nice for our results, but also for the patients. They would be able to get an appointment the entire day and not just in the morning or afternoon. This method of scheduling takes away the problem of the morning session being full and the afternoon session having enough room and vice versa. The result is a dramatic drop in the number of overbooked appointments. The amount of waiting time for the orthopaedic patients has also dropped (as Appendix 12 shows) because the orthopaedic is currently slightly overloaded, which is prevented in this intervention. Overtime has also lowered.

Schedule appointments using the estimated treatment times according to the treatment codes of the treatments that the plaster technicians expect to perform:

Experiment	Overbookings	Overtime	WaitingTime
5	780.17	167.78	2032.18

Table 11: Performance on KPIs for using code list

Most of the people we spoke at MST thought it would be better to schedule appointments using the estimated treatment times according to the list with treatment codes. They stated appointments should be as long as the sum of the estimated time of the treatments that the plaster technicians expect to perform. We expected that this would take away some of the variability of appointment durations compared to how much time MST schedules. However, while looking at the code list and the treatments that plaster technicians perform during appointments, it soon becomes clear that the secretaries schedule appointments for a shorter time than what the code list advises. It is also clear that this usually is enough time. This suggests that the list with treatment times is too pessimistic. Scheduling appointments by the code list therefore results in a big increase of overbooked appointments. The performance on waiting time and overtime are not correct because the processing times are based on the average of appointment lengths with the normal way of scheduling appointments where a 20-minute appointment is the standard. Scheduling based on treatment codes usually results in longer appointments in the schedule and this will often not fit.

Provide the plaster rooms in Enschede with a room where a patient can wait for a specialist during the appointment.

Experiment	Overbookings	Overtime	WaitingTime
6	459.83	61.06	681.95

Table 12: Performance on KPIs for providing extra room for waiting patients in Enschede

The plaster technicians expected that having an extra room where patients can wait for a specialist in Enschede would improve the rate at which they could process appointments. Oldenzaal is a proof of this concept as it already uses an extra table for this purpose. That this intervention is an improvement, convincingly shows in the results. The amount of waiting time drops significantly. The decrease in waiting time is about 36%, which is much more than we expected. Also, the amount of overtime shows strong improvement.

Split WEC appointments in two appointments where patient goes to specialist in between:

Experiment	Overbookings	Overtime	WaitingTime
7	445.89	70.92	1014.44

Table 13: Performance on KPIs for splitting WEC appointments in two appointments

A lot of the appointments at the surgical session are WEC appointments and they often need a specialist. Moving the patient to the specialist instead of having them occupy the plaster room while waiting is therefore preferable. This shows in the results as the amount of waiting time decreases with about 12% for the surgical session in Enschede. Also, the number of overbooked appointments is slightly lower. However, it needs to be inquired if doing this does not cause problems for the WEC. If so, the results might not be significant enough to apply this intervention.

(Extra) More orthopaedics appointments in Oldenzaal and better spread of appointments over Enschede and Oldenzaal
+
Letting orthopaedic appointments and surgical appointments in Enschede be planned in the morning as well as in the afternoon (mix them)

Experiment	Overbookings	Overtime	WaitingTime
8	230.78	40.37	872.33

Table 14: Performance on KPIs for spreading patients over Enschede Oldenzaal + mix orthopaedic and surgical in Enschede

As mentioned in the intervention: ”More orthopaedics appointments in Oldenzaal and better spread of appointments over Enschede and Oldenzaal”, combining the scheduling of appointments based on the city that the patient lives in and mixing orthopaedic and surgical appointments would improve on just mixing the appointments. The results above show that all KPIs significantly improve. For MST it is wise to remember this if they would allow for surgical and orthopaedic appointments to be scheduled over the entire day.

6.3. Results analysis

As the results show there are a lot of improvements MST can make by implementing the proposed interventions. We put the results into perspective by comparing the interventions on each KPI. In Figure 9 we compare the interventions on the number of overbooked appointments; In Figure 10 we compare the interventions on the amount of overtime and in Figure 11 we compare the interventions on the amount of waiting time for patients. In these figures the interventions are numbered as follows:

1. *Current situation*
2. *Give patients a range of days for their appointment to be scheduled*
3. *Spread appointments over Enschede and Oldenzaal*
4. *Mix surgical and orthopaedic appointments*
5. *Schedule according to code list*
6. *Extra room in Enschede to store patient waiting for specialist*
7. *Split WEC appointments in two appointments*
8. *Spread appointments over Enschede and Oldenzaal + mix surgical and orthopaedic appointments*

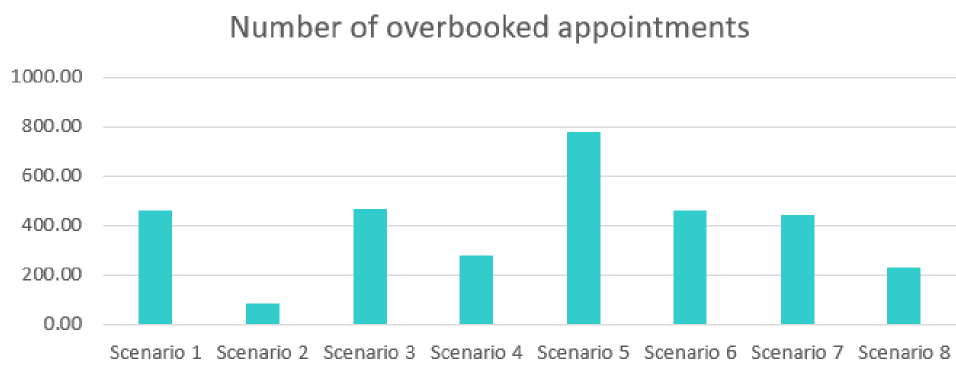

Figure 9: Number of overbooked appointments per intervention

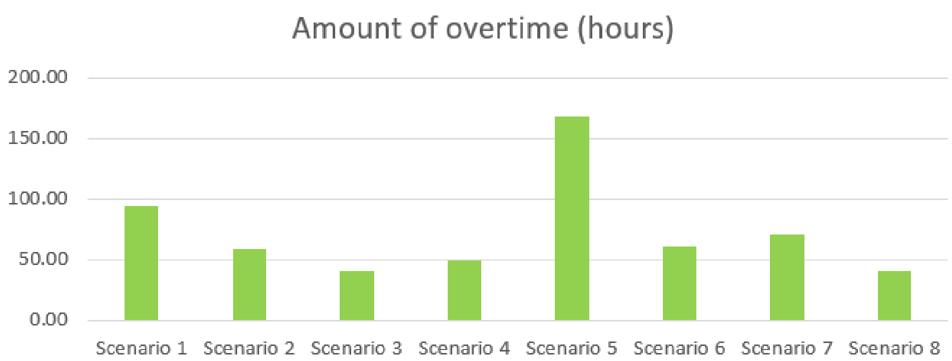

Figure 10: Amount of overtime in hours per intervention

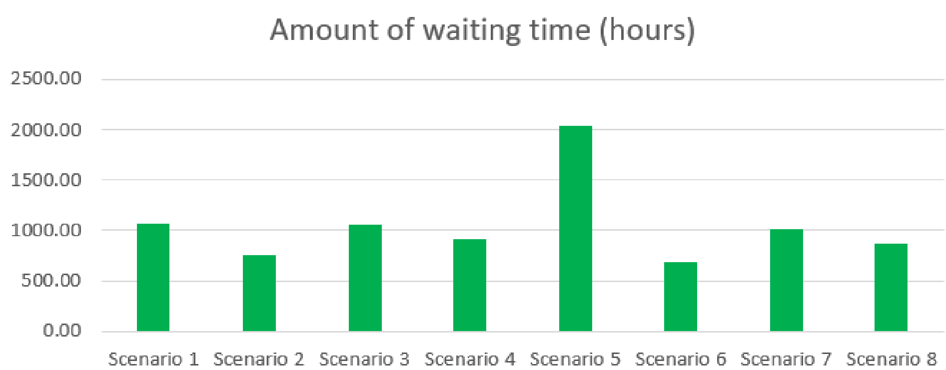

Figure 11: Amount of waiting time in hours per intervention

From these figures we conclude that scheduling using the code list with treatment times (intervention 5) should not be done. The actual processing times for appointments are shorter than what the code list describes. This means that using the code list for scheduling leads to more overbooked appointments and underutilization because the plaster rooms would often be idle. Keep in mind that the amount of overtime and waiting time are not accurate for this intervention because the code list often schedules more time for appointments than what is normally scheduled, while the actual duration of the appointment stays the same.

