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Integral process optimization of the plaster cast room at AMC

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MSc. Graduation Thesis

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MANAGEMENT SUMMARY

INTRODUCTION

This report describes the research of the plaster cast room in the outpatient clinic Orthopedics, Traumatology, and Plastic Surgery at Academic Medical Center, Amsterdam. The cast room annually treats 6,300 patients, which include both inpatients and outpatients. This research focuses on the improvement of the cast room process regarding the interaction between patient flow and capacity.

PROBLEM DESCRIPTION

The cast room has an unbalance in patient waiting time, quality of labor, and quality of care. Hereby, the workload during the week as well as during shifts is not balanced. In addition, the cast room capacity in terms of personnel is not constant as Orthopedic Cast Technicians (OCTS) encounter unscheduled unavailability during the day. The combination of peaks in workload and continuous changes in capacity result in patient waiting time. In addition, the quality of care decreases during busy periods as a result of disturbances during patient treatment. Hereby, quality of labor decreases as shifts both combine high peaks in workload and moments of idle time. The quality of labor further decreases as a result of overtime.

RESEARCH OBJECTIVE

The objective of the research is to design and evaluate several recommendations to improve the performance and service level of the current cast room performance as well as balance the OCT workload per shift. This research uses average patient waiting time and the average number of patients seen within 20 minutes of waiting as the service level measures.

RESEARCH APPROACH

First, this research provides a detailed context analysis of the current cast room process, its actors, and its performance according to the key performance indicators patient waiting time, utilization, and overtime. We connect the findings regarding the cast room performance to the literature and our practical insight of the situation. Hereby, we formulate several recommendations to improve the current situation. These recommendations vary in required commitment, dedication, and resources to improve the current situation. This research focuses on the recommendations regarding appointment planning, staff scheduling, and patient prioritization. We group our recommendations in three interventions:

- *Intervention 1: Less invasive improvement actions*

Intervention 1 combines recommendations regarding improvements in communication and behavior of both the OCTs as the DAs. The goal of intervention 1 is to decrease or remove delay in the cast room process. Hereby, we mean delay as a result of lack in communication between the OCTs and DAs, as well as timeliness of the OCTs at the start of shifts.

- *Intervention 2: Redesign of the agenda system and of the appointment scheduling*

Intervention 2 provides a redesign of the agenda system in combination with several rules of thumb regarding appointment scheduling to spread patients over a shift. Furthermore, we try to schedule patients around peak moments to stimulate the balance in workload during the entire shift. Hereby, the goal of intervention 2 is to balance the workload for OCTs throughout the shift. Intervention 2 also uses intervention 1.

- *Intervention 3: More invasive improvement actions*

Intervention 3 requires additional personnel resources and commitment compared to interventions 1 and 2. Hereby, the sub-interventions of intervention 3 include further alterations in the agenda system regarding the slot duration, improvement in communication regarding the lack in appointment scheduling of walk-in patients and same-day patients, reducing the percentage of no-shows and cancellations, and adjustments in the outpatient clinic capacity to further improve the performance of our interventions in the cast room. Intervention 3 also uses intervention 1 and 2.

RESULTS

We use a computer simulation model to analyze the current situation and evaluate our (sub)-interventions, extensions, and capacity evaluation. We determine a base situation as representation of the current situation. The service level of the base situation is 72.3% with an average patient waiting time of 18.3 minutes. Hereby, the average OCT overtime for the morning and afternoon equals 4.3 minutes and -7.6 minutes respectively. We compare our interventions with this base situation according to 95% confidence interval to evaluate if changes are significant.

Intervention 1 increases the service level to 77.7% with an average patient waiting time of 13.9 minutes. The OCT overtime remains 4.3 minutes overtime in the morning, and increases to -11.1 minutes undertime in the afternoon. Furthermore, we find that we decrease the patient waiting time at the start of shifts.

Intervention 2 increases the service level to 81.3% with an average patient waiting time of 11.4 minutes. The OCT undertime increases to 13.7 minutes overtime in the morning, and decreases to -0.6 minutes undertime in the afternoon.

The best case of Intervention 3 increases the service level to 95%, which is our target service level. However, this situation is hard to implement. The best case situation assumes the elimination of OCT unavailability, the extensive use of a DA to reduce or remove process delays and disturbances, and the spread of specialists' consulting hours. Hereby, the OCT overtime decreases to -6.7 minutes overtime in the morning, and to -46.3 minutes n the afternoon.

CONCLUSIONS & RECOMMENDATIONS

We find that the best case situation improves the service level to 95% and the average patient waiting time to 2.9 minutes. However, the best case situation is hard to implement, certainly on a short notice. Intervention 1 shows that we can improve the current situation with low invasive improvement actions with a reduction of 21% of the average patient waiting time. Furthermore, the adjustments regarding appointment scheduling contribute to the spread of workload for OCTs. We recommend to implement intervention 1 and 2 as soon as possible, as they do not require additional (financial) resources. Intervention 3 indicates the importance of controlling cast room capacity as well as reducing disturbances and variance during treatments. Hereby, we adjust capacity to deal with these occurrences (see Section 4.5.3). Those adjustments require additional financial resources. Therefore, we also recommend that the OCTs collaborate with the outpatient clinic stakeholders to adjust the current capacity levels so that no additional financial resources are required. Furthermore, the increase in coordination of external tasks around peak moments contributes to the desired performance as well.

PREFACE

This report describes my research of the plaster cast room of AMC hospital, Amsterdam. This research is the conclusion of my master *Production and logistics management (Industrial Engineering & Management)* at University of Twente, Enschede. During my research, I was part of the department Quality & Process Innovation (KPI) – Patient oriented Logistics.

Overall, I am satisfied with my research projects and its results. The project included many different stages, which kept the entire process interesting for me. However, throughout the project, it seems that all rumours about a graduation thesis are true, both in positive and less positive aspects. However, that is all in the past now!

This research resulted in several additional documents to this report. These include the detailed analysis report for the observation period, and the recommendations document. Hereby, I am especially satisfied to see that part of the recommendations, as described in this report, already is being implemented at the moment of writing.

To conclude, I thank the following people who were indispensable to my research:

- the Orthopedic Cast Technicians Anja, Bas, Francis, Frank, José, Michel, as well the outpatient clinic personnel. It is a pleasure to see how enthusiastic these people perform their work in and around the cast room every day. In addition, they are always eager to answer my questions and discuss process considerations.
- the cast room project group including Anja, Betty, Dicky, and Matthias. These people are the key stakeholders in the cast room process and provided me with value input and insight of the cast room process and its relation to the outpatient clinic Orthopedics, Traumatology, and Plastic Surgery.
- the KPI project group including Delphine, Nikky, and Paul. These people acted in several roles during our cast room collaboration. Their expertise and skills regarding both logistics as well as coping with the hospital culture and people is a major contribution to my research.
- my KPI colleagues. The ambiance in the KPI department was very pleasant, thanks to my KPI colleagues, who always allowed for amusement and variation to the tasks at hand.

Special gratitude is in place for the supervisors of this research project: Nikky Kortbeek and Erwin Hans. Nikky Kortbeek started this project in December 2008, and played a key role in my research project. We had several meetings to discuss the scope and aspects of the cast room leading to the results included in this report. Erwin Hans is my supervisor from University of Twente. His extensive experience regarding the application of operations research in hospitals is highly valuable. In addition, Erwin made sure that I continuously kept track of the end goal, a high level academic report.

To conclude, I am very proud to finish my master at University of Twente with this report and its findings. But this is not an end, nor is it a beginning, as I just passed another stop on the railway towards the future.

Siebe-Thijs Hoogwout
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CHAPTER 1 - INTRODUCTION

The orthopedic plaster cast room (cast room) of Academic Medical Center (AMC) in Amsterdam, The Netherlands, has an unbalance between supply and demand that results in increased patient waiting times and decreased quality of labor and quality of care. In this report, we describe our research in detail. This includes an in-depth overview of the current cast room performance followed by our research to identify and evaluate several organizational interventions in order to improve the current performance.

This chapter provides an introduction to the research topic. We start with a short context description of AMC (Section 1.1). Next, we formulate the problem description of the cast room (Section 1.2). To conclude, we present the research objectives and approach to reach the research objectives in this report (Section 1.3).

1.1 CONTEXT DESCRIPTION

AMC consists of the Academic Hospital and the Faculty of Medicine of the University of Amsterdam. The core activities of AMC are patient care, scientific education and scientific research (AMC, 2007).

AMC has three cast rooms, namely the cast room at the outpatient clinic Orthopedics, Traumatology and Plastic Surgery, the cast room at the Emergency department and the cast room at the Pediatric outpatient clinic. We focus our research on the first cast room. This cast room annually performs about 6,300 treatments.

The cast room treats mainly patients with bone fractures by placing a plaster cast around the broken bone. These patients visit the cast room for a check of the healing process as they already have a cast around their fracture. The first cast is given to a patient at the Emergency department or at an operating room. Furthermore, patients with weakened physical bone conditions visit the cast room. These patients receive a cast or corset as a support for their bone conditions. During treatment at the cast room, an Orthopedic Cast Technician (OCT) removes a patient's cast, after which in some cases a specialist inspects the healing process of the fracture or the bone conditions. Subsequently, the OCT treats the patient if the fracture has not healed yet or if the patient does not have to visit another AMC-department first. We provide a detailed process description in Section 2.1.

1.2 PROBLEM DESCRIPTION

The stakeholders in the cast room process experience an unbalance between cast room capacity and patient demand. The unbalance results in a decrease of both quality of care and quality of labor. Highly fluctuating workloads during both day and week lead to increasing patient waiting times and practitioner overtime. The fluctuating workload and overtime lead to a decrease in practitioner satisfaction and quality of labor, whereas fluctuating workload and waiting times both decrease the patient-centeredness and quality of care. Furthermore, high patient waiting times conflict with the maximum allowable waiting time per patient as stated in the AMC Patient Manifest. AMC has introduced the AMC Patient Manifest in 2009. That document states several duties for practitioners to fulfill in the patient care process. We quote the following statement about maximum allowable waiting time per patient:

"Your maximum waiting time before treatment is 20 minutes. When the consulting hours exceed regular hours, we will inform you about the reason and the expected delay. You will not go home without being treated."

First, the current performance shows a performance gap for the maximum allowable waiting time per patient: 74 % of all cast room patients is treated within 20 minutes of waiting time (Section 2.2).

Walk-in patients, patients without a prescheduled appointment at the cast room, represent a large and more unpredictable part of the total amount of patients (35 % of the total amount of cast room patients in 2008 (Section 2.2)). These patients contribute to an increase in waiting time for both walk-in patients as scheduled patients. This increase results in times that exceed the maximum allowable waiting time per patient of 20 minutes.

Second, the number of patients fluctuates during both week and day. In addition, capacity decreases as a result of arbitrary external treatments and meetings (Section 2.2). Together, these factors result in highly fluctuating workloads and overtime for the OCTs. Subsequently, OCT-satisfaction and patient friendliness decrease during workload peaks.

Finally, the process of scheduling patients lacks clear communication between patients, doctors' assistants (DAs), OCTs and specialists. For example, this could result in patients visiting the cast room with an appointment on their patient card while the appointment is not registered in the cast room schedule. In addition, a lack of organization in the outpatient clinic contributes to the lack in clear communication.

Based on these facts, we formulate the problem statement for the cast room:

"The cast room in AMC has an unbalance in supply and demand that results in increased patient waiting times and decreased quality of care and quality of labor."

1.3 RESEARCH OBJECTIVE & APPROACH

Given the problem statement, we derive the main research objective as follows:

"What organizational interventions for OCT capacity and appointment scheduling can we design and evaluate in optimizing the cast room performance"

In order to reach the main research objective, we answer the following research questions and investigative sub questions:

1. ***What is the current performance of the cast room process?***

   - *What are the actors in the cast room process?*

   We observe the cast room process to identify the actors and we interview both patients as cast room personnel. Due to a lack in availability of both historical and detailed data, we also use the observation to register detailed information about the actors in the cast room process. In addition to the observation period, we gather actor data from the hospital information system and cast room reports from the past. We analyze the gathered data to identify characteristics in order to group actors if necessary. Section 2.1 describes the main actors of the cast room process.

   - *What is the cast room process?*

   We observe the cast room process in detail during a four week observation period, we interview both patients as cast room personnel, and we use data from the hospital information system and cast room reports from the past. We combine the results to describe the cast room process. Section 2.2 provides a detailed description of the cast room process.

- *What are key performance indicators of the cast room process?*

We identify process key performance indicators from the literature and from our collaboration with the cast room stakeholders. We use these indicators to measure the current performance of the cast room process. Section 2.3.1 describes the key performance indicators.

- *What is the performance of the cast room process for the key performance indicators?*

During our observation period, we gather detailed information about the cast room process from difference sources. We combine and analyze the data to find scores for the key performance indicators and visualize the performance through graphs and tables. Section 2.3.3 summarizes the current performance of the cast room process for the key performance indicators as well as other interesting figures. The document *'Optimalisatie logistiek gipskamer: Analyserapport'* (2009) includes the detailed analysis of the current cast room performance.

Furthermore, we use a personnel questionnaire to identify strengths and potential improvement points of the cast room process. Section 2.3.3 includes the results of the personnel questionnaire.

- *What are bottlenecks in the current cast room process?*

We evaluate the results of our observation period to identify bottlenecks in the cast room process (Section 2.3.4). In addition, we formulate recommended approaches for these bottlenecks.

2. What organizational interventions can we develop to improve the current performance?

- *What topics relate to the cast room process and its problems?*

We link subjects from the literature to our process bottlenecks, and we choose the bottlenecks and subjects for further research (Section 2.3.4).

- *What concepts/theories can we find in the literature when searching with the key terms and topics?*

We use the literature subjects to find relevant concepts and theories. In Section 3.3, we discuss and summarize the literature that is related to the cast room process and bottlenecks.

- *What organizational interventions can we develop from the literature and the observation results?*

We connect our literature findings to the process bottlenecks to design recommendations. In addition, we organize a workshop with the cast room stakeholders to further identify possible recommendations. The report '*Verbeteracties* gipskamer' (2009) describes the recommendations. We group the recommendations in organizational interventions for evaluation (Section 4.5).

3. What is the performance of the organizational interventions?

- *What technique can we use to evaluate the organizational interventions?*

We describe the aspects of our problem to identify the most suitable tool to evaluate the organizational interventions (Section 3.4). We use the tool to build a model that represents the current situation and is able to evaluate the organizational interventions (Chapter 4).

- *What data do we need to build the evaluation model?*

We need detailed information about the cast room process, the patients, their treatments, capacity and a floor plan of the cast room. We use the data from the observation period and the data from the hospital information systems. We fit these data to probability distributions to estimate arrival times and process duration. We use these distributions as the input parameters for the model. Section 4.1 describes the conceptual model of our evaluation model according to the modeling framework of Robinson (2004). Section 4.2 describes the input parameters for the current situation. Section 4.5 describes the adjustments in input parameters to model the organizational interventions.

- *How do we know that the evaluation model is a good measurement tool?*

We need to build an evaluation model that satisfies the measurement criteria validity, reliability and practicality (Cooper, et al., 2008). In order to answer to these criteria, the model needs to represent the actual situation. We validate the model by imitating the observation period. Section 4.4 describes the verification and validation of our model.

- *What are the results of the study?*

We simulate the organizational interventions according to the adjustments in the input factors (see Section 4.5). Chapter 5 presents an analysis of the results based on the computational output from the simulation study. We evaluate the performance based on the key performance indicators.

4. ***How can we explain the findings from our study?***

We analyze and explain the results from the simulation study in Chapter 5. We describe and explain our expectations in combination with our actual findings. Hereby, we clarify both expected and unexpected findings.

5. ***How can we implement the organizational interventions to improve the current performance?***

Chapter 6 describes the steps to be taken to implement the organizational interventions and the possible implications during implementation.

CHAPTER 2 - CONTEXT ANALYSIS OF THE CURRENT SITUATION

Chapter 2 provides a context analysis of the current situation at the cast room. Section 2.1 briefly discusses the main actors in the process. Section 2.2 provides a detailed description of the cast room situation and its process. Section 2.3 describes the performance of the cast room based on key performance indicators. We conclude with a summary of our findings in Section 2.3.4 and narrow down our research on specific literature topics.

2.1 ACTORS IN THE CAST ROOM PROCESS

We identify the actors in the cast room process as patients, orthopedic cast technicians (OCTs), specialists and desk employees (receptionists/doctors' assistants).

2.1.1 PATIENTS

We distinguish eleven patient groups at the cast room. These groups are either inpatients or outpatients:

- Inpatients: patients whose care requires a stay in the hospital.
- Outpatients: a patient who is not an inpatient (not hospitalized) but instead is cared for elsewhere – as in a doctor's office, clinic, or day surgery center (Med09).

Furthermore, we find that these patient groups are scheduled, walk-in or same-day patients:

- Scheduled patients: patients with a pre-scheduled appointment.
- Same-day patients: patients request an appointment that is scheduled on the same day.
- Walk-in patients: patients without an appointment.

Table 2.1 displays the eleven patient groups based on the described characteristics.