All the other interventions that we tested are improvements except for spreading appointments over Enschede and Oldenzaal (intervention 3). This does not clearly show in these figures, but the surgical session in Enschede is overloaded by applying this intervention. However, as we see in experiment 8, combining this with mixing the surgical and orthopaedic appointments results in a substantial improvement. If MST decides against mixing surgical and orthopaedic appointments in Enschede, the optimal proportion of appointments in Enschede and

Oldenzaal would be 68% and 32% respectively. In Enschede the proportion of surgical and orthopaedic appointments is 66% and 34% respectively. The corresponding proportion of surgical and orthopaedic appointments in Oldenzaal is 74% and 26% respectively. Unfortunately, we could not test all combinations of interventions, because of limited time. However, none of our interventions are contradictory so combining one improving intervention with another should always result in better performance.

Mainly interventions 2, 4, 6 and 8 distinguish themselves by performing far better than the current situation. These interventions significantly improve on almost every KPI and are therefore very desirable to implement at MST. Intervention 2 can be implemented immediately and without costs or potential problems. Intervention 4, 6 and 8 require inquiry at the board and might involve extra costs. Furthermore intervention 7 improves on the process for WEC appointments at the surgical sessions since, as Section 6.2 shows, it improves on the KPIs for the surgical session.

6.4. Conclusion

In this chapter, we describe how the experiment interventions translated to changes in the simulation model and we show the results of the experiments. The results show that most interventions improve on the current situation. Only scheduling appointments based on the code list and spreading appointments over Enschede and Oldenzaal based on where they live do not improve. However, when combining the latter with mixing orthopaedic and surgical appointment it does improve a lot compared to only mixing orthopaedic and surgical appointments. The highest performing interventions are:

- *Give patients a range of days for their appointment to be scheduled*
- *Mix surgical and orthopaedic appointments*
- *Extra room in Enschede to store patient waiting for specialist*
- *Spread appointments over Enschede and Oldenzaal + mix surgical and orthopaedic appointments*

Chapter 7: Conclusion and Recommendation

In this concluding chapter, we discuss the results from our research. In Section 7.1 we answer the research questions that we established in Chapter 1. In Section 7.2 we summarize the findings of this research. Then we state some additional recommendations for the plaster rooms at MST in Section 7.3.

7.1. Research Questions

Research question 1: What is the process of scheduling and performing an appointment?

In Chapter 2 we depict the flow of patients using a flow chart. There is also a flow chart that depicts the process of performing a single appointment. These appointments are scheduled by the secretary at the plaster room or on the phone. They usually schedule on the exact day that the plaster technicians indicate the appointment should be scheduled on. The plaster technician writes a day on an appointment card (often this is 7 days or a multiple of this) that the patient hands to the secretary. There are no strict rules as to when a patient is scheduled in Oldenzaal or Enschede. Currently there are too many overbooked appointments because of this scheduling method. Also, MST would like to have lower waiting times and less overtime. These three attributes are our key performance indicators (KPIs).

Research question 2: What interventions should we test in the simulation?

We list possible interventions that we might want to test in Chapter 4. In this chapter, we also decide which ones of these we want to and are able to model. These interventions are:

- Give patients a range of days for their appointment to be scheduled
- Spread appointments over Enschede and Oldenzaal
- Mix surgical and orthopaedic appointments
- Schedule according to code list
- Extra room in Enschede to store patient waiting for specialist
- Split WEC appointments in two appointments

While running the experiments we notice that combining the second intervention with the third one should improve the overall performance, while the second intervention on its own does not improve on the current situation. Therefore, during experimentation, we also run an experiment with the combination of these two interventions.

Research question 3: What is the necessary input data for our simulation model?

In the literature review we describe how to represent data through distributions. For our research we have three data requirements:

- Contextual data
- Data required for model realisation
- Data required for model validation

We satisfy these requirements by obtaining the necessary data. This data is of category A, B or C, which are in order of obtainability, with A being the most obtainable and C the least obtainable. We obtain category A data from the MST database. We collect category B data by making observations and by providing the plaster technicians with a form to fill in after every appointment for a week. Category C data needs to be estimated. To represent the data and unpredictable variability in the data we use empirical distributions and statistical distributions. Statistical distributions are the most desirable and can be determined in three steps:

1) Select a distribution
2) Determine the parameters
3) Test the goodness of fit

However, data often does not follow a statistical distribution, which is why we also need to use empirical distributions. These are less desirable because they only mimic the frequencies of occurrences in the data and cannot take new values.

To make our simulation model work we had to find the following distributions:

- Number of appointments coming in per day of the week
- Ratio orthopaedic appointments and surgical appointments
- Ratio Oldenzaal/Enschede
- Number of days between the moment of scheduling and the start of the appointment per day of the week
- Arrival times (number of minutes early or late)
- Planned durations of appointments per day of week
- Actual duration of appointments linked to what is planned
- Probability of needing a specialist
- Probability of moving to another department
- Additional duration because of specialist or move to another department

To extract these distributions, we used the methods from Robinson (2014) and lecture slides on data collection and analysis & output analysis (Mes, 2017). The resulting distributions can be found in Appendix 5.

Research question 4: Which intervention would be most suitable for use at MST?

The answer does not consist of merely one of our tested interventions. A lot of the interventions are improvements on the current situation and so would be combining the actions in these interventions. The highest performing interventions are:

- *Give patients a range of days for their appointment to be scheduled*
- *Mix surgical and orthopaedic appointments*
- *Extra room in Enschede for patients waiting for specialist*
- *Spread appointments over Enschede and Oldenzaal + mix surgical and orthopaedic appointments*

The fourth intervention obviously also contains the second one. We added this fourth intervention because the synergy of the described interventions improves on the second intervention, whereas spreading appointments based on the city where the patient lives does not improve performance in the current situation. The first intervention decreases the number of overbooked appointments by over 80%, which shows how many unnecessary overbooked appointments there really are. The third intervention decreases the average waiting time with 36%. The fourth intervention reduces overtime with 58% (when scheduling most appointments early on the day). However, these improvements can only be achieved if MST schedules appointments perfectly according to the interventions. In real life human behaviour results in inevitable and unpredictable deviations from the proposed way of scheduling, which can negatively influence the performance. This is something that can happen for each intervention. For more detailed information on the performance of these interventions see Section 6.2, Section 6.3 and Appendix 12. The first three interventions can be combined, as can the first, second and last. None of our interventions are contradictory so combining one improving intervention with another should always result in increased performance. Splitting WEC appointments in two appointments and letting patients go to the other department in between also improves on waiting time for the surgical session, which also makes this intervention desirable for the plaster rooms. However, we do not know what the results for the WEC is if this is done. If this is a problem for the WEC, MST might be better of not doing this.

7.2. Conclusions of experiments

The main goal of this research was to find out how to reduce the number of overbooked appointments. The first way to do this is to give patients a range of 3 days (or more if possible) on the appointment card, which determines on which day the next appointment is scheduled. Then the secretary can see which day is the least busy and schedule an appointment on that day. This spreads appointments over the week and results in a dramatic drop of overbooked appointments. With that the amount of overtime and waiting time also decrease. This intervention potentially decreases the number of overbooked appointments by over 80%, which shows how many unnecessary overbooked appointments there really are.

It is also strongly recommended to let surgical appointments and orthopaedic appointments in Enschede be scheduled in the morning as well as in the afternoon. Taking away the restriction of only being able to plan an appointment in the morning or afternoon based on the type of appointment spreads appointments over the day. Currently there are days where the morning is too full and the afternoon is relatively empty. When we get rid of this restriction appointments can be spread over the entire day, which reduces the number of overbooked appointments.

Providing the plaster rooms with a room where patients can go that wait for a specialist reduces the average waiting time with 36%. It allows for a higher processing rate, because the time a patient waits for a specialist can be used to treat another patient if there is another patient in the waiting room. The amount of overtime is also lower because of this. If MST can spare a room close to the plaster rooms, we would certainly recommend this. However, it is important that moving patients to this extra room is done in a way that is not bothersome for the patient.