Patient groups			Appointment characteristics
Inpatients	○	Post operative	Scheduled/Same-day
	○	Not post operative	Scheduled/Same-day
	○	Discharge	Same-day
Outpatients	○	Combination appointment	Scheduled
	○	Combination – ad hoc	Walk-in
	○	Cast problems	Scheduled/Same-day/Walk-in
	○	Cast replacement	Scheduled/Same-day/Walk-in
	○	Cast removal	Scheduled/Same-day/Walk-in
	○	Emergency – Subsequent appointment	Scheduled
	○	Emergency – ad hoc	Walk-in
	○	2^{nd} consults	Walk-in

Table 2.1: Patient groups in the cast room process (Observation period 2009, N=556)

For more information about these patient groups, please refer to Appendix A.

2.1.2 ORTHOPEDIC CAST TECHNICIANS

The OCTs treat patients in the cast room. Patients are not bound to a specific OCT for treatment. The cast room currently has six OCTs (4,39 FTE) of which one is an OCT in training. The OCT in training cannot execute all treatments and he needs supervision of another OCT during most of his treatments. Table 2.2 shows the OCT availability during the week as planned for 2009.

OCT capacity per shift		Even weeks	Odd weeks
Monday	*a.m.*	4	4
	p.m.	3	3
Tuesday	*a.m.*	5	5
	p.m.	4	5
Wednesday	*a.m.*	3	3
	p.m.	3	3
Thursday	*a.m.*	5	5
	p.m.	5	5
Friday	*a.m.*	3	3
	p.m.	3	3

Table 2.2: OCT schedule for 2009 (consulting hours: 8:30-12:15 a.m. , 13:00-16:30 p.m.)

This schedule is based on past experiences and shows the number of OCTs present in the hospital during the week. However during the consulting hours, the OCTs encounter temporary decreases in actual cast room capacity, which Table 2.2 does not show. We distinguish two types of OCT unavailability:

- Scheduled OCT unavailability: Part of the temporary decrease in capacity is scheduled and known in advance:

    - Pediatric outpatient clinic: During certain shifts, at most two OCTs treat patients at the Pediatric outpatient clinic. Table 2.3 provides an indication of the schedule. It is possible that these OCTs return to the cast room before the end of a shift. This occurs when there are few patients at the Pediatric outpatient clinic.

Shift	OCT requirements
Monday a.m.	1
Tuesday p.m.	1
Wednesday a.m.	1
Wednesday p.m.	1
Thursday a.m.	2

Table 2.3: OCT requirements for the Pediatric outpatient clinic (2009)

    - External treatments: An OCT might be called in to perform an external treatment in the operating room, intensive care, or emergency room. The operating room schedule is known one week in advance. However, the exact time of treatment is not clear.

    - Meetings: The OCTs have a cast room meeting on each Tuesday and an outpatient clinic meeting on each Wednesday. These meetings start on 8:15 a.m. and take approximately 60 minutes. At least one OCT stays in the cast room to treat patients during these meetings.

- Unscheduled OCT unavailability: The remainder of temporary decreases in capacity is not scheduled and not known in advance:
  - Additional Pediatric outpatient clinic requirements: During busy hours at the Pediatric outpatient clinic, an additional OCT is called in to perform treatments.
  - External treatments: An OCT might be called in to perform an external treatment in the operating room, intensive care, or emergency room. Treatments at the Intensive Care and Emergency room are arbitrary. An OCT is called in when needed.

2.1.3 SPECIALISTS

Specialist with cast room patients are either from the department Orthopedics, Traumatology or Plastic Surgery. These departments use a two-week schedule for consulting hours. Table 2.4 shows the consulting hours of the specialists during the week. Appendix B includes the schedule of the specialist's consulting hours during the two-week cycle.

Department	a.m.	p.m.
Orthopedics	8:30-11:30	13:00-15:30
Traumatology	9:00-11:30	13:00-15:30
Plastic Surgery	9:00-11:30	13:00-15:30

Table 2.4: Consulting hours per specialist's department (2009)

Unlike the OCTs, each specialist sees patients that are only treated by this specialist. In most cases, specialists receive patients during consulting hours in their office. However, it is also possible that a specialist is called in to perform a patient check at the cast room. We describe this possibility in Section 2.2.

2.1.4 DESK EMPLOYEES

There are two desks related to the cast room process in the outpatient clinic, namely the yellow desk and the small desk (see figure 2.1, Section 2.2). At the yellow desk, receptionists welcome arriving patients and they handle several administrative tasks. At the small desk, doctors' assistants schedule appointments for patients and they perform several supporting tasks for the outpatient clinic (see Section 2.2).

2.2 DESCRIPTION OF THE CAST ROOM PROCESS

The cast room process can be described per actor. We focus on patient flow and OCT flow in our process description. Before describing the process, we describe the cast room floor plan. To conclude, we identify disturbances in the cast room process in Section 2.2.4 and we explain the current way of scheduling appointments in Section 2.2.5.

2.2.1 DESCRIPTION OF THE CAST ROOM FLOOR PLAN

Figure 2.1 displays the floor plan of the outpatient clinic. The cast room area include cast room 1, cast room 2, office, storage area and technical area as displayed in Figure 2.1. The area around the cast room represents mainly specialists' offices unless stated otherwise.

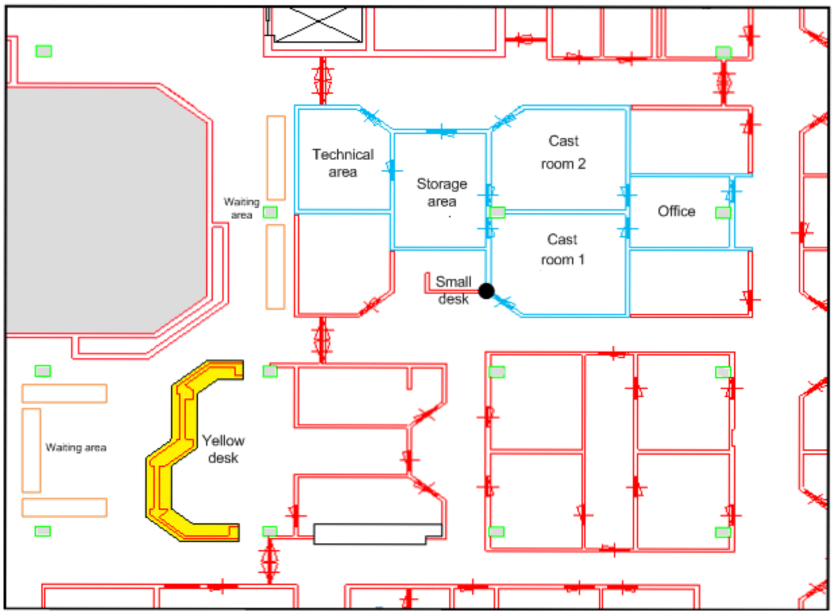

Figure 2.1: The cast room floor plan

The following places are of interest in the cast room process:

- *Cast room 1*: There are two beds for patient treatment. Inpatients are not treated in this room, because of space limitations.
- *Cast room 2:* There are two beds for patient treatment. Before an inpatient is treated in this room, the OCTs move the beds to the side of the room. Subsequently, the OCT moves the bed with the inpatient in between the two beds on the sides. During inpatient treatment, the other beds cannot be used for treatment.
- *Storage area:* The OCTs use the storage area to store equipment and materials for treatment.
- *Technical area:* The OCTs use the technical area for making (detachable) patient braces. Also, the OCTs use this area as a changing area at the beginning and end of the day.
- *Office area:* The office area has a computer to input patient records in the hospital information system after treatment. A telephone is present for scheduling walk-in patients or inpatients on the same day. Also, the OCTs use the office area for coffee breaks.
- *Yellow desk:* Patients who visit the outpatient clinic first indicate their presence at the yellow desk. Note that these are not only cast room patients.
- *Small desk:* DAs use the small desk to schedule future appointments for any outpatient clinic patient.
- *Waiting area:* Patients wait in the waiting area before treatment.
- *Patient appointment card box* (PAC-box) (displayed by the black dot between the small desk and cast room 1): This box contains the patient appointment cards (PACs) of patients waiting to visit the cast room. Note that PACs are only put in the PAC-box after patients have indicated their presence at the outpatient clinic.

We conclude that the maximum capacity of the cast room is either four outpatients, or two outpatients and one inpatient.

2.2.2 PATIENT FLOW PROCESS

We identify the main steps in the patient flow process as patient arrival, patient treatment, and patient departure. Figure 2.2 displays the patient flow process.

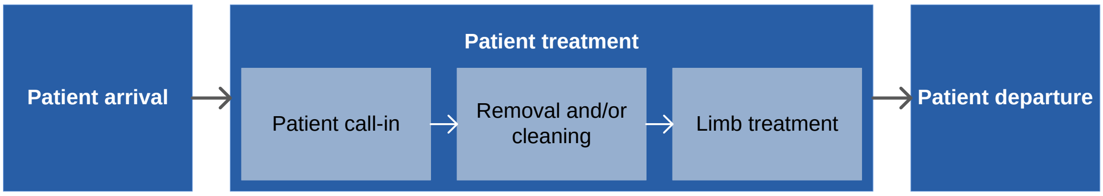

Figure 2.2: Patient flow process

PATIENT ARRIVAL

As described in Section 2.1.1, we identify the following groups for arriving patients:

Outpatients:

- *Scheduled/Same-day outpatient:* These patients visit the yellow desk to notify their presence by handing over their patient appointment card. A doctor's assistant puts this card in the PAC-box at the cast room according to a first come first serve principle.

- *Walk-in outpatient (cast replacement, cast problems, cast removal, emergency – subsequent appointment):* These patients visit the yellow desk to notify their presence by handing over their PAC. Next, a doctor's assistant puts the card in the PAC-box at the cast room according to a first come first serve principle.

- *Walk-in outpatient (combination – ad hoc):* Specialists refers these walk-in patients to the cast room. After a visit to the specialist, these referrals take place in the waiting area. The specialist puts the patient appointment card in the PAC-box at the cast room according to a first come first serve rule.

- *Walk-in outpatient (2nd consults):* When the patients are notified of the need to visit the cast room for a second time on a day, these 2nd consult patients come back to the small desk to indicate the need for a second consult and hand over their PAC. Next, a doctor's assistant puts the card in the PAC-box at the cast room according to a first come first serve principle.

Inpatients:

- *Scheduled inpatient:* These patients are brought to the cast room by an employee of the AMC patient transportation service. This employee notifies the OCTs when the inpatient is present outside the cast room.

- *Same-day inpatient:* When an inpatient requires cast room treatment, a doctor of the clinic calls to the cast room to check whether the OCTs have time to treat the inpatient. The OCTs determine when the inpatient can come to the cast room:

    - *Direct:* sometimes it is possible that capacity is available to treat an inpatient immediately at the cast room.
    - *Later:* in many occasions, the OCT schedules the treatment of the inpatient on a less busy moment later that day. It is also possible that the treatment is delayed to the next day.

In either of the two possibilities, the inpatient is brought to the cast room by an employee of the AMC patient transportation service. This employee notifies the OCTs when the inpatient is present outside the cast room.

PATIENT TREATMENT

The cast room has many different treatment types. We include a list of treatment types and their slot duration for appointments, as devised by the OCTs, in Appendix C. We identify three phases in the patient treatment process:

1) Patient call-in

For patient call-in, we identify two situations for any patient:

- *Outpatient:* The patient is called by an OCT and enters the cast room with the OCT.
- *Inpatient:* The patient is moved from the corridor into cast room 2 by the AMC patient transportation employee assisted by an OCT.

When the patient takes place on the bed in the cast room or when the bed with the inpatient is in position, it is time for the next treatment phase.

2) Removal and/or cleaning

For removal and/or cleaning, we identify the following possible situations:

- *Patient with a cast:* the cast is cut open after which the patient or the OCT cleans the limb.
- *Patient with a (detachable) brace:*
    - If a check of the healing process is needed, the brace is removed after which the patient or the OCT cleans the limb.
    - If a check of the brace is needed, it is either possible that the brace is removed or not.
- *Patient without a cast/brace:* the limb to be treated is freed from clothing.

3) Limb treatment

For limb treatment, we identify several possible situations. These situations are not mutually exclusive, i.e. combinations are possible:

- *Specialist's advice is required:* In this instance, it is not clear for the OCT what treatment is required. The OCT notifies the patient's specialist by placing the PAC in the specialist's appointment box. When the specialist arrives, the OCT and specialist together discuss the steps to be taken.
- *Placement of a cast, (detachable) brace or corset:* The OCT places a cast, brace or corset around the limb.
    - *Cast:* the patient is ready after cast placement
    - *(Detachable) brace:* the brace is a reworked cast. First, an OCT places a cast around the limb. Next, the OCT cuts open and removes the cast, after which the OCT reworks the cast into a brace in the technical area.
    - *Corset:* the corset is created by the orthopedic workshop and is brought to the cast room before treatment. During treatment, the OCT attaches the corset to the patient.
- *Check of the (detachable) brace*: the OCT checks the brace. If necessary, the OCT performs a rework of the brace.

- *No further treatment is required:* In this instance, the limb does not require further treatment in the cast room at this moment. It is possible that the patient returns to the cast room for a 2nd consult (Patient departure) after visiting the X-ray department, rehabilitation department or a specialist.

During a peak moment in terms of the total number of patients waiting for a cast room treatment, OCTs may decide to move patients waiting for advice from a specialist or patients waiting for a brace outside the cast room to free capacity.

PATIENT DEPARTURE

After treatment, the patient leaves the cast room. We identify four possible situations. Each patient is in either one of these situations:

- *The patient is finished at AMC:*
  - *Outpatient:* The patient receives a yellow appointment scheduling card. The yellow card contains information about the date and location (specialist/cast room/department) of the required appointment. The patient leaves the cast room and visits the small desk with the PAC and the yellow card to schedule a new appointment, after which the patient leaves AMC.
  - *Inpatient:* The OCT informs the AMC patient transportation service that the inpatient is ready to be moved back to the inpatient clinic. Next, the OCT moves the inpatient outside the cast room to the corridor to wait for an AMC patient transportation service employee.
- *The patient visits a specialist:* The patient will take place in the waiting room of the specialist, while the OCT puts the PAC in the specialist's appointment card box. It is possible that the specialist refers the patient back to the cast room for a second treatment.
- *The patient visits the X-ray department:* The patient regains his/her PAC and heads over to the X-ray department. After the X-ray process, it is possible that the patient requires additional treatment at the cast room. In this instance, the patient heads back to the cast room.
- *The patients visits the rehabilitation department:* The patient regains his/her PAC and heads over to the rehabilitation department. It is possible that the patient is referred back to the cast room for additional treatment. In this instance, the patients heads back to the cast room.

2.2.3 ORTHOPEDIC CAST TECHNICIAN FLOW PROCESS

We identify the steps in the OCT flow process related to patient treatment as patient call-in, patient treatment and treatment completion. If no patients are present in the waiting room during consulting hours, OCTs either perform administrative tasks, clean the cast rooms, or they resupply the cast materials in the cast rooms. A doctor's assistant knocks on the door to notify that a patient is waiting for treatment. Figure 2.3 displays the OCT flow process for patient treatment.

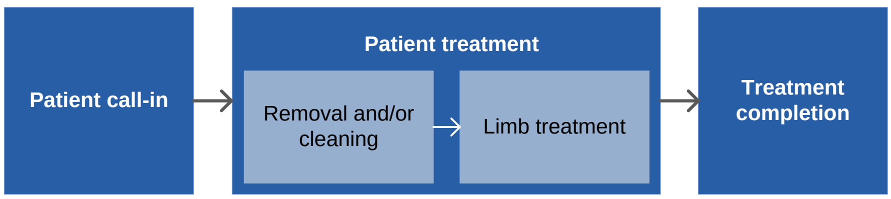

Figure 2.3: OCT flow process

PATIENT CALL-IN

- *Outpatient:* the OCT takes the first appointment card from the appointment box. Next, the OCT checks the patient status. This is done by checking the hardcopy patient status or the digital patient status. Next, the OCT calls in the patient from the waiting area. In some cases, the OCT checks the patient status after calling in the patient in the cast room, just before starting treatment.
- *Inpatient:* the OCT moves the beds in cast room 2 to the sides of the room. Next, the OCT moves the inpatient in between the beds in the cast room, after which the OCT checks the patient status.

PATIENT TREATMENT

See description of patient treatment at 2.2.2, starting at removal and/or cleaning.

TREATMENT COMPLETION

After patient treatment, three possible situations can take place::

- *The patient is ready:*
  - *Outpatient*: the OCT fills in the yellow appointment schedule card and returns the PAC with the yellow card to the patient and gives some additional information.
  - *Inpatient:* The OCT informs the AMC patient transportation service that the inpatient is ready to be moved back to the inpatient clinic. Next, the OCT moves the inpatient outside the cast room in the corridor next to cast room 2.
- *The OCT refers the patient to a specialist:* the OCT gives the patient some additional information and sends the patient to the specialist waiting room, after which the OCT puts the PAC in the appointment card box of the specialist.
- *The OCT refers the patient to the X-ray or rehabilitation department:* the OCT returns the PAC to the patient and gives some additional information.

When the patient leaves the cast room, the OCT cleans the used bed and fills in a patient registration form. This form has to be put directly in the hospital information system. However in practice, this registration mostly takes place during idle time or after consulting hours.

2.2.4 DISTURBANCES IN THE CAST ROOM PROCESS

Patient treatment is not without disturbances. We identify the following possible disturbances during patient treatment:

- *Telephone calls:* the cast room receives several telephone calls during the day. Either outpatients or clinic personnel (for inpatients) use these telephone calls to check whether the OCTs have capacity available to treat another patient on that day. In some cases, OCTs have to call back later, because it is not clear yet whether capacity is available.
- *Questions by a third party:* it is possible that either a doctor's assistant, specialist, OCT or even a patient disturbs a treatment in the cast room with questions. The OCT tries to answer these questions as fast as possible, keeping delay to the minimum.
- *Specialist waiting time:* in some cases, the OCT requires the advice of the patient's specialist. In this instance, the OCT puts the PAC in the specialist's appointment box. From this moment, the patient waits for the specialist to arrive, keeping the bed occupied. As the specialist is treating another patient

at that time, this takes some time. The OCT uses this time to perform administrative tasks, clean the cast room, resupply cast materials or even treat another patient if a cast room bed is available, until the specialist arrives.

2.2.5 APPOINTMENT SCHEDULING IN THE CAST ROOM PROCESS

The cast room uses two agendas for scheduling patients, namely agenda 1 and agenda 2. When an agenda is open, the slots of the agenda allow for appointment scheduling. The cast room scheduling system uses treatment slots of 15 minutes. When the expected treatment time is longer than 15 minutes, the system combines multiple slots in order to fit the expected duration. During any slot, the system schedules only one patient in Agenda 2. However as we will explain later on in this section, Agenda 1 does allow for overbooking, thus scheduling an additional patient in a slot. Table 2.5 displays the available time intervals for scheduling patients in either agenda 1 or 2. The times are based on patient numbers during the week in combination of the number of OCTs present.

Cast room agendas		Agenda 1	Agenda 2
Monday	*a.m.*	08:30-12:00	08:30-11:00
	p.m.	13:00-16:00	13:00-15:00
Tuesday	*a.m.*	08:30-12:00	09:00-12:00
	p.m.	13:00-16:00	13:00-15:00
Wednesday	*a.m.*	09:00-12:00	-
	p.m.	13:00-16:00	-
Thursday	*a.m.*	08:30-12:00	08:30-12:00
	p.m.	13:00-16:00	13:00-15:00
Friday	*a.m.*	08:30-12:00	-
	p.m.	13:00-16:00	-

Table 2.5: Available time intervals for scheduling appointments in cast room agendas (Quickscan cast room 2009)

At the small desk, doctor's assistants (DAs) schedule appointments for the cast room patients as well as other outpatients. After treatment, the patient hands over the yellow appointment card (see Section 2.2.2 – Patient treatment – Patient departure) to the doctor's assistant. The yellow appointment card contains the following information:

- *Required appointment location:* this field indicates the required appointment location. In case of a required visit to the cast room, the expected treatment type is filled in as well. This treatment type corresponds with a specific treatment duration. We include the list of cast room treatments in Appendix C.
- *Required visit information:* name of the specialist, doctor's assistant to visit (if applicable).
- *Required date to schedule:* this field indicates in how many weeks the next appointment should take place. According to possibly appointment requirements, the DA determines the allowed days for appointment during the specified week. If the card does not show specific requirements, the DA uses the patient's preference for a day during the specified week to find available agenda slots.

The doctor's assistant fills in the information in the scheduling system. Next, the system searches in agenda 1 and 2 for free treatment slots combining the listed information. In most cases, a patient needs a combination appointment with a specific specialist.

A combination appointment can only take place during shifts when the required specialist has consulting hours. Hereby, if for example a specialist has consulting hours between 9.00-11.30 AM of the morning shift, the system allows the combination appointment at the cast room to take place before 9.00 AM or after 11.30 AM if no other appointment slots are allowed. It is possible that the system does not find any available appointment slots given the listed information on the yellow appointment card (for either a combination appointment or not). In this instance, overbooking is used. As stated before, agenda 1 allows for overbooking. The doctor's assistant notifies the patient of the slot possibilities, after which the patient chooses the most preferred slot if more than one slot is available.

It is also possible that patients call to the small desk to schedule an appointment, for instance in case of cast problems. Then, the doctor's assistant asks for the required information. Subsequently, the doctor's assistant follows the process as described in this section.

2.3 PERFORMANCE OF THE CURRENT SITUATION

This paragraph presents the current performance of the cast room. First, we define key performance indicators (Section 2.3.1). Second, we outline the required data and data gathering method (Section 2.3.2). Third, we evaluate the cast room performance based on the key performance indicators according to the gathered data (Section 2.3.3). We include only a summary of the most important findings in this report, as we describe the current performance in detail in the report *'Optimalisatie logistiek gipskamer: Analyserapport'* (2009). For detailed insight in the current cast room performance, we refer to the analysis report. Finally, we summarize our findings in a problem summary to conclude this chapter (Section 2.3.4).

2.3.1 DEFINITION OF KEY PERFORMANCE INDICATORS

In order to measure the current performance of the cast room process, we need to identify key performance indicators. First, we define possible process indicators. Subsequently, we discuss these with cast room stakeholders to determine which indicators to use during our research. Table 2.6 shows the key performance indicators for our research. These performance indicators are in line with Cayirli et al. (2003), Klassen et al. (2004) and Hutzschenreuter (2004).

Measure	Definition
Patient waiting time (PWT)	*Scheduled/same-day patients:* Time between the cast room appointment time and the actual start time of appointment (in minutes per patient). When the patient arrives late for his appointment time, the waiting time is the time between arrival in the waiting area and start time of treatment. *Walk-in patients:* Time between arrival in the waiting area and start time of treatment (in minutes per patient)
OCT overtime (OOT)	Time between the end of the last treatment and the end of the consulting hours (in minutes per shift). We refer to negative overtime as undertime (underutilized time during a shift)
OCT utilization (UTIL)	Proportion of the actual available session length that OCTs treat patients*

Table 2.6: Key performance indicators

* We calculate the utilization by the ratio of demand over capacity. We calculate demand as the total duration of patient treatments in the cast room, either cast room 1 or 2 (thus exclude external treatments) minus the treatment duration during overtime and disturbances during treatment. We calculate capacity as the available OCT capacity in the cast room (thus exclude external capacity) during a shift (overtime not included).

In addition to the indicators of Table 2.6, cast room stakeholders mention quality of labor and quality of care as important performance indicators as well. Both quality of labor and quality of care are hard to quantify.

First, Lee et al. (2002) use workload as an important performance indicator for quality of labor. Workload depends on the balance between demand (the number of cast room patients) and supply (the number of available OCTs) during a shift. A peak in workload is a result of a high demand over supply ratio. If supply and demand balance, patient waiting time improves. In addition, we find that quality of labor increases if overtime decreases.

Second, the quality of care increases if a treatment is carried out with patience rather than rushing a treatment. This results in fewer or no mistakes in the process at all, and the patient experiences a higher quality of care as well. To be able to perform treatments with patience, OCTs should not experience any pressure during treatment. Pressure could increase as a result of a peak in workload. Also, disturbances during treatment could increase OCT pressure or impatience. Disturbances and peaks in workload both result in an increase of patient waiting time.

To conclude, we will not measure quality of labor nor quality of care, but we argue that both measures are positive correlated with the performance indicators patient waiting time and OCT overtime. In addition, we conclude that patient waiting time is the most important indicator in analyzing the performance of the current situation, as we link patient waiting time to both quality of labor and quality of care. Together with the cast room stakeholders, we set the following target for patient waiting time by which we use the AMC Patient Manifest (see Section 1.2):

"At least 95 % of all cast room patients is served within 20 minutes."

2.3.2 GATHERING DATA FOR PERFORMANCE ANALYSIS

In order to comment on the current performance of the cast room, we need data to measure our key performance indicators. AMC uses two information systems to store information: XCare and the Diagnosebehandelcombinatie-database (DBC). XCare is the agenda system of AMC. Every patient appointment is scheduled in XCare. DBC stores information about the actual treatments. Both systems lack in providing detailed process data. Key performance indicators are not stored in the current situation. Therefore, we cannot make use of relevant historical information other than the total number of treated patients per day. In order to evaluate the actual performance in the current situation, we gather detailed information through a four-week observation period.

During the observation period, we gather information about cast room patients, treatments and capacity through three forms:

- *Patient waiting time form:* this form registers patient waiting time, the reason to visit and patient origin.
- *Patient treatment form:* this forms registers treatment type, duration of treatment phases and possible disturbances.
- *Cast room capacity form:* this form registers information about the OCT presence during the day, their times and reasons for unavailability, OCT overtime and both incoming as outgoing telephone calls.

The report *'Optimalisatie logistiek gipskamer: Analyserapport'* (2009) includes the observation period forms. The following section describes the results of the observation period.

2.3.3 CURRENT CAST ROOM PERFORMANCE

This section summarizes the current cast room performance based on the results from our four-week observation period. For the detailed analysis report, we refer to the document *'Optimalisatie logistiek gipskamer: Analyserapport'* (2009). This document contains the cast room performance evaluation and recommendations to improve the current performance. Please note that this document also contains the observation period forms.

We start with a description of patient supply followed by the cast room capacity. Subsequently, we discuss the results for the key performance indicators that follow from the interaction between supply and capacity. To conclude, we describe the results of the employee satisfaction questionnaire.

PATIENT SUPPLY

Patient groups

Table 2.7 shows the number of patients per patient group as a percentage of the total number of patients during the observation period. We find that at least 56% of all patients is related to an appointment with a specialist during the same day (Combination appointment + Combination – ad hoc). The percentage is at least 56%, because both cast replacement and cast removal usually require a combination appointment with a specialist as well. Thus, we conclude that the specialists have a high impact on the number of patients visiting the cast room during a shift.

Patient groups		Percentage
Inpatients	○ Post operative	3%
	○ Not post operative	7%
	○ Discharge	1%
Outpatients	○ Combination appointment	40%
	○ Combination – ad hoc	16%
	○ Cast problems	4%
	○ Cast replacement	14%
	○ Cast removal	3%
	○ Emergency – Subsequent appointment	1%
	○ Emergency – ad hoc	0%
	○ 2nd consults	8%
	○ Unknown	2%
	Total	***100%***

Table 2.7: Realized percentages per patient group (Observation period 25 May – 19 June 2009, N=556 patients)

Patient numbers during the week

The number of patients per shift fluctuates during both day and week (see Figure 2.4). As indicated in the previous section, we find that most of the cast room patients also have an appointment with a specialist. As all patients have a fixed specialist, we conclude that certain specialists have a higher impact on the cast room than others. Thus, the schedule of specialist consulting hours directly influences the expected number of cast room patients on a certain shift. In addition, we find that during some shifts, the schedule for specialist consulting hours combines several specialists with a high impact on the cast room.

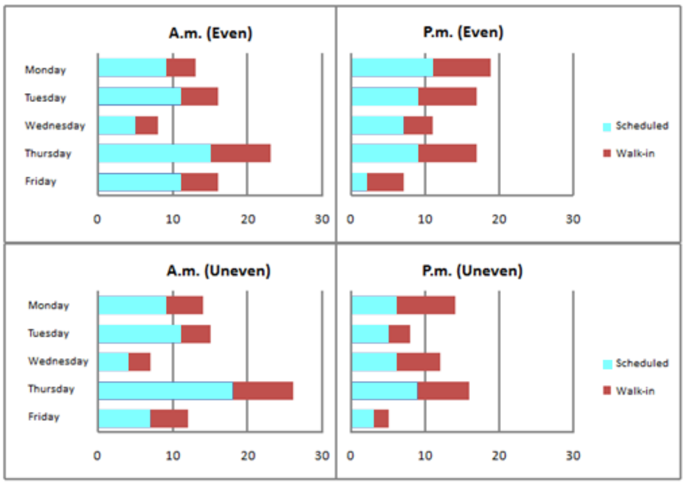

Figure 2.4: Average number of patients per shift (Observation period 25 May – 19 June 2009, N=556 patients)

Patient numbers during the day

We find that the number of patients during the day highly fluctuates as well. The number of patients (or patient minutes) during a day can be seen as OCT workload (see Figure 2.4). We find that one of the main peaks in patient minutes during a shift is at the start of a shift (either morning or afternoon). Remarkably, we find that the arrival of walk-in patients is variable but quite stationary, whereas scheduled patients show a more fluctuating pattern during the day. This is unexpected, because these patients can be balanced during a shift by appointment scheduling.

Patient characteristics

We find that only a small percentage of 4.5% of the patients shows up late for an appointment. 9.3% of the patients does not show up at all. We find that 80.6% of these no-show patients cancel their appointment during the day, or a specialist cancels the appointment for the patient. As the cast room stakeholders do not monitor the appointment system continuously, the cast room perceives these cancellations as no-shows. This also means that the cast room perceives same-day patients as walk-in patients (see Section 2.1).

Actual treatment duration of scheduled patients does not always correspond with the scheduled treatment duration (see Table 2.8). We find that the average treatment duration does not differ much from the scheduled duration (except for B30), however the standard deviation is quite high (see Table 2.8).

Appointment slot	Percentage	Average time (in minutes)	Standard deviation (in minutes)
B15	60%	0:15	0:14
B30	37%	0:21	0:15
B45	1%	0:44	0:26
B60	1%	1:08	0:30
B90	1%	1:40	n.a.

Table 2.8: Realized treatment duration for appointment slots (Observation period 25 May – 19 June 2009, N=302 patients)

Also, the duration of the available agenda slots is not sufficient to match any treatment, because the actual treatment duration is hard to estimate beforehand. In addition, we find that a lack of clear communication about the expected treatment type results in the mismatch between scheduled and realized treatment duration (see Table 2.8). For a detailed comparison between the patient groups per appointment slot, we refer to the analysis report.

CAPACITY

Realized capacity

The capacity of the cast room highly fluctuates during the day (see Figure 2.5). This is a result of arbitrary external treatments, meetings, and scheduled OCT presence at the Pediatric outpatient clinic. However, the realized presence at the Pediatric outpatient clinic differs from the scheduled presence, which often leads to a decrease in cast room capacity. Figure 2.3 shows the differences in scheduled and realized capacity. We refer to Table 2.3 for the Pediatric outpatient clinic schedule.

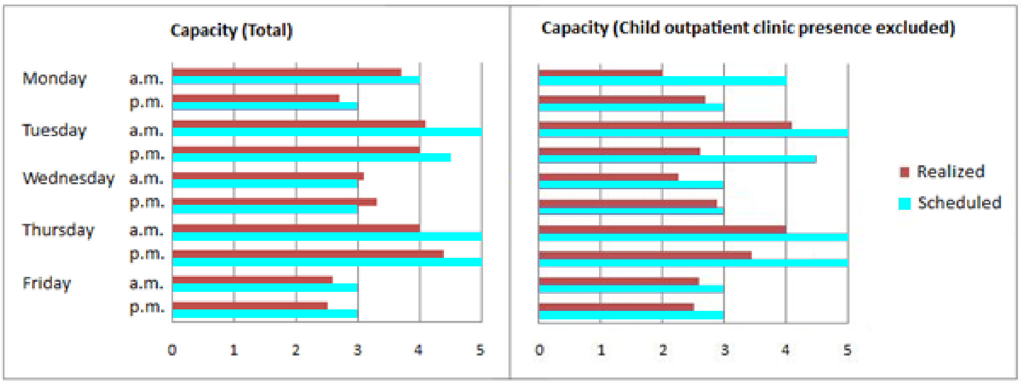

Figure 2.5: Cast room capacity (Observation period 25 May – 19 June 2009, N=19 days)

Starting time of consulting hours

We find that the starting times of a shift are on average 11 minutes later than planned. In the morning, the OCTs start too late with patient treatments although they are present on time. The delay in the afternoon results from overtime in the morning as well as starting too late with the lunch break by the OCTs. These delays have a negative impact on patient waiting time, as we analyzed that there is a peak in patients at the start of a shift. This means that the cast room starts with patient waiting time that increases during the shift.

Disturbances

We find that disturbances during treatment deteriorate the cast room performance, because disturbances result in a temporary decrease of capacity. OCTs deal with disturbances during treatment. This delays the treatment and increases patient waiting time. During the observation period, disturbances occurred in 10% of all treatments. Hereby, the average duration of delay caused by disturbances is 5 minutes (standard deviation is 7 minutes).

Capacity blocking

In some cases, the OCT consults with a specialist to determine the treatment procedure. As a specialist is not immediately available, this leads to internal waiting time for both patient and OCT. During the observation period, OCTs consult with a specialists in 11% of all treatments. Hereby, the average duration of internal waiting time is 10 minutes (standard deviation is 8 minutes). These internal waiting times block capacity.