Should MST apply our recommendation of spreading surgical and orthopaedic appointments over the day, then we recommend also scheduling patients at the location that is closest to the city they live in. This is a heuristic rule that spreads patients over the two locations very well. In Appendix 10 there is a list of the cities where ten or more patients in 2017 came from and if they are closer to Enschede or Oldenzaal. This combination could reduce overtime with up to 58% (when scheduling most appointments early on the day).

However, if MST decides not to mix orthopaedic and surgical appointments in Enschede, there is a distribution of appointments over Enschede and Oldenzaal that we advise them to follow. The optimal distribution of appointments is 32% in Oldenzaal and 68% in Enschede. With this distribution of appointments over Enschede and Oldenzaal, the optimal percentage of orthopaedic appointments in Enschede is 34% and 66% surgical appointments. Using these values, we can calculate that the corresponding percentage of orthopaedic appointments in Oldenzaal is 26% and 74% surgical appointments. This distribution results in the lowest number of overbooked appointments.

It is preferable for the plaster rooms if they split WEC appointments in two short appointments in between which the patient goes to the WEC instead of the specialist coming to the plaster room. This should only be done if it is expected that the patient has to go to the WEC. The average amount of waiting time for surgical appointments would decrease with about 12%. Also, the number of overbooked appointments slightly improves. However, this way of performing appointments might result in issues for the WEC. That is why MST should communicate with the plaster rooms and the WEC to see if any problems would occur according to one of the departments. If this is the case, MST should consider if the improved performance caused by this intervention outweighs the emerging issues.

Finally, all the mentioned interventions that improve on the situation are not conflicting to each other and can thus be combined without issues. Therefore, we recommend MST to discuss which of these interventions they want to apply, based on our recommendations, and then apply all those changes. We can easily achieve our goal of less than 10 overbooked appointments per week by applying these interventions. The combination of all these changes should substantially improve on the current performance of the plaster rooms on number of overbooked appointments as well as on waiting time for patients and overtime for the plaster technicians.

7.3. Recommendations

We recommend MST to look into some of the changes that we could not test, because these might also be improvements for higher performance on our KPIs. These changes are:

- *Schedule appointments in the schedule of a specialist when the plaster technicians know they will need one, so the specialist approximately knows when he/she is needed.*
- *Let plaster technicians go to the patient at the other department instead of having a specialist come to the plaster room.*

We also recommend MST to try to improve data gathering in the future. Currently, a lot of data in the system is not correct (because it is entered or processed incorrectly) and a lot of valuable data is missing. It would for instance be good to document the actual appointment durations and if a specialist was needed. This is information may benefit any future researchers. Finally, we recommend MST to schedule more appointments in the beginning of the sessions than at the end to easily reduce overtime, if it is possible with respect to the number of appointments. We did not experiment with this because it usually increases the number of overbooked appointments, but on days that are not busy this should decrease overtime without causing overbooked appointments.

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Appendix

Appendix 1

Problems that were mentioned by MST (can differ from what is mentioned in thesis because some problems were merged into one problem, formulated differently or left out of thesis).

Not enough plaster rooms to handle all patients;
Complicated scheduling;
Overbooking;
No knowledge of how changes to scheduling will influence reality;
WEC and Children's Orthopaedics will does not fit in schedule;
'Green' flow has to wait too long (people that come for the first time);
Over hours for plaster technicians;
Tables in Oldenzaal not always used enough;
Appointments often take longer than what is scheduled.

Appendix 2

Detailed understanding of layout of process, to use for simulation and to show the process to principal.

Research question 1: What is the process of scheduling and performing an appointment?

Subquestions:
Which departments make use of the plaster rooms?
What paths can patients have in the process (through which locations)?
Which decisions are taken to determine where patients go?
From how late to how late can appointments be scheduled?
How does the computer system that is used to schedule appointments work?
What scheduling method do they use right now?
Which aspects of scheduling can be changed, and which aspects cannot?

We want to know what the process looks like to get a better understanding of the situation and to make a process flow chart to base our simulation model on. For this it is necessary to know from where patients flow to the plaster rooms to depict in the model and make sure we do not miss a flow of patients to the plaster rooms. Also, we need to know which paths patients can have when visiting the plaster rooms. A patient could for instance go from orthopaedics to the plaster rooms to radiology (for X-ray) back to the plaster rooms and back to orthopaedics. We need to know what makes a patient go to which location to simulate this logically.

To know what scheduling methods are possible improvements, we need to know how scheduling takes place right now. We want to know from how late to how late appointments can be scheduled so there are no miscalculations. The computer system in which appointments are made is important to understand for us, since our solution has to be so that it is compatible with the system and the secretary's capabilities. Then, it is also important to know which scheduling method MST uses now to use for the simulation model to simulate the current situation. Following the answers from the first three subquestions, we need to find out which parts of scheduling can be changed. My solution needs to be applicable at MST, so it can only be altered on the aspects that come up while answering the fourth subquestion.

Knowledge of scheduling methods and process improvements to test.

Research question 2: What interventions should we test?

Subquestions:
What scheduling methods are there?
Which of them can be used for scheduling at MST?
Which of these have a chance of performing better than the current method?

We want to try different ways of scheduling appointments. It is good to know what some easy to apply methods are. After that we need to know which of these are applicable in the situation at MST, so we do not advise a method that is impossible to use. Then we make things easier for ourselves by finding out which of the methods do not have a chance of being better than the original method and which ones do to decrease the number of them that we need to model.

Probability distributions of MST data, as input for simulation model.

Research question 3: What is the necessary input data for our simulation model?

Subquestions:
What data is needed?
To what extent is the data available?
Which scheduling methods were already used and during which period?
How much data is sufficient to perform valid simulation?
How do I extract a probability distribution from data?

To get the simulation model working we need to have the probability distributions of how patients arrive and how they are handled at all locations in the process. By doing this properly the patients in the simulation will go through the process just as they do in real life, with the same probabilities as to where they will go next. To get these probability distributions we need the right data. We need to know what data we need. After this we can see to what extent that data is extractable from the databases. We need to be sure that the situation remained relatively unaltered during the period from which we will use the information. That is why we cannot use information when different scheduling methods were applied which is why we need to know which methods were used when. One of the most important parts of this research is validity. We need to be sure how much data can be seen as sufficient to have a valid simulation study. Then it will be time to extract the probability distributions from the data. To do this properly we will have to refresh our knowledge of the subject to find out how this should be done.

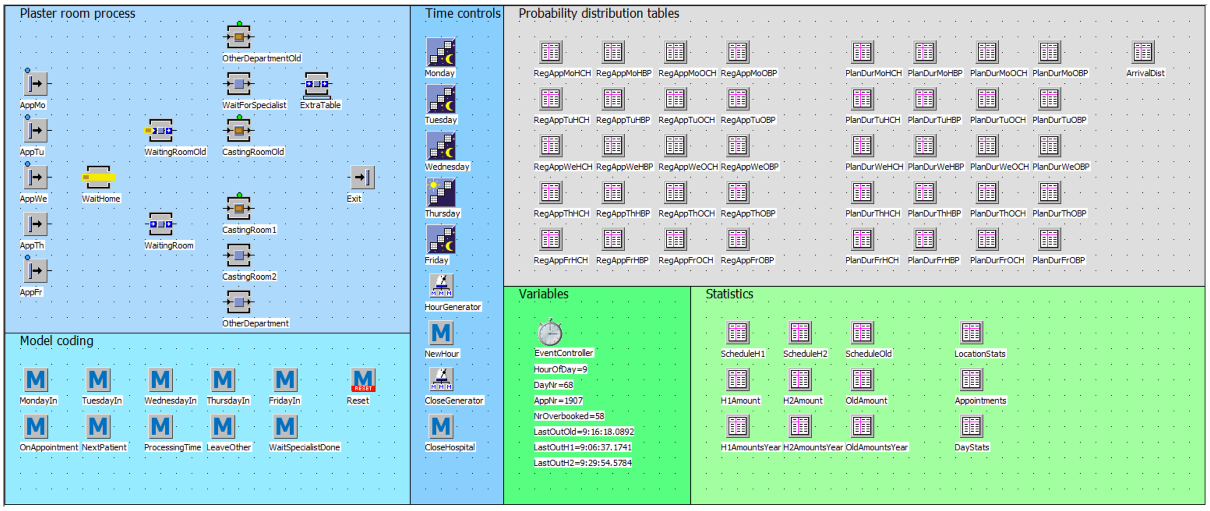
Knowing which scheduling method will be advised to MST.