Section 2.2.2 describes that the cast room allows for treatment of inpatients directly after the treatment request. The inpatients travels from the inpatient clinic to the cast room, which has an average transportation time of 25 minutes. However, we find that the standard deviation is 12 minutes. When the cast room expects an inpatient, the OCTs do not perform treatments in cast room 2. Therefore, the transportation time of inpatients can result in capacity blocking of uncertain duration. Please note that when an inpatient receives a scheduled appointment time, we find that the inpatient arrives on time for his appointment.

KEY PERFORMANCE INDICATORS

The key performance indicators patient waiting time, OCT overtime, OCT utilization, and spread of workload results from the interaction between patient supply and capacity.

Patient waiting time

We find that 74% of all cast room patients is seen within 20 minutes of waiting time. Hereby, the average waiting time is 17.06 minutes per patient. Further analysis shows that about 33% of all shifts during a week shows percentages equal or higher than 80%. Table 2.9 indicates the differences per shift.

% patients treated within 20 minutes of waiting time		Even	Odd
Monday	*a.m.*	77%	75%
	p.m.	69%	64%
Tuesday	*a.m.*	79%	89%
	p.m.	52%	83%
Wednesday	*a.m.*	69%	64%
	p.m.	85%	89%
Thursday	*a.m.*	72%	48%
	p.m.	75%	86%
Friday	*a.m.*	78%	87%
	p.m.	92%	70%

Table 2.9: Waiting time percentage per shift (Observation period 25 May – 19 June, N=556 patients)

The analysis of waiting time during the day indicates that a shift starts with a substantial amount of waiting time (see Figure 2.6). The waiting time increases during the shift and then slowly decreases towards the end of the shift. The amount of waiting time at the start of a shift is the result of the delay in starting time of the consulting hours. To conclude, we find that inpatients on average have a lower waiting time than outpatients. When an inpatient is expected, the OCTs try to reserve cast room 2 for inpatient treatment. This contributes to the difference in waiting time.

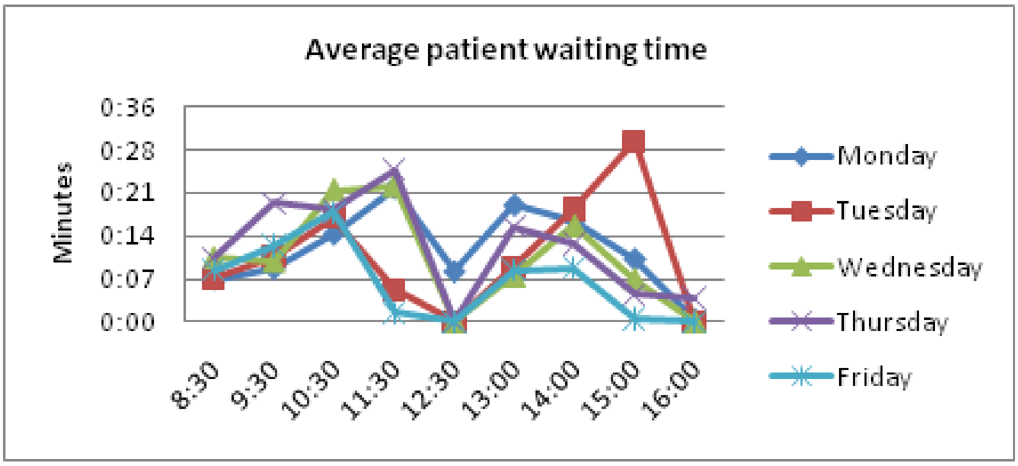

Figure 2.6: Average patient waiting time (Observation period 25 May – 19 June 2009, N=556 patients)

OCT overtime

Table 2.10 shows the OCT overtime (or undertime between brackets). The OCTs have overtime in the morning after busy morning shifts like Monday, Thursday and Friday. Overtime in the morning contributes to the delay in start time at the beginning of afternoon shifts.

The OCTs rarely encounter overtime in the afternoon. Instead, there is a lot of under-time. Overtime in the afternoon is calculated from 16.30h. However, agenda 1 and 2 allow appointments till 16.00h, which contributes to undertime if no walk-in patients are present or when treatments do not exceed their scheduled duration.

Average OCT overtime/(under-time) (in minutes)		Even	Odd
Monday	*a.m.*	0:53	0:13
	p.m.	(0:20)	0:00
Tuesday	*a.m.*	(0:13)	(0:13)
	p.m.	(0:35)	(0:57)
Wednesday	*a.m.*	(0:09)	0:06
	p.m.	(0:33)	(0:17)
Thursday	*a.m.*	0:13	0:21
	p.m.	(0:15)	(0:06)
Friday	*a.m.*	0:02	0:17
	p.m.	(1:04)	(1:06)

Table 2.10: Average overtime per shift (Observation period 25 May – 19 June 2009, N=556 patients)

OCT utilization

Table 2.11 shows the OCT utilization during the observation period. Analysis of the utilization of the OCTs shows very low levels during the week: 50% of the shifts has an utilization rate lower than 50%. However, in addition to patient treatment, the OCTs perform other tasks as well. Also, sometimes two OCTs perform one treatment. Both aspects are not included in the utilization ratio.

OCT utilization		Even	Odd
Monday	*a.m.*	71%	49%
	p.m.	70%	66%
Tuesday	*a.m.*	31%	41%
	p.m.	54%	61%
Wednesday	*a.m.*	63%	27%
	p.m.	45%	38%
Thursday	*a.m.*	54%	65%
	p.m.	50%	49%
Friday	*a.m.*	66%	49%
	p.m.	31%	29%

Table 2.11: OCT utilization per shift (Observation Period 25 May – 19 June 2009, N=556 patients)

Workload balance

We calculate the average workload per OCT by dividing the average number of patient minutes during an interval by the number of OCTs present. Figure 2.7 shows this spread of workload during the day.

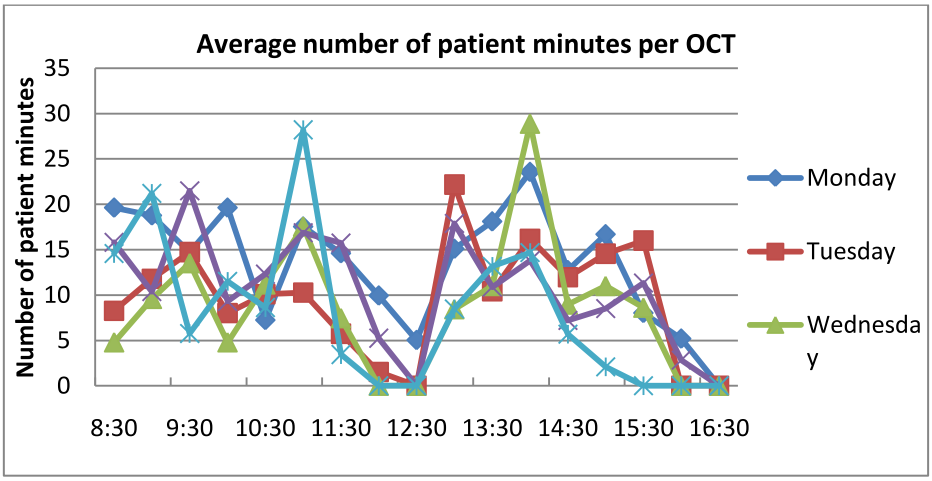

Figure 2.7: Average number of patient minutes per OCT (Observation period 25 May – 19 June 2009, N= 556 patients)

We find that the average workload highly varies and does not show a spread of workload during the day.

EMPLOYEE SATISFACTION

In order to maximize personnel commitment to our research and findings, we investigate the labor satisfaction related to the cast room process. We use an employee satisfaction form and ask participation of all actors in the cast room process to state strengths as well as improvement points in the cast room process. We include the employee satisfaction questionnaire in the analysis report.

We find that the employees identify the following strengths in the current cast room process:

- Task diversity (Treatments, patients)
- Atmosphere and colleagues
- Teamwork during the day
- Quality of care

The employees identify the following improvement points in the current cast room process:

- Unbalance in patient demand (Scheduling, communication)
- Lack of space in the cast room
- Lack of satisfactory IT facilities

2.3.4 PROBLEM SUMMARY

The summary of the data analysis in Section 2.3.4 supports our statement that the cast room has an unbalance in supply and demand that results in an increase of patient waiting times and a decrease of both quality of labor and quality of care. To conclude Chapter 2, we summarize the process bottlenecks and give recommended approaches in order to improve the current performance. In addition, we indicate the related literature subjects for further research. Table 2.12 provides an overview of these aspects.

Process aspect	Bottleneck	Recommended approach	Subject
Patient supply	The number of patients fluctuates through both week and days	Spread appointments (day fluctuation)	Appointment scheduling
		Spread specialists' impact (week fluctuation)	Staff scheduling
	Difference between scheduled and realized treatment duration	Improve estimation of treatment duration	Appointment scheduling
		Allow freedom in scheduled duration	
	Differences in punctuality between patient groups	Predict punctuality and both schedule and act accordingly	Appointment scheduling
	Communication related to patient supply is not optimal	Improve communication	n.a.
Capacity	Limited controllability of OCT presence	Development of base cast room schedule	Staff scheduling
	Limited cast room space	n.a.	Layout planning
	Delay in consulting hours' starting time	Start on time	n.a.
	Internal waiting time blocks capacity	Space requirements	Layout planning
	Inpatient transportation time blocks capacity	Predict inpatient treatment and schedule beforehand accordingly	Appointment scheduling
Synchronization	Arrival of walk-in and same-day patients is not anticipated accordingly	Predict arrival and reserve capacity accordingly	Appointment scheduling
Treatment of patients	Disturbances delay treatments	Doctor's assistant in the cast room	Staff scheduling
	Lack in treatment registration	Doctor's assistant in the cast room	Staff scheduling
	Communication for scheduling appointments is not optimal	Evaluate process of information exchange	
	Prioritizing of patients is not optimal	Prioritize patients according to longest waiting time	Patient prioritization
IT	Treatment characteristics and key performance indicators are not registered	Allow for user friendly registration system	IT
	System failures result in delay	Allow for user friendly registration system	IT

Table 2.12: Overview of problems and recommended approaches for current cast room process

We translate these solution approaches into specific recommendations to improve the current situation in the document 'Verbeteracties Gipskamer' (2009). Hereby, we define recommendations that are more practical and we connect these to short-term improvement actions. These are being implemented at the moment. Also, we define long-term recommendations that first require more research and evaluation. In the remainder of this report, we study the expected benefit of some of the short-term recommendations as well as the long-term recommendations. For these long-term recommendations, we focus our research on the bottlenecks for three main subjects regarding planning, namely appointment scheduling, patient prioritization, and staff scheduling. Thus, we exclude the grey shaded areas in table 2.12 from our research as a specific implementation project group at AMC performs the research and possible implementation of these recommendations.

Section 3.3 provides a discussion of the literature regarding the three topics as stated before. We use this literature in combination with practical insight from the observation period to describe improvement actions for the related bottlenecks. Subsequently, we study and evaluate the performance of these improvement actions compared to the current situation (see Chapters 4-7).

CHAPTER 3 - FORMULATION OF SOLUTION APPROACH

Chapter 3 presents the formulation of the solution approach to improve the cast room process. First, we present a framework for hospital planning and control (Section 3.1). Second, we translate the findings of Table 2.12 according to the framework for hospital planning and control into the formal problem description (Section 3.2). Third, we study the literature for the identified subjects for further research in Section 2.4. We combine the literature findings with the results from the process description (Chapter 2) to design organizational interventions (Section 3.3). Finally, we discuss the aspects of our problem and solution approach to find the most suitable tool for evaluation in our research (Section 3.4).

3.1 FRAMEWORK FOR HOSPITAL PLANNING AND CONTROL

Van Houdenhoven (2007) presents a framework for hospital planning and control. Figure 3.1 shows the framework.

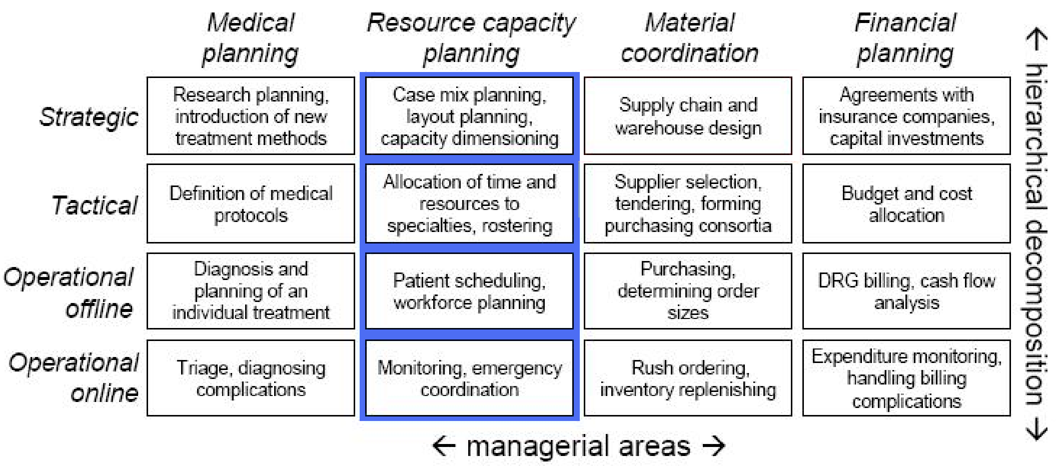

Figure 3.1: Framework for hospital planning and control (van Houdenhoven, 2007)

Van Houdenhoven (2007) defines four managerial areas in a hospital: medical planning involves the coordination and planning of medical activities, resource capacity planning involves the planning and control of health care resources, material coordination involves the coordination of hospital materials, and financial planning involves the coordination of financial aspects of the hospital processes.

We find that the content of our problem statement (Section 1.2) and the findings of Chapter 2 match the managerial area of resource capacity planning in the framework. Resource capacity planning deals with efficiently using the scarce resources of a hospital. These resources include people, tools and space requirements. The planning of capacity either involves the acquisition of additional resources or the allocation of existing resources (Smith-Daniels, et al., 1988). The framework provides four hierarchical levels for which we can derive organizational interventions: strategic decisions are made for the long term (1-5 years), tactical decisions are made for the medium term (months-years), and operational decisions are made for the short term (days-weeks). Offline decisions concern proactive scheduling of either staff or patients, whereas online decisions are reactive: how to respond to current events.

In the following paragraph, we connect the findings of Table 2.10 to the related managerial levels of the framework for hospital planning and control. Hereby, we define the formal problem description for each level.

3.2 FORMAL PROBLEM DESCRIPTION

Chapter 2 shows that the problem at stake in the cast room process relates to different managerial levels. We use the framework for hospital planning and control (Section 3.1) to distinguish the different aspects of the problem. Per managerial level, we specify the parameters and decision variables of the problem. In the remainder of this report, we define and evaluate organizational interventions and scenarios based on the decision variables. We include a glossary for the formal problem description terms in Appendix A.

Strategic problem description		Parameters	Decision variables	Time horizon
Jobs	Size of demand	-	-	5 years
Resources	OCTs Specialists Beds	-	# OCTs # beds # specialists	
Constraints	Capacity is feasible to perform OCT tasks.			
Objective	Minimize # OCTs.			
Tactical problem description		**Parameters**	**Decision variables**	**Time horizon**
Jobs	Demand per cycle	-	-	1 year
Resources	OCTs Specialists	Specialist impact None-specialist impact	Specialist schedule OCT schedule Shift duration Agenda schedule Capacity reserving Slot duration	
Constraints	Specialists have a required number of consulting hours per cycle. This is required to be scheduled. Specialists have various tasks, and thus preferences for when to have their consulting hours. OCT schedule satisfies OCT contractual agreements (Hours per cycle). # OCTs ≤ # beds Anticipate OCT unavailability due to illness.			
Objective	Match the number of OCTs per shift to the expected number of patients per shift.			
Operational offline problem description		**Parameters**	**Decision variables**	**Time horizon**
Jobs	Appointment requests	Patient type Treatment type Specialist requirements Treatment date	Appointment scheduling rule	Weeks
Resources	Agendas Specialists OCTs	Agenda schedule Slot duration Shift duration Specialist schedule OCT schedule	Appointment time Appointment duration	
Constraints	Schedule all appointment requests. Patient appointments only during specialist consulting hours if combination appointment required. Patient appointments only in free agenda slots (see Tactical decision variable).			
Objective	Level the workload during a two-week cycle.			

Operational online problem description		Parameters	Decision variables	Time horizon
Jobs	Same-day requests Walk-in patients Scheduled patients Additional tasks	Disturbance occurrence Specialist advice occurrence Punctuality / no-shows Arrival time	Patient priority rule	1 day
Resources	OCTs Beds Agenda	OCT schedule Agenda schedule Slot duration Shift duration Probability OCT unavailability DA presence (yes/no)	Appointment time Appointment duration (Same-day patients) Appointment scheduling rule	
Constraints	Inpatients cannot be treated in cast room 1. Maximum one inpatient can be treated at the same time. Treat all patients. Same-day appointments only in free agenda slots			
Objective	Minimize patient waiting time Minimize OCT overtime			

Table 3.1: Overview of the formal problem description

The Workplace Management (WPM) makes the decisions on strategic and tactical level together with the related personnel. On operational level, doctors' assistants make the decisions (scheduling of appointment requests, and patient prioritization). The following paragraph discusses the literature related to the bottlenecks and formal problem description. Subsequently, we present organizational interventions to improve the current situation for the tactical and operational level.