Research question 4: Which intervention would be most suitable for use at MST?

Subquestions:
What criteria are important from a technical (scores on indicators) and a social perspective (effects on the patients and employees)?
How do I weight these criteria?
How do the different interventions from research question 3 score on these criteria?

When we have modelled the necessary scheduling methods it becomes clear how they score on each indicator. Then we ask ourselves which one will be best for MST. This is of course done in consultation with MST. It is important to know which criteria are important from a technical perspective and a social one. The criteria from a technical perspective are the three indicators: number of overbooked appointments, waiting time and overtime. The criteria from a social perspective are also important. We need to consider that WEC and Children's Orthopaedics need special attention and this needs to be addressed in the eventual intervention. Next to that, we need to make sure that most people at MST are satisfied with this new method. If the method scores better at all indicators but no one is satisfied because they do not like the new method, then I will still have failed. Problems like these could possibly be concluded in criteria from a social perspective. Then the question arises how to weight the criteria to scientifically choose the right solution. These criteria need to be set up with my contact at MST. Then we want to know how the different heuristics score on these criteria. This will result in an intervention that proves best from these criteria and weights.

Appendix 3



This figure shows what the simulation model looks like. We split the layout in parts with distinct functions in the coloured blocks. The top left area is where the process happens in which we make and appointments and sent patients to the plaster rooms etc. The rest of the model controls this process or contains the necessary statistics. The bottom left contains all the “methods” which contain code. This code controls how we schedule and perform appointments. This is also where we model the various experiment interventions that concern the scheduling of appointments. The middle column contains the controls of how time influences the system reacts to the time. For instance, when the hospital closes and opens. To the bottom right of that, in the darker green block, we have the most important variables. To the right of that, are the statistics, which are of course important to see which intervention performs best. Above that, there are tables containing data to base probability distributions on that are the input for this model (e.g. amount of days between scheduling and performing an appointment coming in on a Monday).

The top left is the direct result of converting the conceptual model to a simulation model. The MUs (appointments) move around from event to event. In Oldenzaal there is a plaster room, an extra table and the possibility to go to another department. In Enschede there are two plaster rooms and the other departments that patients can go to. The other departments in Enschede and Oldenzaal are simplified to one object per location, as we explain in Section 5.3. The event that a specialist is needed happens in the plaster room itself and we model this in the model coding part (bottom left).

Appendix 4

Formulier gipskamer onderzoek

Gipskamer + sessie:
- □ Gipskamer 1, Enschede, Chirurgie
- □ Gipskamer 2, Enschede, Chirurgie
- □ Gipskamer 1, Enschede, Orthopedie
- □ Gipskamer 2, Enschede, Orthopedie
- □ Gipskamer 3
- □ Gipskamer 1, Oldenzaal
- □ Gipskamer Divers, Oldenzaal

Naam patiënt: …………………….

Datum afspraak: ……………………

Daadwerkelijke begintijd afspraak: …………………..

Daadwerkelijk eindtijd afspraak: ……………………

Is er een arts langs geweest? □ Ja □ Nee

Zo ja, Schatting verloren tijd door wachten op arts: ……………………… minuten

Afdeling raadgevende arts:
- □ Chirurgie
- □ Orthopedie
- □ WEC
- □ Kinderorthopedie
- □ Andere, namelijk: ……………………

Moest de patiënt tijdens de afspraak naar een andere afdeling en weer terug? □ Ja □ Nee

Zo ja, Schatting verloren tijd door wachten op patiënt: …………………… minuten

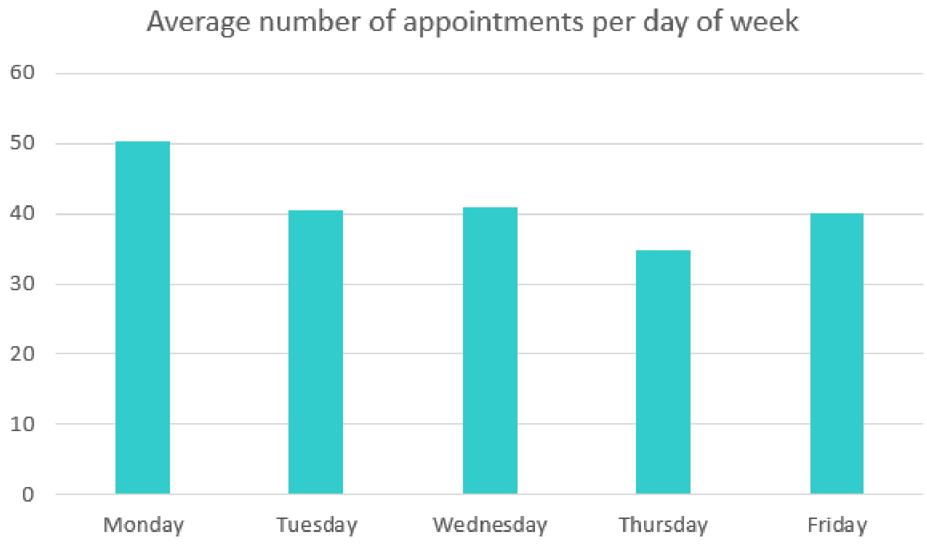
Is er in deze tijd een andere patiënt behandeld? □ Ja □ Nee

Afdeling waar patiënt heen moest:
- □ Radiologie
- □ Andere, namelijk: …………………….

Opmerking:
………
………
………

Appendix 5

Average number of appointments per day of week

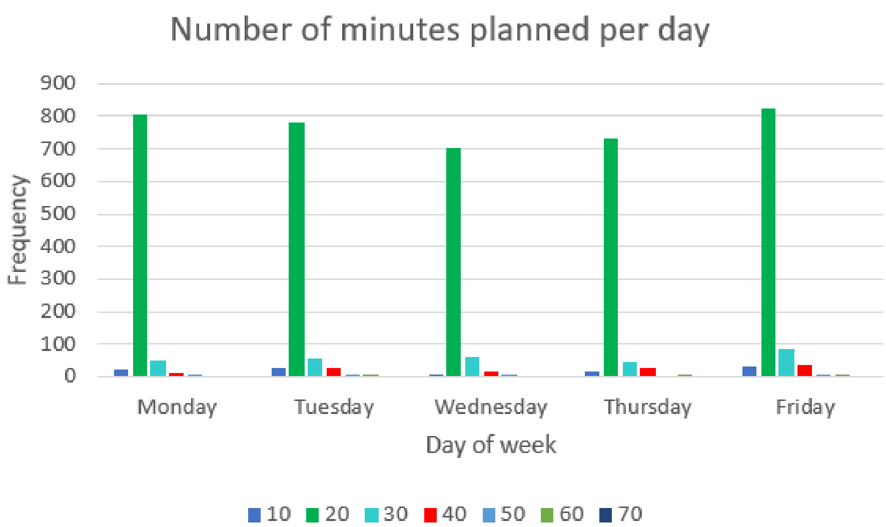


The distributions that we found are exponential distributions for Monday, Tuesday, Wednesday, Thursday and Friday with respective average inter-arrival times of 597.5, 772.5, 776.9, 882.4, 778.8. This means that the average time between scheduling of appointments is the lowest on Monday.