3.3 ORGANIZATIONAL INTERVENTIONS

Section 2.3.4 concludes with the bottlenecks in the current cast room process. We categorize the bottlenecks in subjects according to the literature, namely appointment scheduling, patient prioritization, and staff scheduling. In this paragraph, we describe the main findings in the literature for these subjects. We link our findings to organizational interventions for the bottlenecks in the cast room process. Also, we state organizational interventions that do not follow from the literature. These organizational interventions follow from the observation period and our own experience.

3.3.1 APPOINTMENT SCHEDULING

LITERATURE FINDINGS

Appointment scheduling focuses on setting a timetable to match patients with health care professionals. This involves rules or policies determining when appointments can be made (Jacobson, et al., 2006). Kaandorp et al. (2007) define the objective of appointment scheduling as trading off the interests of both physicians and patients. Whereas patients prefer a short waiting time, physicians prefer a minimum of idle time and they want to be finished on time.

Static appointment scheduling

Bailey (1952) describes consulting time and punctuality as the two main factors that affect the design of an appointment system. He recommends scheduling two present patients at the start of the consulting hours and then scheduling patients at intervals equal to the average consulting time. His purpose is to prevent excessive waiting times for patients. Rising et al. (1973) found that in order to improve patient throughput and patient waiting times, the smoothing in distribution of patient demand should be used. They show that an increase in the number of appointment slots in an outpatient clinic on those days that had the least number of walk-ins smoothed the demand on the physician. Their case uses variable-block rules with fixed intervals in one agenda, which is not the case in the cast room situation. However, we apply Rising's idea of increasing the number of appointments slots in an outpatient clinic during moments when a low number of walk-in patients is expected.

Hutzschenreuter (2005) uses simulation with one type of patients with fixed inter-arrival times to study various appointment scheduling rules, namely individual scheduling, Bailey-Welch, two-at-a-time, and proportional scheduling. Proportional scheduling uses patients with different average treatment times. For example, the appointment system first schedules patients according to 20 minutes intervals, while later on, the system schedules patient according to 30 minutes intervals. She found that if the variability of treatment time increases, the patient's waiting time increases and the practitioner's utilization decreases. From a physician's perspective, it is optimal to apply the Bailey rule. From the patients' perspective, individual appointments are preferable. Proportional scheduling is recommended if patients can be classified by expected treatment duration. Hutzschenreuter's experiments indicate that patients with a short expected treatment should be scheduled first in order to guarantee low waiting times for both patients and doctors. Hutzschenreuter (2005) recommends a combination of proportional scheduling with other appointment scheduling rules like Bailey's rule. Please note that Hutzschenreuter did not include walk-in patients in her research. Although Hutzschenreuter uses only one patient type, we apply her proposition to schedule patients with a short expected treatment duration at the first part of a shift.

Dynamic appointment scheduling

The cases of Bailey (1952) and Rising et al. (1973) evaluate static appointment scheduling. In reality, appointment scheduling is dynamic. This means that patient requests arrive dynamically over time rather than knowing exactly which and how many patients to schedule in a shift, like in static appointment scheduling. For each request, an appointment has to be determined immediately after the request has been stated. Klassen et al. (1996) and Klassen et al. (2004) conducted studies on dynamic appointment scheduling both for a single-period and a multi-period environment for a single-server system. They try to minimize the waiting time of patients in a situation that represents an on-going, multi-period scheduling environment where patients can be scheduled days or even weeks into the future. In their case, Klassen et al. found that the best scheduling rule was 'Low variance at the beginning' (LVBEG). LVBEG reserves the first half of the slots in any period for low variance clients and the second half for high variance. Hereby, potential delays in the start of the shift have a smaller impact than when patients with a high variance are present in the beginning of the shift. A second objective of their research involved the placement of slots left open for urgent clients or walk-ins. Klassen et al. (2004) show that spreading these slots evenly over the day yields the best results, in their case. Although Klassen et al. did not perform their research for several patients types, as is the case in the cast room situation, we apply their ideas of LVBEG and capacity reserving in our research.

Cayirli et al. (2003) describe an individual-block/variable-interval rule in which customers are scheduled individually at varying appointment intervals. Ho et al. (1992) use simulation to evaluate appointment rules with variable intervals. They find that increasing appointment intervals toward the latter part of the session improves performance the most. However according to Cayirli et al. (2003), recent analytical studies show that optimal appointment intervals exhibit a common pattern that initially increases toward the middle of the session and then decreases. Gupta et al. (2008) refers to this pattern as the dome shape. The goal of this dome shape is to counteract variability in the treatment duration. As the cast room has several patient types and high variability in the overall treatment duration, we apply the idea of dome shaped scheduling in our research.

Patient classification

Most studies tend to schedule patients on a first-call, first appointment basis. However, when patient classification is used, it would be more useful to schedule certain patient types in specific reserved slots. Cayirli et al. (2003) state that patient classification can be used for two purposes in outpatient scheduling. First, to sequence patients at the time of booking. Second, to adjust the appointment intervals based on the distinct service time characteristics of different patients classes. The use of patient classification requires a manageable number of groups and the possibility to schedule a certain patient to pre-marked slots.

Capacity reserving

Murray et al. (2003) outline a traditional model, a carve-out model and an advanced access model to cope with appointment demand. The traditional model tries to schedule urgent patients as soon as possible in a possibly saturated schedule. The carve-out model reserves time to meet urgent demand. The advantage is that urgent patients can be seen, however on most cases not by their personal physician, which threatens the continuity of care. The advanced access model tries to eliminate appointment delay. Hereby, patients that call for an appointment or walk-in patients can be seen at the same day. They conclude that the advanced access model helps to improve the allocation of supply to demand by making better predictions of both, and subsequently acting according these predications.

Planned slack

Walk-in patients might be compared to uncertain emergency patients at the general surgery operating room. Wullink et al. (2007) use simulation to evaluate different configurations in reserving capacity for emergency patients at the operating theatre. They find that reserving time at each operating room for emergency patients performs best for the process indicators waiting time, overtime and cost efficiency. Emergency patients are treated in the first available operating room. Although the operation rooms is a different situation, one might consider these emergency patients as walk-in patients in an outpatient clinic. We adopt the idea of reserving capacity for our organizational interventions.

Mismatch in consultation duration and the appointment slot length

Savin (2006) defines real-time delays as a result of a complex combination of general service inefficiency. Examples of these real-time delays include patient/provider lateness as well as the potential mismatch between the average consultation duration and the length of an appointment slot. Savin states specific recipes that aim at minimizing the impact of most real-time delay factors. However, these factors cannot be entirely avoided due to the random, unpredictable nature of primary care service duration. In addition, Savin states that demand for appointments cannot be accurately estimated using past appointment data. Instead, a clinic should record all appointment requests continuously in order to establish repetitive daily demand patterns. This could result in a decrease of the difference between scheduled and realized treatment duration. We adopt the idea of decreasing the mismatch in consultation duration and scheduled appointment length to design our organizational interventions.

ORGANIZATIONAL INTERVENTIONS

First, we recall the bottlenecks from Table 2.12 regarding appointment scheduling. Subsequently, we connect interventions from the literature to these bottlenecks. We describe the evaluation and possible implementation of these interventions in Chapters 4 to 6.

The number of patients fluctuates through the day

- Evaluate the use of LVBEG and/or dome-shaped scheduling to balance patients through the day.
- Schedule specific patient types on specific time slots.
- Schedule patients that do not require a combination appointment around peak moments.

Arrival of walk-in and same-day patients is not anticipated accordingly

- Reserve capacity for walk-in and same-day patients (both inpatients and outpatients).

Inpatient transportation time blocks capacity

- Improve communication between the inpatient clinic and the cast room.

Difference between scheduled and realized treatment duration

- Introduce agenda slot lengths that fit any treatment duration.
- Improve estimation of treatment duration.
- Improve communication between outpatient clinic personnel (and patients).

3.3.2 PATIENT PRIORITIZATION

LITERATURE FINDINGS

Health care professionals see patients according to their appointment time if an appointment schedule is in place. When different classes of patients arrive randomly, it might be worthwhile to select patients waiting for service according to their costs (Sickinger, et al., 2009). Hereby, they considered the problem for a radiology department and two identical servers evaluated under different outpatient appointment schedules. They propose that costs have to be assigned beforehand to a certain patient class. The idea is interesting for discharge inpatients. Furthermore, the concept of patient prioritization is able to stimulate the fairness of the patient treatment sequence.

Cayirli, et al. (2006) define the term sequencing rule for short time selection of patients waiting for service. Hereby they use patient and doctor-related measures to assess the ambulatory care performance and investigate the interactions among appointment system elements and patient characteristics. After testing six sequencing rules using two patient types, they find that the simpler rules generally perform better. These include altering the types in the schedule or starting with one type and finishing with the other type.

ORGANIZATIONAL INTERVENTIONS

First, we recall the bottleneck from Table 2.12 regarding patient prioritization. Subsequently, we connect interventions from the literature to this bottleneck. We describe the evaluation and possible implementation of these interventions in Chapters 4 to 6.

Prioritization of patients is not optimal

- Use a patient prioritization rule rather than ' first come first serve' to minimize patient waiting time and stimulate fairness in the patient treatment sequence.

3.3.3 STAFF SCHEDULING

LITERATURE FINDINGS

Any hospital requires a combination of both sufficient and highly skilled medical professionals to perform the care process. The tradeoff between insufficient staff to meet demand (hence unacceptable patient times) and underutilization of staff can have disastrous effects on the viability of a medical facility. Jun et al. (1999) conclude that staffing levels and staff distribution have a significant impact on patient throughput and patient waiting times.

Flexible staffing

Most discrete-event simulation studies are directed at patient scheduling. However, Jacobson et al. (2006) and Jun et al. (1999) identify a number of studies that address the reverse problem. Hereby, the focus is to schedule staff to satisfy patient demand given a collection of patients arrivals. They describe that walk-in clinics, which are unable to control the arrival rate of patients, must schedule their staff accordingly. In addition, Green et al. (2006) describe the case of an emergency room, which requires flexible staffing throughout an entire day. They use queuing theory to determine the required available capacity based on the expected arrival of emergency patients throughout the day. Several studies show that performance improvements are possible by optimization of the staff schedule without any increase in costs. Jacobson et al. (2006) conclude that when patient flow patterns cannot be controlled, staffing strategies can be employed to smooth some of the unavoidable variability in the systems. We apply the idea of adjusting capacity to the expected demand in our research.

Shift staffing decision

Warner (2006) discusses the shift staffing decision, in which the modeling requires to deal with uncertainty of both demand and supply in the near future (zero to eight days ahead). By using simulation, a patient projection is constructed for a certain period. This projection includes new admissions and no-shows. According to the projection, staff is scheduled to shifts. Brunner et al. (2009) also mention flexibility as an important aspect of staff scheduling. Flexibility is the ability to arbitrarily shift lengths, shift starting times, and break periods, and to accommodate individual preferences, requests and constraints. They find that as the length of shifts shorten, it becomes more difficult to find an optimal combination of shifts that covers patient supply without creating unnecessary overtime. Flexible starting times do not impact overtime by themselves, whereas the length of a shift plays a more vital role.

Unfortunately, we were not able to find any literature that discusses the impact of physicians on patient supply in the hospital. The impact is the number of patients during a certain shift as a result of the presence of a specific physician during that shift. Different physician schedules result in different numbers of total patients during a shift.

ORGANIZATIONAL INTERVENTIONS

First, we recall the bottlenecks from Table 2.12 regarding patient prioritization. Subsequently, we connect interventions from the literature to these bottlenecks. We describe the evaluation and possible implementation of these interventions in Chapters 4 to 6.

Limited controllability of OCT presence

- Cast room treatments require core staffing: Creation of a base OCT presence schedule for regular treatments and estimate additional OCT presence for external treatments.

Disturbances delay treatments

- Placement of a doctors' assistant in the cast room to support OCTs and take over several OCT tasks.

The number of patients fluctuates through the week (impact of specialists)

- Spread the expected total impact of specialists over the week.

3.4 DISCUSSION FOR EVALUATION TOOL

Section 3.3 describes several organizational interventions. It is not cost-effective to just implement all interventions without an indication of success. Therefore, we need a tool to evaluate the interventions before the actual implementation takes place. This section provides the discussion and choice for a tool to evaluate our organizational interventions. Law & Kelton (2000) propose to use either an analytical solution or a computer simulation model (simulation) to evaluate several interventions. Before we introduce these tools, we first outline the modelling characteristics of the cast room situation (Section 3.4.1). Subsequently, we evaluate the tools for these characteristics (Section 3.4.2) and choose the tool with the best allround fit to these characteristics (Section 3.4.3).

3.4.1 CAST ROOM CHARACTERISTICS

Complexity

Complexity is hard to define. Robinson (2004) distinguishes two forms of complexity:

- *Combinatorial complexity:* related to the number of components in the system and the possible combinations between those components.
- *Dynamic complexity:* arises from the interaction of components in a system over time (Sterman, 2000).

Chapter 2 and Section 3.2 show the various complex relationships both between managerial levels as within managerial levels in the cast room process. These relationships result in both combinatorial complexity and dynamic complexity with the various actors and their role in the outpatient clinic. The effects of this highly complexity make it difficult to predict the performance of the system.

Variability

Variability results from possible variations in the system. Robinson (2004) defines two main forms of variability, to which we add cast room examples:

- *Predictable variation:* for instance changes in capacity between shifts or scheduled OCT unavailability.
- *Unpredictable variation:* for instance the total number of patients per type/shift, different treatment types, the actual duration of treatment, or the occurrence of a disturbance, and so forth.

The examples indicate the high level of variability in the cast room process. Chapter 2 shows more examples of the variability of the cast room process.

3.4.2 DESCRIPTION OF EVALUATION TOOLS

ANALYTICAL SOLUTION

An analytical solution is a useful tool for the evaluation of a model with simple relationships to obtain an exact solution on questions of interest (Law & Kelton, 2000). An analytical solution is suitable for cases with low complexity and allows for variability in terms of arrival patterns as well as service durations. However, analytical solutions require restrictive assumptions to simplify the actual situation by means of steady state behavior, which is a limitation. An example of this steady behavior is that analytical solutions assume a fixed arrival rate for any day. In addition, analytical solutions do not improve transparency: a cast room stakeholder faced with a set of mathematical equations may struggle to understand, or believe, the results from the model (Robinson, 2004).

COMPUTER SIMULATION MODEL

A computer simulation model allows for experimentation with a simplified imitation of a system as it progresses through time (Robinson, 2004). Although simulation allows for a simplified imitation of system, it can be made as complex as required. There are no limitations on complexity whatsoever. Computer simulation allows for variability to be modeled in detail. Hereby, any distribution may be used to represent any detail of the system. The disadvantage of building a valid simulation model is that it is time consuming. In addition, a model requires a significant amount of data before the model is a valid representation of the real system.

3.4.3 CHOICE FOR AN EVALUATION TOOL

The cast room situation includes various levels of variability. Robinson (2004) states that if systems being modeled are subject to significant levels of variability, then simulation is often the only means for accurately predicting the performance. Hereby, he explains that an analytical solutions uses a static analysis. This means that variability is accounted for by using averages for the various process arrival times and durations. It is vital to model variability properly in order to predict the performance. Simulation allows to schedule the variability in detail. Briefly, we explained restrictive assumptions in the previous section. Simulation does not require many restrictive assumptions as any distribution can be selected, while an analytical solution may often assume particular distributions for arrival and service times. Furthermore, we find that an analytical solution has limitations for the cast room situation regarding complexity, while a computer simulation model does not have limitations regarding complexity nor variability. The limitations of transparency are not at stake when using simulation, because a simulation model is more intuitive and the animations improve the transparency. The limitation of data requirements are not at stake, because of the observation period at the cast room and the analysis of the observation data in Section 2.3.

Based on these facts in combination wit the cast room situation regarding complexity and variability, we find that a computer simulation model is the most appropriate evaluation tool. There are different types of computer simulation studies. To determine the best type of computer simulation study for our research, we use three dimensions as presented by Law & Kelton (2000).

1. *Static vs. Dynamic Simulation Models:* Static models represent a system at a particular time, or a system in which time simply plays no role. Dynamic models represent a system as it evolves over time. Patients arrive during the day during consulting hours. Furthermore, the number of patients differs per day as a result of the specialist consulting hours schedule and the agenda. We conclude that we require a dynamic simulation model rather than a static model.

2. *Deterministic vs. Stochastic Simulation Models:* Deterministic models do not contain any probabilistic or random components. The output of deterministic models is "determined" once the set of input quantities and relationships in the model have been specified. On the contrary, stochastic models must be modeled having at least some probabilistic input components. Therefore, the output is random itself and must be treated as only an estimate of the true characteristics of the model. We specified the level of variability in the cast room situation earlier in this section. Therefore, we conclude that we require a stochastic simulation model.