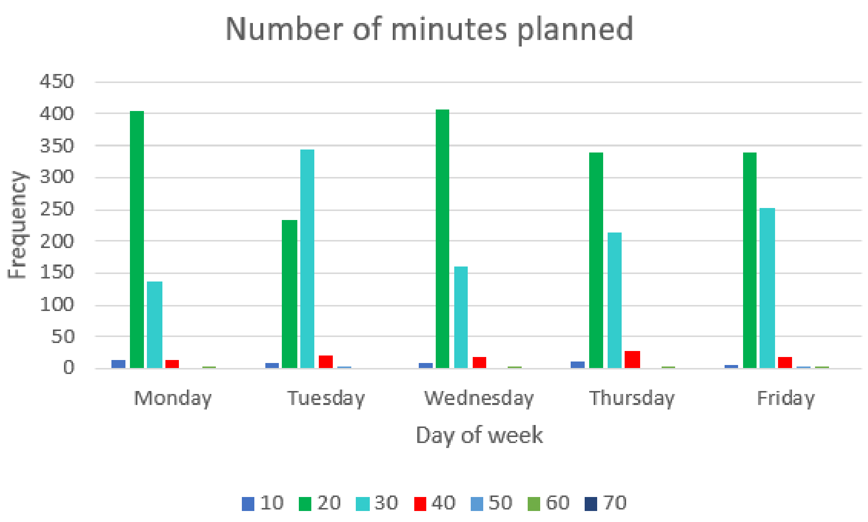
Number of minutes planned per day of week

The following figures show how often appointments of 10, 20, 30, 40, 50, 60 and 70 minutes are planned. The frequency of occurrences of the number of minutes planned for an appointment is our input for an empirical distribution. This means that the number of minutes planned for appointments will be picked based on how often it occurs in real life.

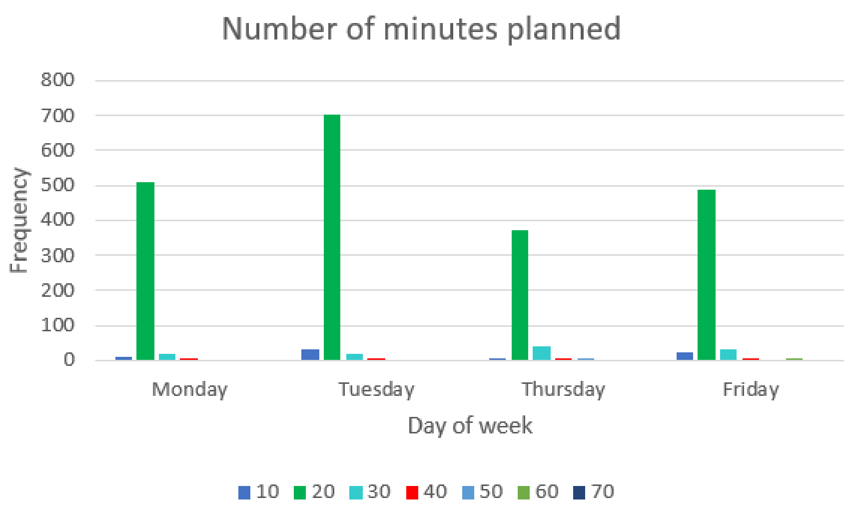
For surgical appointments in Enschede:



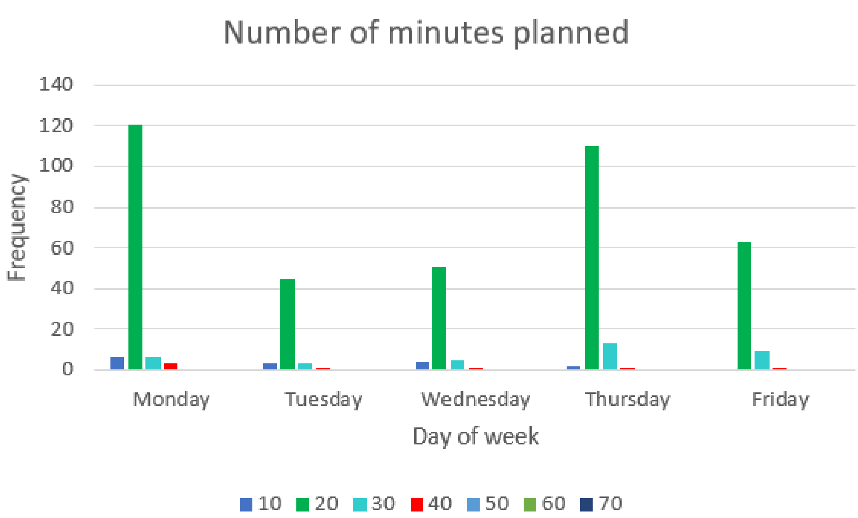
For orthopaedic appointments in Enschede:



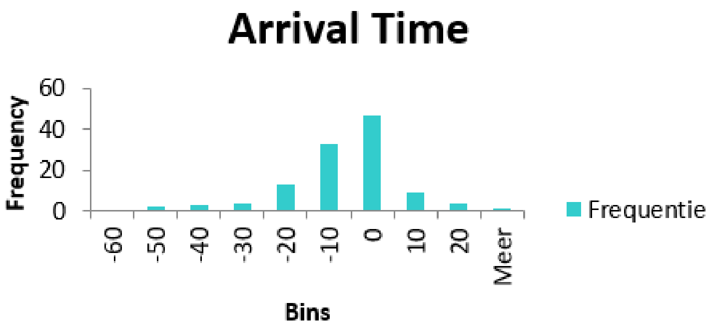
For surgical appointments in Oldenzaal:



For orthopaedic appointments in Oldenzaal:



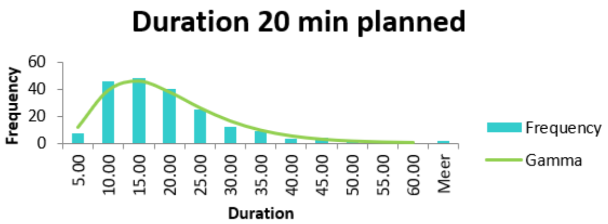
Number of minutes deviation between arrival time and start appointment

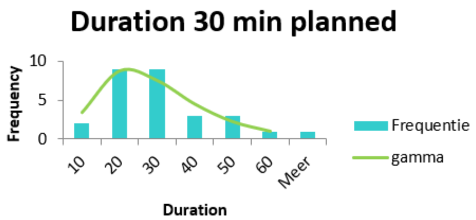


To describe how arrival times of patients are distributed we use an empirical distribution. This is a distribution based on the frequency of occurrences in historical data. The empirical distribution is used if the data does not seem to follow a statistical distribution.

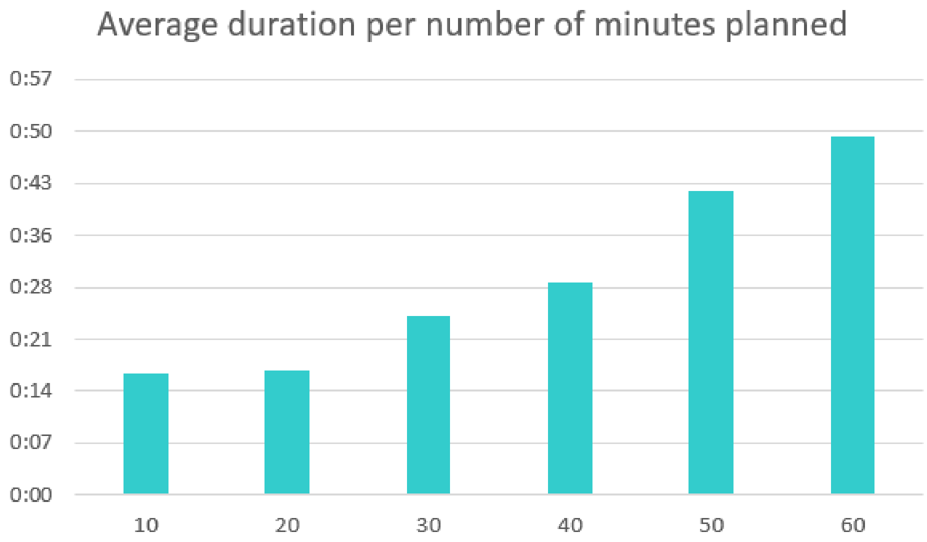
Average duration appointments based on the amount of time planned

The 20 and 30-minute appointments are the only appointments lengths that we have collected enough data for to be able to extract a distribution. For the 20 and 30-minute appointments, we see that they follow a gamma distribution with shape parameter (theta) of 3 (processing times often follow a gamma distribution). We therefore assume that all appointments are gamma distributed with shape parameter 3. The other parameter (k) is the average duration of the appointments (depending on how much time is planned for it) divided by theta. Below we see how the distribution of appointment durations follows a gamma distribution with theta of 3 and k of average duration/theta. We validate the distribution of the 20-minute appointments in Appendix 6.





We gathered enough data about 40-minute appointments to determine what the average duration of these appointments is, but not enough for the 50 and 60-minute appointments. The average durations of 50 and 60-minute appointments are estimated by adding the average duration of a 20-minute and a 30-minute appointment (for 50-minute appointments) and by adding the average duration of two 30-minute appointments (for 60-minute appointments) respectively. The following figure shows how much time appointments last on average based on how much time MST schedules for the appointment.



As you can see, the 10-minute appointments take longer than 10 minutes on average. The reason for this is that these appointments are most often used to fit a 20-minute appointment in the schedule without having to overbook. As a result, 10-minute appointments last 16 minutes on average, just one minute less than 20-minute appointments. The estimated average durations of 50-minute appointments is 42 minutes. For 60-minute appointments it is 49 minutes. Since these appointments rarely occur, this assumption does not have a substantial impact on our model. Also, because this assumption is used for the current intervention as well as for the experiment interventions, the changes in the model still have the same effect as when we would have had the exact distribution of the duration of these appointments. It is only proportionally slightly different for these few appointments.

Occurrence and additional time specialist and move to another department

	Average additional time appointment (seconds)
Specialist	**386**
Move	**1560**

	Occurrence/Total
Specialist needed	
10 min appointment	0.3445
20 min appointment	0.3445
30 min appointment	0.4643
40 min appointment	0.875
50 min appointment	0.875
60 min appointment	0.875
Move needed	0.1434

Appendix 6

The results of the chi-squared test can be seen in the figure below. The column bin contains values (in minutes) that define the bins from which we want to know how much of the appointments are in. The first bin value means 5 minutes or lower, the next between 10 and 5 minutes, after that between 10 and 15 minutes, etc. We then count the number of times that an appointment had a duration in these bins in the column frequency data. We also have a column in which we determine the amount of times appointments would be in the bins with a gamma distribution (expected frequency).

The chi-squared value is defined the following formula: $X^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}$. This means the sum of all frequencies in the data minus the expected frequencies squared divided by the expected frequencies. These values can be seen in the chi-squared column, but only for bins where the frequency is higher than 5 since a chi-square value is not reliable if there are only a few observations. The sum of these values is in the top green cell in the bottom right corner. If this value is equal to or higher than the critical value that we can get from the table of critical values with the right level of significance and degrees of freedom (number of bins used minus 1, so 6) for the chi-squared test. A study's defined significance level, α, is the probability of the study rejecting the null hypothesis, given that it were true (Dalgaard, 2008). The null hypothesis in our case is that the distribution fits the data and the significance level is α = 5% (typical for this type of research). The value from the table is 12.6 and 4.5 is lower than that so our distribution does fit the data with level of significance 5%.

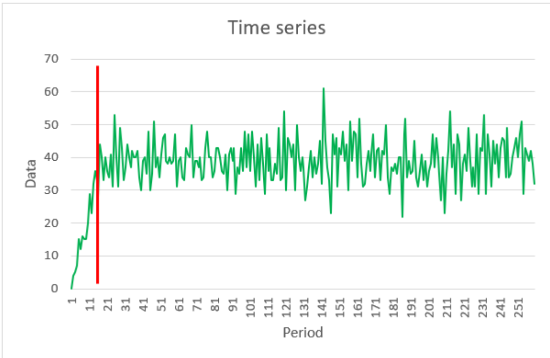
Bin	Gamma probability	Expected frequency	Frequency data	Chi-squared value
5.00	0.059187351	11.7190955	7	1.90030556
10.00	0.257308135	39.22791527	46	1.169094285
15.00	0.489623916	45.9985246	48	0.087087658
20.00	0.680924973	37.87760925	40	0.118923622
25.00	0.813307424	26.21172543	25	0.056016095
30.00	0.895922514	16.35778768	12	1.160934095
35.00	0.944067121	9.532632324	9	0.029760635
40.00	0.970789908	5.291111821	3	
45.00	0.985091976	2.831809453	4	
50.00	0.992533169	1.473356061	2	
55.00	0.99631834	0.749463897	0	
60.00	0.9982086	0.374271596	0	
			Sum chi-squared value	**4.522121951**
			Chi-squared test table value	**12.59158724**

Appendix 7

The warmup period is the period in which the output data is not valid because the model is not in its steady state yet (not yet warmed up). The reason for this in our model is that appointments come in and are scheduled for a number of days ahead. At the beginning of the year the schedule is empty though, so only after a certain number of days the model starts acting like it does in reality.

We determine this warmup period by using the MSER (Marginal Standard Error Rule). The figure below shows the process in excel. We want to know when the number of patients that are treated per day is realistic. In excel we note the number of treated patients per workday. We get 254 periods with corresponding number of treated patients. After that we make column in which we calculate the variance of the data set that is left if we leave out the data above that row so in the 10th cell in this column the variance of the data from cell 10 to 254 is calculated. The MSER value is then denoted by the next formula: $MSER(d) = \frac{1}{(m-d)^2}\sum_{i=d+1}^{m}\left(Y_i - \bar{Y}(m,d)\right)^2$. In this formula m is the total number of days (254), d is our warmup period length in days, Y_i is the number of treated patients on day i and $\bar{Y}(m, d)$ is the average number of patients per day from day d+1 till day 254. The day with the lowest MSER value is the best length for our warmup period according to this method. For our simulation the lowest MSER value is found on workday 12 which is day 18 in our model (weekend days added).

Period without weekends	Data	d (period in figure)	VAR	MSER		
2	0	0	70.82245322	0.277730806	min	0.167447
3	4	1	65.51931998	0.257946049	d*	12
4	5	2	61.25671885	0.242117606		
5	7	3	57.18935433	0.22693828		
6	15	4	53.56446078	0.213400812		
9	12	5	51.61287633	0.206448176		
10	16	6	49.03397031	0.196920374		
11	15	7	47.19612272	0.190303827		
12	15	8	45.14203503	0.182758255		
13	20	9	43.05357769	0.175011628		
16	29	10	41.79156627	0.170574956		
17	23	11	41.56007903	0.170325308		
18	32	12	40.69033238	0.167447068		
19	36	13	40.65320431	0.167985555		
20	33	14	40.78043803	0.169210498		
23	28	15	40.79518234	0.169976951		
24	44	16	40.45301221	0.169256477		
25	40	17	40.5228038	0.17026085		
26	33	18	40.68783649	0.171675553		
27	40	19	40.70003458	0.172454651		
30	36	20	40.86734658	0.173900427		
31	34	21	40.99708168	0.175197977		
32	41	22	41.05692657	0.176206711		
33	31	23	41.216942	0.177655903		
34	53	24	41.10629282	0.177945956		

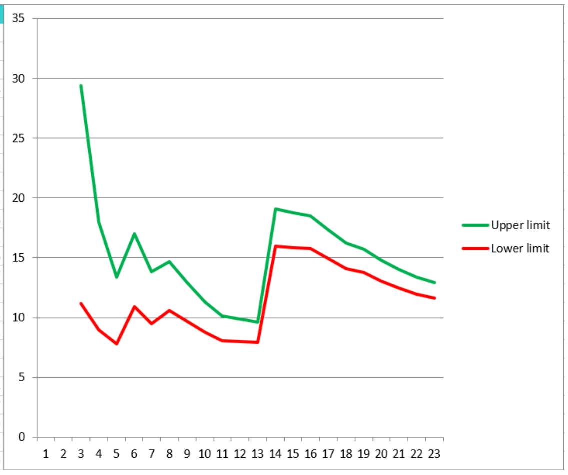


Appendix 8

We apply the confidence interval method to determine the number of replications needed for accurate results for our simulation study. A confidence interval is a statistical means for giving an estimated range within which the true mean average is expected to lie (Robinson, 2014). $\bar{X}_n \pm t_{n-1,1-\alpha/2}\sqrt{\frac{S_n^2}{n}}$ is the formula that gives us the lower and upper boundaries of a confidence interval (-t… for lower and +t… for upper). The $\bar{X}_n$ is the average number of overbooked appointments per day over n replications, S_n^2 is the variance over n replications, n is the number of replications over which we calculate the confidence interval, α is the level of significance and t stands for the "student's t-distribution" from which we calculate a value based on the variables that are in the subscript behind the t.