3. *Continuous vs. Discrete Simulation Models:* A computer simulation model is either continuous or discrete. A continuous model represents a system as it evolves over time in which the state variables change continuously with respect to time. Discrete-event simulation shows a system as it evolves over time by a representation in which the state variable change instantaneously by the occurrence of an event. An event is an instantaneous occurrence that may change the state of the system. Jun et al. (1999) indicate that discrete-event simulation can be used to forecast the impact of changes in patient flow, to examine resource needs, or to investigate complex relationships among the different model variables.

The cast room process does not evolve over time, but is altered by the occurrence of events. For example, the arrival of a patient, the completion of a treatment, or a disturbance all require the system to respond. Furthermore, our organizational interventions and solution aim to correspond with the aspects of discre-event simulation as indicated by Jun et al. (1999). Therefore, we conclude that we require discrete-event simulation (with both dynamic and stochastic characteristics) as the best tool to evaluate the organizational interventions for the cast room process.

Chapter 4 describes the steps of our simulation study. We use our computer simulation model to evaluate our organizational interventions in Chapter 5. Furthermore, Chapter 6 describes the organizational implementation of our interventions. Finally, Chapter 7 provides the conclusions and recommendations regarding the results of Chapter 5 and 6.

CHAPTER 4 - SIMULATION STUDY

This chapter describes the design and aspects of our simulation model of the cast room situation. Hereby, we use the structure of Robinson (2004) to actually construct our simulation model. The structure describes the following process steps of a simulation study:

1. *Conceptual design:* we define the scope of the model and its level of detail (Section 4.1).
2. *Data gathering:* we gather data of the cast room process (see Summary in Section 2.3) and fit probability distributions to the relevant aspects of the process (Section 4.2).
3. *Technical design:* we translate the conceptual design in a technical design before we can actually build the simulation model (Section 4.3).
4. *Build simulation model:* we build the simulation model using Siemens Plant Simulation 8.2 as simulation software.
5. *Verification and validation:* we verify our model by stakeholders meetings and we validate our model by imitating the observation period based on key performance indicators (Section 4.4).
6. *Experimentation:* We group recommendations for improvement of the current situation in several interventions (Section 4.5). Hereby, we specify any changes in input parameters or our model. Subsequently, we run these interventions in our model. We describe and explain our results in Chapter 5.

4.1 CONCEPTUAL DESIGN OF THE MODEL

First, we design a conceptual model before we actually build the simulation model. The model design impacts all aspects of the study and if well designed, the model significantly enhances the possibility that a simulation study will meet its objectives within the required time-scale (Robinson, 2004). The conceptual model is a non-software specific description of the simulation model that is to be developed, describing the objectives, inputs, outputs, content, assumptions and simplifications of the model (Robinson, 2006)**.** Please note that we present the specification of input parameters and data in Section 4.2.

4.1.1 OBJECTIVES OF THE SIMULATION MODEL

We formulate the following objectives of the cast room simulation model:

- The model describes and analyzes the process and patient flow for the cast room.
- The model is user-friendly, enabling users to easily run various interventions (sets of decision variables) and/or set decision variables within these interventions.
- The model measures output in terms of patient waiting time, the service level, resource utilization, and resource overtime.

4.1.2 CONTENTS OF THE SIMULATION MODEL

OVERVIEW OF THE MODEL

We require our model to be a clear representation of the cast room situation and its process steps. Therefore, the model closely follows the aspects described in Chapter 2. We translate these aspects into the process overview in Figure 4.1.

Patients arrive in three types, namely as walk-in patients without an appointment (1), as scheduled patients (2), or as same-day patients (3). Patients arrive and take place in the waiting area. If capacity is available, OCTs treat patients in the cast room. After treatment, patients may require a second consult, if not, the patient leaves the hospital. If the patient requires a second consult, this consults takes place only if an OCT is present in the cast room. If not, the patient receives a new appointment for the second consult.

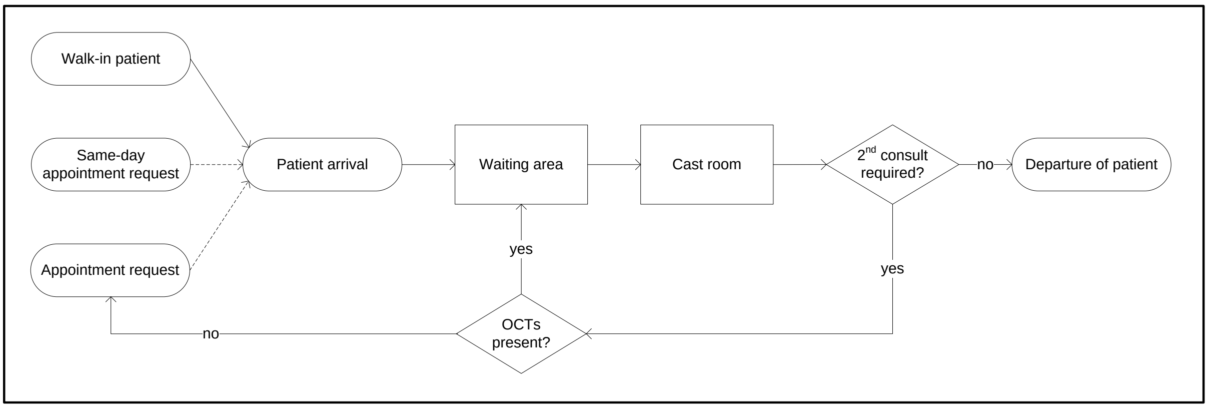

Figure 4.1: Overview of the process in the simulation model

RESOURCES AND CAPACITY

In our model, we use the following instances to indicate resources and capacity aspects:

- *Waiting area capacity:* The waiting area of the outpatient clinic does not have capacity restrictions.
- *Cast room capacity:* There are two cast room for patient treatment, namely cast room 1 and cast room 2.
- *Bed capacity:* The bed capacity is fixed: the cast room has four beds available, two in each cast room. Hereby, OCTs cannot treat inpatients in cast room 1 due to space limitations (see Section 2.2), and at most one inpatient at a time in cast room 2.
- *Outpatient clinic consulting hours:* The consulting hours indicate the times that OCTs and specialists perform patient treatments, thus the time that capacity is available.
- *OCT schedule:* how many OCTs are scheduled during a shift.
- *OCT unavailability:* OCTs also work outside the cast room (see Section 2.2):
  - *Scheduled OCT unavailability:* Scheduled unavailability is known in advance:
    - *Known more than a week in advance:* Examples include lunch break, Pediatric outpatient clinic treatments and meetings. The exact starting time of these of examples is known.
    - *Known a week in advance:* Treatments at the operating room are known in advance, however, the exact starting time is not known.
  - *Unscheduled OCT unavailability:* Unscheduled unavailability is not known in advance. Examples of unscheduled unavailability include OCT punctuality, additional Pediatric outpatient clinic treatments and external treatments.

- *Agenda capacity:* The agenda capacity specifies the times per day that appointment requests can be scheduled. Hereby, the number of available slots during a specific time interval is also indicated.

- *Specialist capacity:* The specialist capacity depends on the specialist consulting hours schedule. This schedule indicates the presence of a specific specialists during a shift.

Please note that these capacity aspects are fixed for a cycle of two weeks (10 days and 20 shifts in total).

APPOINTMENT REQUEST

During the day, appointment requests arrive at the cast room according to a theoretical distribution function. Figure 4.2 shows the steps and decisions for appointment scheduling.

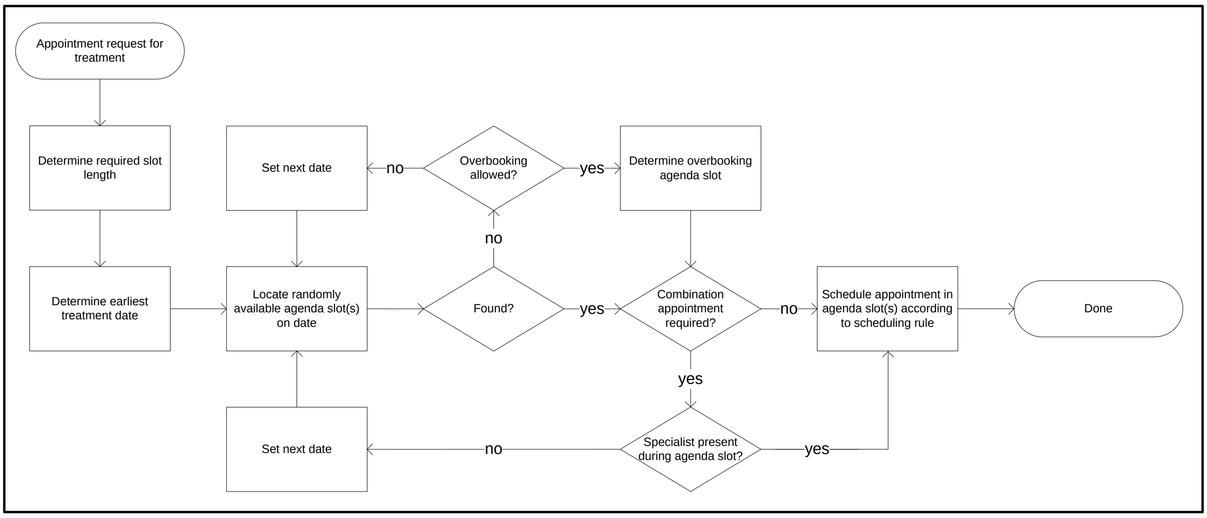

Figure 4.2: Overview of appointment scheduling

Appointment requests are either for same-day appointments or for follow-up appointments that are part of the total treatment procedure. We define the following input characteristics of patients required for appointment scheduling:

- *Appointment patient type:*
  - Same-day inpatient
  - Same-day outpatient
  - Scheduled outpatient

- *Treatment type:* specifies the type of the treatment [1,..k]. This type corresponds with a distribution function to assign the actual processing time.

- *Specialist requirements:* determines whether an appointment should be scheduled during the consulting hours of a specific specialist:
  - 0: no specialist requirements
  - 1,..,n: specialist x requirements.

- *Treatment week:* determines when an appointment should be scheduled [1,..,w]. Hereby, the earliest date to schedule an appointment is known. If the patient requires a combination appointment (see

Specialist requirements), the system checks whether a specific specialist is present on the earliest date. If not, then the system tries the next day.

The treatment type determines the required agenda slot in the agenda:

- *Agenda slots:* the agenda uses the following slots to schedule appointments:
    - B10
    - B15
    - B20
    - B25
    - ……
    - B75
    - B80
    - B90

In the current situation, the agenda only allows for a slot duration as a multiple of fifteen minutes. An appointment scheduling rules specifies the availability of these slots. We evaluate different appointment scheduling rules during our experimentation (see Section 4.5):

- *Appointment scheduling rule:*
    - Schedule a random available agenda slot according to patient attributes
    - Reservation of agenda slots for specific patient or treatment types.
    - Additional rules based on the literature (see Section 4.5)

In our representation of the current situation, we use the patients' attributes to locate the first available shift for treatment. Subsequently, our model randomly picks an available slot during that shift to schedule the appointment.

- *Overbooking: Agenda 1 allows for overbooking. Overbooking is only allowed once per agenda slot.*

Same-day requests receive an appointment on earliest one hour after the time of request due to travel time to AMC (outpatients) or patient transportation requirements (inpatients). Same-day patients should receive their treatment as soon as possible. Therefore, we specify the following rules:

- *Same-day request (morning):*
    - Find free agenda slot during current day (use of appointment scheduling rule).
    - If not find, schedule same-day request at 1 PM of the current day (overbooking).
    - If already taken by same-day patient, schedule same-day request directly after that slot.
- *Same-day request (afternoon):*
    - Find free agenda slot during current day (use of appointment scheduling rule).
    - If not found, find free agenda slot during morning of next day.
    - If not found, schedule same-day request at 8.30 AM of the next day (overbooking).
    - If already taken by same-day patient, schedule same-day request directly after that slot.

PATIENT ARRIVAL / WAITING AREA

Patient types

Patients arrive in the outpatient clinic and take place in the waiting area. The following patient type is applicable along with the appointment patients types (see page 42):

- *Walk-in patient type:*
    - Walk-in outpatient

It is possible that scheduled patients cancel their appointments with p_{cancel}, or do not show up without any notice with $p_{\text{no-show}}$. Cancellations take place before the morning shift and result in free agenda slots for possible same-day patients. The patients with an appointment that do show up arrive with punctuality:

- *Punctuality (appointment time vs. arrival time):* Patients with a scheduled appointment arrive either early or late for their appointments.

Furthermore, the same-day and scheduled patients have the characteristics as described at *appointment request.* We use the following characteristic for walk-in patients:

- *Walk-in treatment duration:* specifies the treatment duration.

As more than 56% of the walk-in patients is referred to the cast room by a specialist, the arrival rate of these walk-in patients depends on the specialist consulting hours schedule (see Section 4.2).

Patient prioritization

OCTs see patients according to a patient prioritization rule. We evaluate different prioritization rules during the experimentation of our interventions (see Section 4.5):

- *Patient prioritization rule:*
    - "First come, first serve" with a priority of inpatients over outpatients.
    - Scheduled/Same-day patients have priority if their appointment time has passed. Before the appointment time of scheduled/same-day patients, walk-in patients or second consults have priority. If patients have an equal priority, first, inpatients have priority over outpatients, and second, OCTs apply the first come first serve rule.

We use the "First come, first serve"-rule with a priority of inpatients over outpatients as patient prioritization rule to represent the current situation..

CAST ROOM

Treatment setup

When capacity is available (in terms of both beds and OCTs to perform the treatment), the available OCT checks the patients' status and picks up the first patient in line (see *Patient prioritization)*. We define treatment setup as the time required before the actual treatment starts:

- *Treatment setup time:*

  The duration of the OCT to check a patient's status and move the patient from the waiting area to the cast room. Also, we include the time to register the patient treatment in the Zorgdesktop-database (see Section 2.2).

Treatment

Patient treatment begins in either cast room 1 or 2, depending on available capacity and/or patient type: inpatients can only be treated in cast room 2. Due to this capacity restrictions, OCTs try to treat patients in cast room 1 to reserve capacity for possible inpatients.

In 10% of the treatments, two OCTs perform the treatment of a patient. The treatment starts with one OCT after which the second OCT joins during the treatment in case the second OCT is busy with another patient.

It is possible that a delay occurs during the treatment. We define two possible reasons for delay:

- *Disturbance during treatment:*

  The OCT has to deal with a disturbance during treatment. Disturbances occur based on the observation period data (see Section 4.2).

- *Specialist requirements during treatment:*

  Before the OCT is able to finish the treatment, the advice of a specialist is required with $p_{\text{specialist}}$. The duration of this delay includes the time waiting for the specialist to arrive as well as the duration of the advice.

Second consult requirements

After treatment, it is possible that an outpatient visits the cast room for a second time that day. This depends on either the advice of specialist or the results of a X-ray. Figure 4.3 summarizes the steps and decisions in the cast room. The box *"consult outside the cast room"* represents the patient consult at a specialist or the X-ray department before a patient visits the cast room for a second time during that day. We refer to the duration of this time as the *external consult duration* further on in this report.

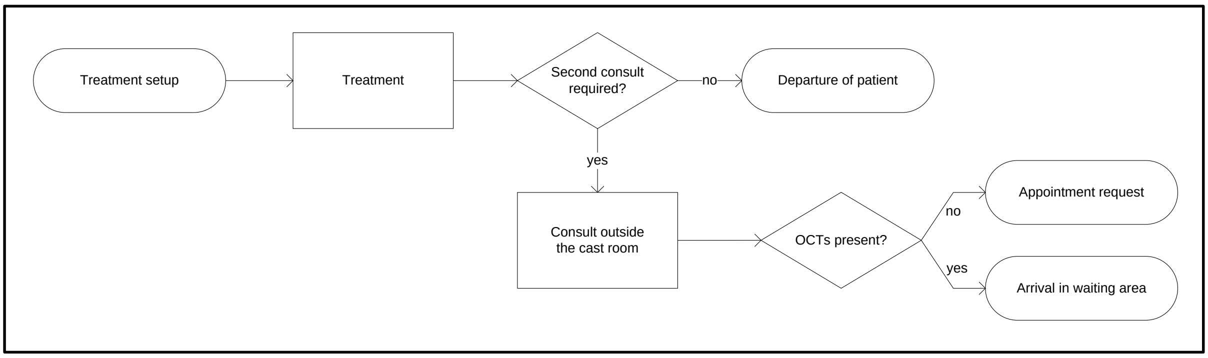

Figure 4.3: Process steps regarding patient treatment within cast room in the simulation model

4.1.4 OUTPUT OF THE SIMULATION MODEL (KEY PERFORMANCE INDICATORS)

The model registers output according to the key performance indicators defined in Section 2.3:

- Patient waiting time (Service level)
- OCT overtime
- OCT utilization

We use the term service level to indicate the percentage of patients served within 20 minutes of waiting time.

4.1.5 ADDITIONAL ASSUMPTIONS

- *Treatment setup time uses the same probability distribution for all patient types:* Before treatment, an OCT first checks the patient's status, and subsequently, the OCT brings the patient to the cast room.