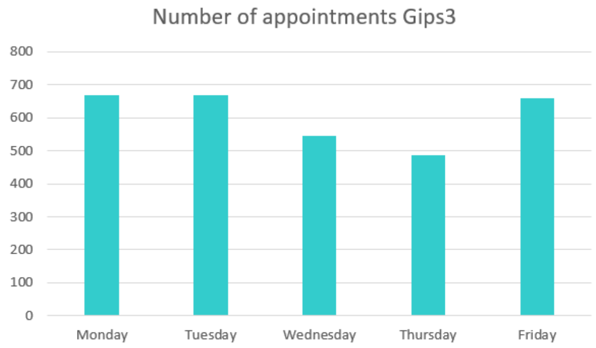
The confidence interval method calculates a confidence interval for each number of replications until the number of replications is enough to have a narrow enough confidence interval which based on our level of significance is a 95% confidence interval (typical in this type of research). What this looks like can be seen in the figure below. From left to right we have the number of replications n, the number of overbooked appointments in that replication, the mean number of overbooked appointments over all replications, the variance over all replications, the t value based on these variables and then the error between the lower and upper boundary of the confidence interval. This error is calculated with the formula $\frac{t_{n-1,1-\alpha/2}\sqrt{S_n^2/i}}{|\bar{X}_n|}$. The estimated upper boundary and lower boundary are in the last two columns. When the error is smaller than 5% (level of significance) the number of replications is enough. We see that at 12 this is the case but at 15 the confidence interval is not narrow enough anymore anymore so to be sure we took 18 replications since from that moment it steadily meets our requirements.

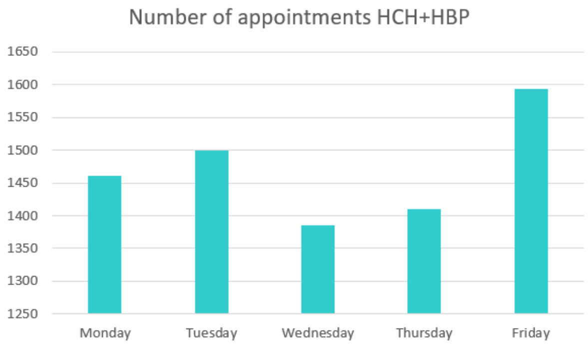
n	KPI	Mean	Var	Tvalue	Error	Test	Schatting1	Schatting2
1	481							
2	393	437	3872	12.7062	1.279343	NIET GENOEG		
3	463	445.6667	2161.333	4.302653	0.259135	NIET GENOEG		
4	453	447.5	1454.333	3.182446	0.135603	NIET GENOEG	29.42117682	11.15963558
5	470	452	1192	2.776445	0.094843	NIET GENOEG	17.99026495	8.965438171
6	432	448.6667	1020.267	2.570582	0.074712	NIET GENOEG	13.39642595	7.788220193
7	388	440	1376	2.446912	0.07797	NIET GENOEG	17.02196609	10.92157355
8	431	438.875	1189.554	2.364624	0.0657	NIET GENOEG	13.81295479	9.4901801
9	493	444.8889	1366.361	2.306004	0.063866	NIET GENOEG	14.68393755	10.60802435
10	429	443.3	1239.789	2.262157	0.05682	NIET GENOEG	12.91391183	9.694477595
11	452	444.0909	1122.691	2.228139	0.050688	NIET GENOEG	11.30474927	8.747593118
12	434	443.25	1029.114	2.200985	0.045984	GENOEG	10.14986029	8.048926812
13	477	445.8462	1030.974	2.178813	0.04352	GENOEG	9.848671556	7.96984636
14	416	443.7143	1015.297	2.160369	0.041463	GENOEG	9.627241806	7.924252167
15	577	452.6	2127.114	2.144787	0.056431	NIET GENOEG	19.10688665	15.95636121
16	503	455.75	2144.067	2.13145	0.054139	NIET GENOEG	18.75836729	15.86196782
17	507	458.7647	2164.566	2.119905	0.052142	NIET GENOEG	18.48773819	15.80385382
18	478	459.8333	2057.794	2.109816	0.049058	GENOEG	17.32806234	14.95454332
19	463	460	1944	2.100922	0.046198	GENOEG	16.22035903	14.11733535
20	431	458.55	1883.734	2.093024	0.044298	GENOEG	15.69837358	13.76633594
21	465	458.8571	1791.529	2.085963	0.041989	GENOEG	14.80955895	13.07497537
22	473	459.5	1715.31	2.079614	0.039963	GENOEG	14.0539	12.48370799
23	456	459.3478	1637.874	2.073873	0.038099	GENOEG	13.35430728	11.92804213
24	436	458.375	1589.375	2.068658	0.036726	GENOEG	12.94856835	11.62402849



Appendix 9

The figure on the left depicts the number of appointments per week day on the emergency table and the figure on the right shows the number of appointments per week day for plaster rooms 1 and 2 for surgical and orthopaedic appointments added together. We see that the less busy days are Wednesday and Thursday for both and that the plaster rooms 1 and 2 are really busy on Friday.





Appendix 10

We only take cities with more than 10 patients into consideration because otherwise it is just too much of an effort to determine the distance from the city to Enschede and Oldenzaal for all of them. If the third column says E, then the city centre of that city is closer to Enschede and if it is an O it is closer to Oldenzaal. We calculate the number of patients closer to Enschede and Oldenzaal in the 5th column and in the 7th portion we calculate the proportion of patients closer to Enschede and Oldenzaal.

Steden	Aantal	Dichterbij Enschede/Oldenzaal		
ENSCHEDE	2296	E	som E	2778
OLDENZAAL	593	O	som O	1393
HAAKSBERGEN	316	E	Proportion E	0.666027332
LOSSER	246	O	Proportion O	0.333972668
DENEKAMP	139	O		
HENGELO OV	103	E		
OVERDINKEL	76	O		
DE LUTTE	63	O		
OOTMARSUM	60	O		
ROSSUM OV	48	O		
WEERSELO	39	O		
NEEDE	33	E		
LATTROP-BREKLENKAMP	21	O		
BORNE	19	O		
ALMELO	19	O		
BEUNINGEN OV	18	O		
DEURNINGEN	15	O		
TILLIGTE	14	O		
REUTUM	13	O		
RIJSSEN	10	O		
EIBERGEN	10	E		
DELDEN	10	E		
BORCULO	10	E		

Appendix 11

Time to schedule for appointments according to treatment codes on the left (hours:minutes:seconds.) and frequency of occurrence on the right.

	time 1	real 2
string	Time	Frequency
1	10:00.0000	22.00
2	20:00.0000	16.00
3	30:00.0000	41.00
4	40:00.0000	4.00
5	50:00.0000	2.00
6	1:00:00.0000	2.00

Appendix 12

These tables contain the results of all experiments with statistics for each session. CH1 and CH2 are surgical appointments in plaster room 1 and 2 in Enschede. O1 and O2 are orthopaedic appointments in plaster room 1 and 2 in Enschede. CHOld means surgical appointments in Oldenzaal and OOld means orthopaedic appointments in Oldenzaal. From left to right we have the number of overbooked appointments in a year, the total amount of overtime in a year and the total waiting time for patients in a year.

Current situation

Session	Overbookings	Overtime	WaitingTime
CH1	60.89	39.97	199.20
CH2	59.67	39.12	197.70
CHOld	140.28	15.37	254.43
O1	93.11		196.10
O2	95.22		196.58
OOld	10.67		28.25

Instead of giving patients a certain day for their appointment, give them a range of days from which the secretary can decide which is best:

Session	Overbookings	Overtime	WaitingTime
CH1	7.83	26.52	157.03
CH2	7.44	26.98	155.75
CHOld	26.17	5.35	170.62
O1	20.28		125.55
O2	20.72		123.73
OOld	1.94		22.63

More orthopaedics appointments in Oldenzaal and better spread of appointments over Enschede and Oldenzaal:

Session	Overbookings	Overtime	WaitingTime
CH1	144.44	13.65	303.45
CH2	144.00	13.42	306.07
CHOld	95.06	14.28	182.17
O1	21.44		95.57
O2	20.61		92.45
OOld	38.61		80.65

Letting orthopaedic appointments and surgical appointments in Enschede be planned in the morning as well as in the afternoon (mix them):

Session	Overbookings	Overtime	WaitingTime
CH1	35.44	16.87	195.55
CH2	35.39	16.87	197.60
CHOld	134.61	14.90	258.25
O1	29.67		115.43
O2	30.56		117.28
OOld	10.22		27.68

Schedule appointments using the estimated treatment times according to the treatment codes of the treatments that the plaster technicians expect to perform:

Session	Overbookings	Overtime	WaitingTime
CH1	134.06	63.57	412.17
CH2	137.89	67.62	410.30
CHOld	278.89	36.60	514.55
O1	100.33		314.27
O2	102.56		324.87
OOld	26.44		56.03

Provide the plaster rooms in Enschede with a room where they can store a patient that is waiting for a specialist:

Session	Overbookings	Overtime	WaitingTime
CH1	60.89	22.22	95.05
CH2	59.67	22.97	91.10
CHOld	140.28	15.88	248.10
O1	93.11		107.22
O2	95.22		111.58
OOld	10.67		28.90

Split WEC appointments in two appointments where patient goes to specialist in between:

Session	Overbookings	Overtime	WaitingTime
CH1	58.61	39.77	175.53
CH2	57.17	15.37	177.33
CHOld	138.39	15.78	253.25
O1	89.06		194.78
O2	91.06		185.05
OOld	11.61		28.50

(Extra) More orthopaedics appointments in Oldenzaal and better spread of appointments over Enschede and Oldenzaal
+
Letting orthopaedic appointments and surgical appointments in Enschede be planned in the morning as well as in the afternoon (mix them):

Session	Overbookings	Overtime	WaitingTime
CH1	31.00	12.52	212.68
CH2	33.67	14.35	217.88
CHOld	93.50	13.50	190.67
O1	17.39		81.05
O2	17.94		89.48
OOld	37.28		80.57

Appendix 13

We perform a sensitivity analysis to find out what the best distribution of appointment over the locations is. Sensitivity analysis is the study of how the uncertainty in the output of a mathematical model or system (numerical or otherwise) can be apportioned to different sources of uncertainty in its inputs (Saltelli, 2002). The two input variables that we experiment with are the percentage of appointments that goes to Enschede and the percentage of appointments in Enschede that are Orthopaedic. From this, the percentage of appointments that goes to Oldenzaal and the percentage of appointments in Oldenzaal that is orthopaedic can be deducted, because the proportions of orthopaedic and surgical appointments are constant. For this sensitivity analysis we use a few less replications because the time it would take to do 18 replications for each experiment would be too long. We use 12 replications because in Appendix 8 we see that this is the first replication where the confidence interval is small enough. We use 18 replications in the rest of our research because at 15 replications there is an outlier that causes the confidence interval to be too wide and from 18 replications this no longer happens. To be sure to have valid results in our experiments we therefore chose to do 18 replications. However, since we now perform a sensitivity analysis with a lot of different experiments the accuracy is slightly less relevant.

The input values are the percentage of appointments that we schedule in Oldenzaal and the percentage of appointments in Enschede that is orthopaedic. We cannot perform separate sensitivity analyses for these input values because they are interdependent. The simulation model calculates the percentage of orthopaedic appointments in Oldenzaal by using our input values and the known proportion of orthopaedic/surgical appointments in total, which is 31.41% (as calculated from the historical data of 2017). The output values of this sensitivity analysis are our KPIs: number of overbooked appointments, waiting time and overtime, over a 1 year-period and averaged over 12 replications. The following table is the result of this sensitivity analysis.

	Input		Output		
	% Patients in Oldenzaal/Total	% Orthopaedic in Enschede	Total Number of Overbooked Appointments	Total Amount of Overtime (hours)	Total Amount of Waiting Time (hours)
Exp 01	0.25	0.3	721	42	1426.9
Exp 02	0.25	0.35	583.9166667	73.52	1258.333333
Exp 03	0.25	0.4	570.0833333	116.73	1217.833333
Exp 04	0.3	0.3	511.75	35.07	1157.7
Exp 05	0.3	0.35	440.25	56.27	1037.6
Exp 06	0.3	0.4	445.3333333	91.35	1077
Exp 07	0.35	0.3	478.5833333	35.98	1045.116667
Exp 08	0.35	0.35	418	54.73	990.8333333
Exp 09	0.35	0.4	434.6666667	85.13	1021.816667
Exp 10	0.4	0.3	529.25	45.98	1054.416667
Exp 11	0.4	0.35	497.6666667	56.93	1034
Exp 12	0.4	0.4	541.3333333	80.62	1077.533333

We see that the number of overbooked appointments is lowest when the percentage of patients in Oldenzaal/Total is between 35% and 30%, which seems logical since 2 of the 3 plaster rooms are in Enschede and 2/3 of the appointments in Enschede would seem to provide the best spread. The optimal percentage of orthopaedic and surgical appointments seems to be between 35% and 40% in Enschede. We also see that overtime is lower when there are less orthopaedic appointments in Enschede. This is because the orthopaedic session in Enschede is in the afternoon and therefore is the only session in Enschede that causes overtime. Also, in Oldenzaal all appointments can be planned over the entire day and this causes that it is often not necessary to schedule appointments in the last slots of the day. We now approximately know what the best proportions are, but we prefer to get a more accurate estimation than the 5% windows (e.g. between 35% and 40%) that we have now. Therefore, we perform another sensitivity analysis that is more accurate by taking steps of 1%. To limit the number of experiments that we have to run we choose to take input values 32%, 33%, 34% for the percentage of appointments in Oldenzaal as part of the total number of appointments. We do this because we already suspect that the optimal percentage is around 33%, since Oldenzaal has 1 of a total of 3 plaster rooms (for elective appointments). As input values for the percentage of orthopaedic appointments in Enschede as part of the total number of appointments in Enschede we use 31%, 32%, 33% and 34%. This means we have a total of 3 * 4 = 12 experiments, which are all replicated 12 times. The result is the following table.

	Input		Output		
	% Patients in Oldenzaal/Total	% Orthopaedic in Enschede	Total Number of Overbooked Appointments	Total Amount of Overtime (hours)	Total Amount of Waiting Time (hours)
Exp 01	0.32	0.31	475.9166667	37.83	45:09:50:14.9120
Exp 02	0.32	0.32	454.4166667	43.38	44:08:04:25.8767
Exp 03	0.32	0.33	440.1666667	48.55	44:12:22:02.7001
Exp 04	0.32	0.34	414.75	54.05	43:12:37:42.2658
Exp 05	0.33	0.31	466.75	41.03	43:21:10:42.8555
Exp 06	0.33	0.32	443.6666667	40.87	43:03:24:25.9584
Exp 07	0.33	0.33	434	47.48	42:12:50:36.7165
Exp 08	0.33	0.34	418.75	51.65	42:12:47:54.2351
Exp 09	0.34	0.31	448.8333333	41.42	42:13:43:38.1293
Exp 10	0.34	0.32	436.9166667	44.85	42:18:22:32.4282
Exp 11	0.34	0.33	436.5	48.9	43:12:29:33.9438
Exp 12	0.34	0.34	426.4166667	52.2	43:01:41:56.6661

We see that the optimal percentage of appointments in Oldenzaal as part of the total number of appointments is 32%. The corresponding optimal percentage of orthopaedic appointments in Enschede as part of the total number of appointments in Enschede is 34%. Considering these findings and the fact that 31.41% of the total number of appointments is orthopaedic, we can calculate the percentage of orthopaedic appointments in Oldenzaal with the following equation:

$HBP * H + OBP * O = BP.$

H is the percentage of appointments that we schedule in Enschede (Haaksbergerstraat), O is the percentage of appointments that we schedule in Oldenzaal and HBP and OBP are the corresponding percentages of number of orthopaedic appointments Enschede and Oldenzaal as part of the total number of appointments at those locations.

$H + O = 1$, so filling in the equation gives us $0.34 * (1 - 0.32) + OBP * 0.32 = 0.3141$. Solving this equation tells us OBP = 26%. We can conclude that the optimal values are O = 0.32, H = 0.68, HBP = 0.34, OBP = 0.26