This setup time uses the same probability distribution to calculate the setup duration for any patient type. The treatment setup time takes place before a treatment in our the simulation.

- *The OCTs have the same capabilities:* The OCTs are able to perform any patient treatments and they have the same workrate.
- *Specialists are not modeled as distinct resources:* The waiting time for a specialist and delay in patient treatment as a result of specialist's advice is modeled as a form of disturbance. This means that any patient treatment is delayed with a certain specialist probability and duration.
- *OCTs do not treat other patients during waiting time for a specialist:* Hereby, the worst case performance is regarded during simulation for this aspect.
- *No-shows only occur for scheduled outpatients:* Scheduled inpatients and same-day patients always show up for their appointments.
- *Specialist requirements probability:* All patients have the same probability to determine the requirements of a specialist during treatment.
- *Punctuality:* Same-day patients arrive on time for their appointment.
- *Second consult probability:* All outpatients have the same probability to determine requirements of a second consult.
- *Waiting time is not registered until the day starts:* The waiting time registration of walk-in patients that arrive before the starting time of the day is not registered until the morning shift starts (before 8.30 A.M.).

4.2 DATA GATHERING: FITTING DATA TO PROBABILITY DISTRIBUTIONS

The previous paragraph describes several input parameters. In this paragraph, we explain what data we use for these parameters and for probability distributions to imitate the current cast room situation. Please note that all durations are in minutes. We summarize all input parameters in Table 4.7 at the end of this paragraph.

CAPACITY

Waiting area

There are no capacity restrictions for the waiting area in our model.

Cast room & bed capacity

The cast room has two rooms for treatment. Each room has two beds available for patient treatment. Inpatient treatments are only allowed in cast room 2. Hereby, the other bed in this cast room is not available for treatment of patients.

Outpatient clinic consulting hours

The consulting hours are daily between 8.30-12.30 A.M. and between 13.00-16.30 P.M.

OCT Schedule

We use the observation period data to determine the number of OCTs per shift during the cycle. Furthermore, we subtract the Pediatric outpatient clinic capacity requirements from the OCT schedule. Table 4.1 shows the OCT schedule.

OCT schedule per shift		Even weeks	Odd weeks
Monday	*a.m.*	2	3
	p.m.	3	3
Tuesday	*a.m.*	4	4
	p.m.	3	3
Wednesday	*a.m.*	2	3
	p.m.	3	3
Thursday	*a.m.*	4	4
	p.m.	4	4
Friday	*a.m.*	3	3
	p.m.	3	3

Table 4.1: OCT schedule (Observation period 25 May – 19 June 2009, N=19 days)

OCT punctuality

In the morning, OCTs either start treatments on time or with a delay. We use the observation period data to fit a Weibull function for the OCT punctuality.

Scheduled OCT unavailability

- *Lunch break:* We generate dummy patients per OCT present in the morning with a duration of 30 minutes to represent the lunch break. These dummy patients arrive at 12.30 AM in the waiting area and have priority over the other patients. Patients cannot enter the cast room when a lunch break dummy patient is present in the cast room. This is a result of the shared lunch breaks by OCTs. This means that the lunch break starts for all OCTs when the last morning shift patient leaves the cast room.

Unscheduled OCT unavailability

- *Operating room treatment:* OCTs performs patient treatments at the operating room. These treatments are known one week in advance.
- *Unavailability not regarding treatments:* These tasks include meetings and other outpatient clinic tasks which do not regard the treatment of patients. Also, we include the non-presence of OCTs without a specific reason.
- *Pediatric outpatient clinic:* Next to the Pediatric outpatient clinic schedule, additional OCTs can be required during peak moments at the Pediatric outpatient clinic. This additional presence can only take place during the Pediatric outpatient clinic consulting hours.

For each possibility, we determine the number of occurrences and their duration from the observation period. According to the consulting hours per day, we calculate the total of consulting hours during the observation period. We use the number of occurrences of unscheduled OCT capacity to determine a Poisson process arrival rate for each occurrence of unscheduled OCT capacity. According to the duration per occurrence in the observation period, we fit a probability distribution for the duration of each instance of unscheduled OCT unavailability.

Agenda capacity

Table 4.2 summarizes the available time duration in either agenda 1 or agenda 2. Please note that the overbooking agenda uses the same availability and agenda times of agenda 1.

Cast room agendas		Agenda 1	Agenda 2
Monday	*a.m.*	08:30-12:00	08:30-11:00
	p.m.	13:00-16:00	13:00-15:00
Tuesday	*a.m.*	08:30-12:00	09:00-12:00
	p.m.	13:00-16:00	13:00-15:00
Wednesday	*a.m.*	09:00-12:00	-
	p.m.	13:00-16:00	-
Thursday	*a.m.*	08:30-12:00	08:30-12:00
	p.m.	13:00-16:00	13:00-15:00
Friday	*a.m.*	08:30-12:00	-
	p.m.	13:00-16:00	-

Table 4.2: Available agenda times (Outpatient clinic Orthopedics, Traumatology & Plastic Surgery, 2009-2010)

Specialist consulting hours schedule

We use the specialist consulting hours schedule from the outpatient clinic as input to our model (see Figure 4.4). The blue fields indicate the presence of a specialist during a specific shift.

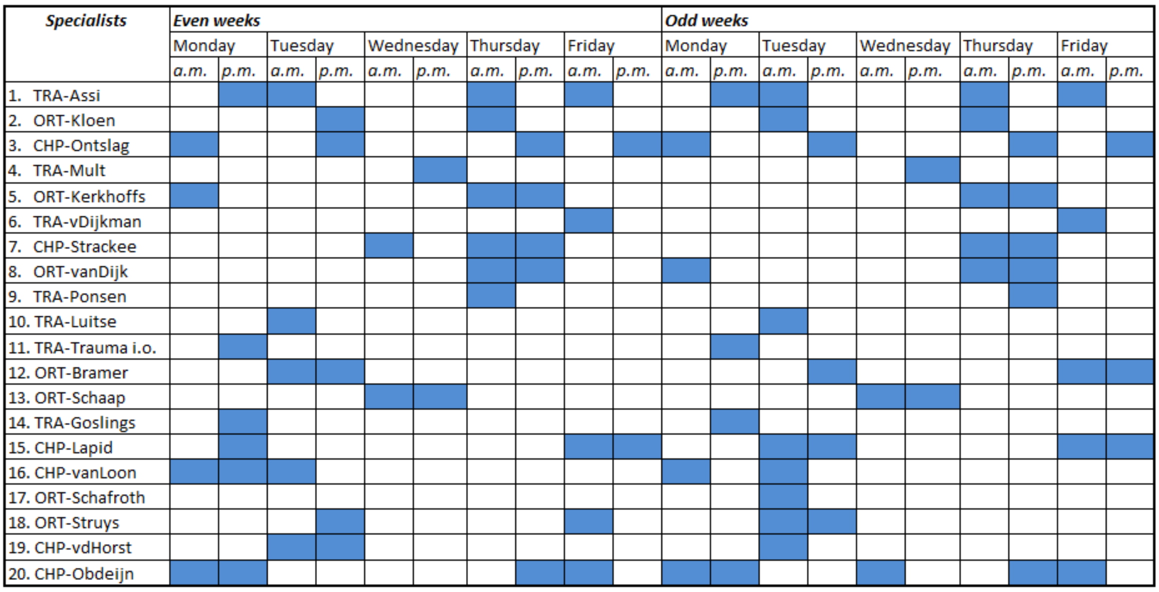

Figure 4.4: Specialist consulting hours schedule (October 2008 – September 2009)

APPOINTMENT REQUEST

Arrival rate of appointment requests

We derive the total number of combination appointments for each specialist during the observation period. Appointment requests arrive during the day during consulting hours, i.e. between 8.30 AM and 4.30 PM. The total number of scheduled appointments during the observation period is equal to 317. Based on eight hours, we can determine the arrival rate of appointment requests. However, before we do, we include the no-show probability of 9.3% in our calculation to make sure that the required number of patients actually enters the system. We find that the arrival rate of appointment requests is equal to 27.46 minutes by means of a Poisson process.

We use the number of appointments per specialists to determine probabilities for specific combination appointments with specialists. Hereby, the number 0 is used for scheduled patients that do not require combination appointment. Table 4.3 shows the probabilities for specialists.

#	Specialist	P	#	Specialist	P	#	Specialist	P
0.	No specialist required	22.2%	**7.**	CHP-Strackee	1.0%	**14.**	TRA-Goslings	1.3%
1.	TRA-Assi	18.9%	**8.**	ORT-vanDijk	2.6%	**15.**	CHP-Lapid	1.0%
2.	ORT-Kloen	15.6%	**9.**	TRA-Ponsen	2.3%	**16.**	CHP-vanLoon	0.3%
3.	CHP-Ontslag	9.3%	**10.**	TRA-Luitse	1.3%	**17.**	ORT-Schafroth	0.7%
4.	TRA-Mult	7.0%	**11.**	TRA-Traumatoloog i.o.	2.6%	**18.**	ORT-Struys	0.3%
5.	ORT-Kerkhoffs	6.0%	**12.**	ORT-Bramer	0.7%	**19.**	CHP-vdHorst	0.0%
6.	TRA-vDijkman	6.0%	**13.**	ORT-Schaap	1.0%	**20.**	CHP-Obdeijn	0.0%

Table 4.3: Specialist requirement probabilities (Observation period 25 May – 19 June 2009, N=317 patients)

Arrival rate of same-day request

We use the observation period to determine the total number of same-day patients. According to the consulting hours per day, we determine the total of consulting hours during the observation period. We use the number of same-day patients to determine a Poisson process arrival rate for the arrival of Same-day patients per day. Same-day requests do not require a combination appointment and can be scheduled during any shift.

Patient type

Same-day requests are either for inpatients or outpatients. We use the observation period to determine the probabilities of these patients for each category (see Table 4.4).

Probabilities	Inpatient	Outpatient
Same-day request	88%	12%

Table 4.4: Probability of inpatient vs. outpatient for same-day requests (Observation period 25 May – 19 June 2009, N=556 patients)

Treatment type and duration

We do not have sufficient data for statistical significance to use the specific treatments in our model (see Appendix C), except for cast removal. Therefore, we group the treatment types in five main groups according to corresponding scheduled treatment duration. We use both historical data as well as data from the observation period to indicate the probabilities per group. Table 4.5 summarizes the probabilities.

Treatment type probability	
Type 1	60.9%
Type 2	37.1%
Type 3	0.9%
Type 4	0.9%
Type 5	0.2%

Table 4.5: Probability of treatment type (XCare information system 19 September 2006 – 18 September 2009, N=12270 patients)

We determine the realized treatment duration for each treatment group. We use these realized treatment durations to fit a probability distribution for each group. We do not have sufficient observations for group 5. Therefore, we assume a Normal distribution for these treatments.

We determine the realized treatment duration for each inpatient. Hereby, inpatients encounter either a discharge treatment or a non-discharge treatment. We use the realized treatment durations to fit two Weibull distributions to assign the inpatient treatment duration in our model.

Treatment week

We use historical data from the information system XCare to determine the treatment week. Table 4.6 summarizes the treatment weeks and probabilities.

Treatment week probability	
1 week	56%
2 weeks	17%
3 weeks	8%
4 weeks	9%
5 weeks	6%
6 weeks	4%

Table 4.6: Probability per treatment week (XCare information system 19 September 2006 – 18 September 2009, N=12270 patients)

PATIENT ARRIVAL / WAITING AREA

Arrival of a walk-in patient

We use the consulting hours to calculate the impact per specialist in terms of walk-in patients per half hour. Please note that we determine the number of patients per half hour that did not combine an appointment with a specialist as well.

Subsequently, we divide each day in a cycle in seventeen periods of thirty minutes (8.00 AM – 4.30 PM). According to the specialist's consulting hours schedule in Figure 4.4, and consulting hours per department in Table 4.7, the impact per period per day is filled in for each specialist.

Department	a.m.	p.m.
Orthopedics	8:30-11:30	13:00-15:30
Traumatology	9:00-11:30	13:00-15:30
Plastic Surgery	9:00-11:30	13:00-15:30

Table 4.7: Consulting hours per department (AMC)

Figure 4.5 shows an example of this procedure for TRA-Assi.

TRA-Assi	Even weeks					Odd weeks				
	Monday	Tuesday	Wednesday	Thursday	Friday	Monday	Tuesday	Wednesday	Thursday	Friday
8:00										
8:30										
9:00		0.13		0.13	0.13		0.13		0.13	0.13
9:30		0.13		0.13	0.13		0.13		0.13	0.13
10:00		0.13		0.13	0.13		0.13		0.13	0.13
10:30		0.13		0.13	0.13		0.13		0.13	0.13
11:00		0.13		0.13	0.13		0.13		0.13	0.13
11:30										
12:00										
12:30										
13:00	0.13					0.13				
13:30	0.13					0.13				
14:00	0.13					0.13				
14:30	0.13					0.13				
15:00	0.13					0.13				
15:30										

Figure 4.5: Walk-in arrival rate for specialist TRA-Assi (Observation period 25 May – 19 June 2009, N=19 days)

We combine the tables of each specialist (and no specialist) into one 'sum' table. Hereby, we find the expected number of walk-in patients per period per day during a cycle (see Figure 4.6).

Total walk-in	Even weeks					Odd weeks				
	Monday	Tuesday	Wednesday	Thursday	Friday	Monday	Tuesday	Wednesday	Thursday	Friday
8:00	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
8:30	0.35	0.33	0.30	0.69	0.26	0.36	0.61	0.30	0.69	0.33
9:00	0.43	0.86	0.58	1.45	0.52	0.45	1.16	0.32	1.10	0.59
9:30	0.43	0.86	0.58	1.45	0.52	0.45	1.16	0.32	1.10	0.59
10:00	0.43	0.86	0.58	1.45	0.52	0.45	1.16	0.32	1.10	0.59
10:30	0.43	0.86	0.58	1.45	0.52	0.45	1.16	0.32	1.10	0.59
11:00	0.43	0.86	0.58	1.45	0.52	0.45	1.16	0.32	1.10	0.59
11:30	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
12:00	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
12:30	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
13:00	0.46	0.69	0.55	0.78	0.30	0.40	0.40	0.55	1.13	0.37
13:30	0.46	0.69	0.55	0.78	0.30	0.40	0.40	0.55	1.13	0.37
14:00	0.46	0.69	0.55	0.78	0.30	0.40	0.40	0.55	1.13	0.37
14:30	0.46	0.69	0.55	0.78	0.30	0.40	0.40	0.55	1.13	0.37
15:00	0.46	0.69	0.55	0.78	0.30	0.40	0.40	0.55	1.13	0.37
15:30	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26

Figure 4.6: Walk-in patient arrival rates (Observation period 25 May – 19 June 2009, N=19 days)

We translate these impacts into a Poisson process arrival rate, which we use as input as our model to generate the arrival of walk-in patients.

Cancellation or no-show of scheduled patient

We use the number of cancellations and no-shows for the scheduled patients during the observation period to fit a Bernoulli distribution for both aspects.

Patient punctuality

For each scheduled patient, we determine the difference between appointment time and arrival time in the outpatient clinic. According to these punctuality, we fit a probability distribution to patient punctuality. We are not able to fit one distribution with an allowed significance level. Therefore, we fit four distribution functions to patient punctuality, namely three Normal distributions and a Gamma distribution.

Walk-in treatment duration

According to the treatment duration per walk-in patient in the observation period, we fit a Gamma distribution to determine the walk-in treatment duration in our model.

CAST ROOM

Treatment setup duration

We determine the time between the departure of an OCT to pick up a patient and the return of an OCT for every treatment during the observation period. Also, we include the time to register the patient treatment in the Zorgdesktop-database. We use these setup times to determine a probability function for setup times in our model. Unfortunately, we are not able to fit a distribution with sufficient significance. Therefore, we translate our findings of the observation period into probabilities for the observation period. Table 4.8 summarizes the probabilities and related treatment setup times.

Treatment setup time	Probability
1 minute	26%
2 minutes	43%
3 minutes	20%
4 minutes	17%
5 minutes	2%
6 minutes	0.5%
10 minutes	1.5%

Table 4.8: Treatment setup time probabilities (Observation period 25 May – 19 June 2009, N=556 patients)

Disturbances during treatment

We determine the number of disturbances during treatment during the observation period. According to these occurrences, and the total number of consulting hours during the observation period, we use a Poisson process to model the occurrence of a disturbance during patient treatment in our model. Hereby, when a disturbance occurs, the model adds a disturbance duration to the setup time of the treatment that is disturbed. According to the disturbance duration in the observation period, we fit two Weibull distributions to determine the disturbance duration in our model.

Specialist advice requirements during treatment

According to the disturbances during treatment in the observation period, we fit a Bernoulli distribution to determine a patient’s specialist requirements. According to the waiting for specialist time in the observation period, we fit a Weibull distributions to determine the specialist waiting time in our model.

Second consults

According to the second consult patients in the observation period, we fit a Bernoulli distribution to determine the second consult requirements of an outpatient. According to the treatment duration per second consult patient in the observation period, we fit a Normal distribution to determine the walk-in treatment duration in our model.

Second consults do not return to the cast room immediately. We use the observation period data to calculate the time between the first treatment and the second arrival in the waiting area for each second consult patient. We use these times to fit a Normal distribution to determine the external consult duration in our model.

OVERVIEW OF THE INPUT PARAMETERS

We determined several input parameters in this paragraph. We summarize these input parameters, their parameters, and their statistic goodness for a fit significance in Table 4.9. All input parameters are fit with a chi square significance level of 99%. As described before, some of the input parameters require more than one distribution to yield allowable result. Note that *Appointment punctuality (1)* is not accepted by a 99% chi square test. However, we find that it is accepted by the 99% Kolmogorov-Smirnov goodness for fit. We do not perform a goodness for a fit test for the input parameters modeled by Poisson process, because of insufficient data, as well as the Bernoulli distributions, because these only have two possible outcomes, either yes or no. Please note that the input parameters are in minutes, except for the Bernoulli distributions.

Input parameters	Modeled (in minutes) by:	Z value < critical value	
OCT punctuality	Weibull distribution: α=54.94, β=524.8	0.17 < 6.63	*Do not reject*
Unscheduled OCT unavailability arrival rate	Poisson process with λ=220.00	n.a.	
Unscheduled OCT unavailability duration	Weibull distribution: α=1.97, β=42.95	0.80 < 11.35	*Do not reject*
Same-day request arrival rate	Poisson process with λ=47.91	n.a.	
Appointment request arrival rate	Poisson process with λ=27.46	n.a.	
Patient type	Probability distribution (see Table 4.1)	n.a.	
Treatment 1 duration (1) (45%)	Weibull distribution: α=1.211, β=4.84	1.09 < 15.09	*Do not reject*
Treatment 1 duration (2) (55%)	Gamma distribution: α=3.31, β=7.33	5.97 < 16.81	*Do not reject*
Treatment 2 duration	Weibull distribution: α=1.59, β=23.48	1.79 < 16.81	*Do not reject*
Treatment 3 duration	Normal distribution: μ=44.00, σ=22.87	5.95 < 9.21	*Do not reject*
Treatment 4 duration	Normal distribution: μ=68.00, σ=25.13	2.06 < 9.21	*Do not reject*
Treatment 5 duration	Normal distribution: μ=90.00, σ=5.00	n.a.	
Inpatient discharge duration (34%)	Gamma distribution: α=1.92, β=5.95, γ=10.19	2.05<9.21	*Do not reject*
Inpatient non-discharge duration (66%)	Gamma distribution: α=4.24, β=6.58	0.88<13.28	*Do not reject*
Specialist requirements	Probability distribution (see Table 4.2)	n.a.	
Treatment week	Probability distribution (see Table 4.3)	n.a.	
Cancellation probability	Bernoulli distribution: p=0.08	n.a.	
No-show probability	Bernoulli distribution: p=0.02	n.a.	
Appointment punctuality (1) (3%)	Normal distribution: μ=-55.56, σ=24.68	0.37 < 0.51 (K.S.)	*Do not reject*
Appointment punctuality (2) (10%)	Normal distribution: μ=-30.42, σ=4.15	4.20 < 9.21	*Do not reject*
Appointment punctuality (3) (79%)	Normal distribution: μ=-7.30, σ=7.88	7.88 < 13.28	*Do not reject*
Appointment punctuality (4) (8%)	Gamma distribution: α=0.65, β=14.28, γ=15.00	2.95 < 9.21	*Do not reject*
Walk-in arrival rate	Poisson process with λ per half hour	n.a.	
Walk-in treatment duration	Gamma distribution: α=2.20, β=8.93	8.05 < 18.48	*Do not reject*
Treatment setup duration	Probability distribution (see Table 4.5)	n.a.	
Disturbance probability per hour	Poisson process with λ=142.5	n.a.	
Disturbance duration (1) (70%)	Weibull distribution: α=1.72, β=7.13	8.21 < 16.81	*Do not reject*
Disturbance duration (2) (30%)	Weibull distribution: α=2.79, β=12.77	1.19 < 11.35	*Do not reject*
Specialist advice probability	Bernoulli distribution: p=0.19	n.a.	
Specialist advice duration	Weibull distribution: α=1.35, β=11.18	8.16 < 16.81	*Do not reject*
2nd consult probability	Bernoulli distribution: p=0.09	n.a.	
2nd consult external consult duration	Normal distribution: μ=70.37, σ=35.44	4.79 < 13.28	*Do not reject*
2nd consult treatment duration	Normal distribution: μ=16.57, σ=7.88	3.70 < 13.28	*Do not reject*

Table 4.9: Overview of the input parameters for the simulation model (Observation period 25 May – 19 June 2009, N=556 patients)

Please note that these input parameters represent the current situation. For some of the input parameters, we use different settings during our experimentation. We describe these changes in Section 4.5.

4.3 TECHNICAL DESIGN OF THE MODEL

The technical design programs the conceptual model into our simulation software. Hereby, we did not encounter issues, except for the following one.

The OCT schedule indicates the capacity during a shift. In addition, capacity temporarily decreases as a result of either scheduled or unscheduled OCT unavailability (see Section 2.2 and 4.1). In either case, an OCT will first finish patient treatment before temporarily leaving the cast room. This is called non-pre-emptive downtime. Our software tool does not allow for non-pre-emptive downtime. Therefore, we choose to make use of dummy patients that have priority over 'normal' patients to simulate OCT unavailability during experimentation.

4.4 VERIFICATION AND VALIDATION OF THE SIMULATION MODEL

We use the methods verification and validation to declare that our model actually represents the current situation of the cast room. Sargent (2005) defines the verification of a computer model as ensuring that the computerized model and its implementation are correct. Validation evaluates if the computerized model shows a performance comparable to the actual situation.

4.4.1 ACCURACY OF EXPERIMENTATION

Before we are able to comment on the validity of our model, we determine three important simulation factors, namely the length of the warm-up period, the number of replications, and the length of a simulation run (Law & Kelton, 2000).

LENGTH OF WARM-UP PERIOD

First, we remove initialization bias: for instance, our model starts with an empty agenda, while in reality each day is filled, to a certain degree, with scheduled appointments. This behavior corresponds with a non-terminating simulation. To remove the bias of initialization, we determine a warm-up period of experimentation. A warm-up period is used to fill the model with appointments by which we ensure that the model is in a realistic condition after the warm-up period. This means that the model registers key performance indicators only after the warm-up period is finished. To determine the warm-up period, we use Welch's method as described by Robinson (2004). Hereby, we follow the following steps:

- Perform a series of at least five replications to obtain time-series of the output data.
- Calculate the mean of the output data across the replications for each period.
- Calculate a moving average based on a window size of *w* (start with *w*=5).
- Plot the moving average on a time-series.
- Are the data smooth? If not, increase the size of the window (*w)* and return to the previous two steps.
- Identify the warm-up period as the point where time-series becomes flat.

A replication is a run of a simulation that uses specific streams of random numbers (Robinson, 2004). By using multiple replications, a better estimate of the mean performance of the model is ensured.

We chose to run 20 replications in order to determine the warm-up period. Hereby, we register the average patient waiting time per day. We run a replication for 1000 days. Figure 4.4 shows our moving average results with *w=5.*

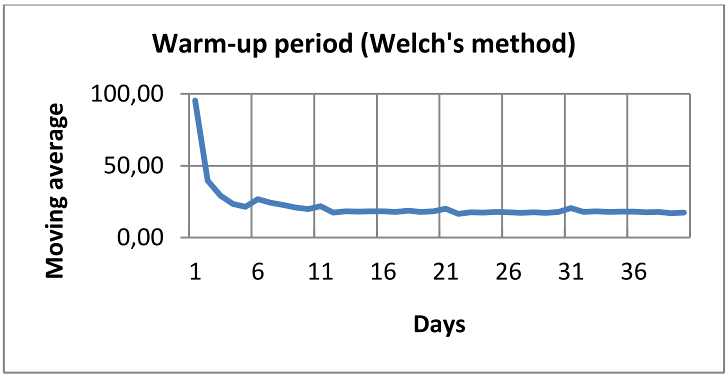

Figure 4.7: Warm-up period (Welch's method with a window size of 5)

Figure 4.7 shows that the moving average is smooth after approximately 15 days. As an extra precaution, we set the warm-up period equal to 40 days. Hereby, we start after exactly four system cycles. A cycle equals two weeks, which is also followed by the consulting hours schedules by both OCTs and specialists. Furthermore, patients can receive appointments up to six weeks into the future. With 40 days, we make sure that the system actually contains these patients as well.

NUMBER OF REPLICATIONS PER RUN

In the previous section, we briefly described the importance of using multiple replications. In this section, we determine the number of replications per simulation run. Hereby, we follow the graphical method combined with the confidence interval method (Robinson, 2004). The graphical method plots the cumulative mean of the output data from a series of replications. We perform 20 replications to receive our data for the graphical method. Hereby, we do not use data that is stored during the warm-up period. Figure 4.8 shows the results of the graphical method in combination with the confidence interval for a significance level of 5%.

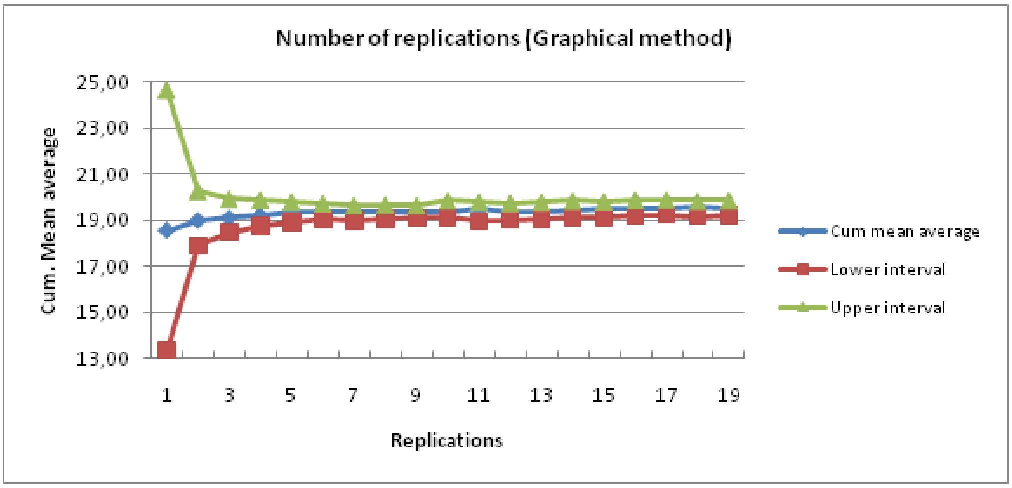

Figure 4.8: Number of replications (Graphical & convergence method)

The point at which the cumulative mean average becomes flat defines the number of required replications. We also use the lower and upper interval of the confidence level (the deviation is equal to 2.5%) to set the number of replications equal to 10.

LENGTH OF EXPERIMENTAL RUN

Finally, we decide upon the length of a experimental run. Hereby, we use the convergence method as described by Robinson (2004). The convergence method uses three replications that are run for longer than the anticipated run length. As a rule of thumb, Robinson (2004) proposes that the run-length is to be 10 times the length of the warm-up period. Our initial run length of 1000 days satisfies this proposition. The method calculates the level of convergence between the replications. The run length is acceptable when the level of convergence is 5% or less. We find that the three replications lead to a convergence level of 4.84% after 852 days. We decide the experimental run length to be 1000 days (equal to 4 years with 250 working days per year). The total run length will be 1040 days (including warm-up period).

INPUT VERIFICATION

To conclude the verification phase, we make sure that the input of our model is correct. Hereby, we evaluate the average duration of each occurrence in the model and compare these with the observation period. We find that these values match the mean values of the observation period. Table 4.10 provides a summary of the input verification for the main input variables regarding patients.

Input verification		***Observation period***		***Simulation model***	
		Number per cycle (%)	*Total duration per cycle*	*Number per cycle (%)*	*Total duration per cycle*
Patients	Walk-in patients	103 (35.7%)	2,852 min.	103 (35.7%)	2,852 min.
	Scheduled patients	159 (55.1%)	1,908 min.	159 (55.1%)	1,908 min.
	Same-day patients	29 (9.2%)	645 min.	29 (9.2%)	645 min.
		Total duration per cycle		*Total duration per cycle*	
Capacity	Sum of OCT unavailability	731		731	
	Treatment disturbances	162		162	

Table 4.10: Input verification (Observation period vs. simulation model)

We find that the input is the same as the observation period result. Hereby, we have verified our input.

4.4.2 VALIDATION

The input parameters of the model and simulation settings allow for model validation. Model validation evaluates the computerized model by comparing its performance with the actual situation. Differences in performance can be explained due to specific assumptions and the intended application of the model. (Sargent, 2005). We use validation techniques presented by Sargent (2005) and Balci (1998) to ensure that our model is valid for further experimentation:

- *Face validity:* We introduce our model with stakeholders of the cast room process. We discuss the process steps, simplifications, and assumptions made during modeling and we make sure that these are justified or improved according to the stakeholders' view of the system.
- *Data validation:* We use the data from both the observation period and data from the hospital information systems to compare the scores for the key performance indicators.

UTILIZATION ANALYSIS

We start our validation phase with an analysis of the utilization levels of our model. Hereby, we evaluate the utilization rates per shift. Utilization is appropriate, because we use both capacity and arrival of patients and their treatments as input in our model. Table 4.11 shows the utilization rates per shift of both the observation period as our model.

Utilization		***Even week***					***Odd week***				
		Mo	*Tu*	*We*	*Th*	*Fr*	*Mo*	*Tu*	*We*	*Th*	*Fr*
Observation	*a.m.*	75%	51%	35%	64%	55%	34%	54%	43%	64%	25%
Model	*a.m.*	58%	68%	33%	74%	44%	37%	58%	42%	40%	27%
Observation	*p.m.*	41%	60%	37%	40%	32%	45%	66%	36%	37%	19%
Model	*p.m.*	50%	58%	46%	50%	24%	35%	50%	46%	42%	28%

Table 4.11: Utilization rates per shift (Observation period vs. Simulation model)

The overall utilization rate for a cycle of two weeks is 45.6% in the model, while the average of the observation period equals 45.7%. We clarify that the overall utilization rate of our model is equal to the utilization rate during the observation period. We conclude that we have modeled our input correctly in the computer simulation model.

On shift level, Table 4.11 shows differences larger than 5% for several shifts. First, the utilization rates for our computer simulation model represent averages values for 10 replications of 1000 days. The utilization rates for the observation period represent only two observation per shift. To provide insight in the different observation for our model, Figure 4.9 all individual observations for Friday afternoon (odd weeks) from our simulation model.

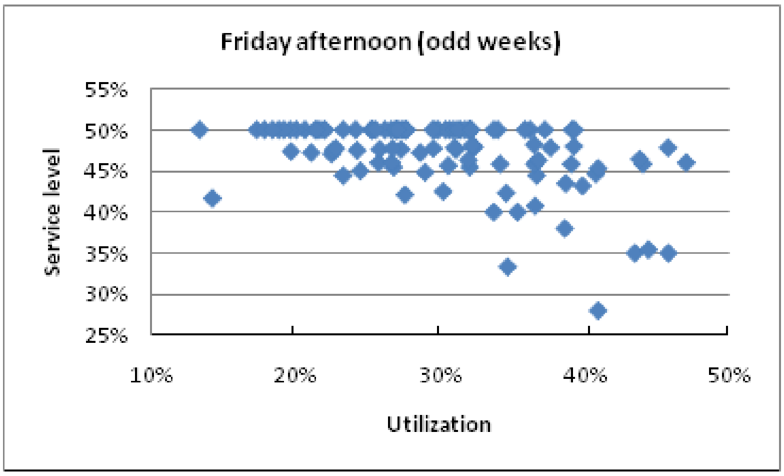

Figure 4.9: Individual observation of Friday afternoon (odd weeks) in our observation model (N=100 shifts)

Figure 4.9 shows the different observations of our model. On average, the utilization is 28% as Table 4.11 indicates. We find that the 19% of the observation period is also in Figure 4.9.

Second, we explain these differences as a result of our modeling assumptions. For instance, the arrival of same-day patients and the arrival of unscheduled OCT unavailability are stationary input data during our simulation: they have the same arrival rate every shift. Section 2.3 shows the impact on performance of unscheduled OCT unavailability. The combination of our assumptions contributes to differences higher than 5% on shift level, but does result in an equal level of overall utilization. We admit that based on these utilization numbers the assumptions to use averages for any shift might have been wrong. However, due to the lack in data to implement these instances with statistical significance, there was no other option.

REGRESSION ANALYSIS

To evaluate the performance of our model, we perform a regression analysis of the service level vs. utilization for each shift (see Figure 4.10) to evaluate whether the model shows a comparable trend to the observation period and to our expectations. Please note that service level is the percentage of patients that is seen in the cast room within a waiting time of 20 minutes. We show the total graph as well as graphs per number of OCTs present to better clarify possible differences. We include the number of OCTs, number of patients, and percentages per specific patient types for each shift in Appendix E.

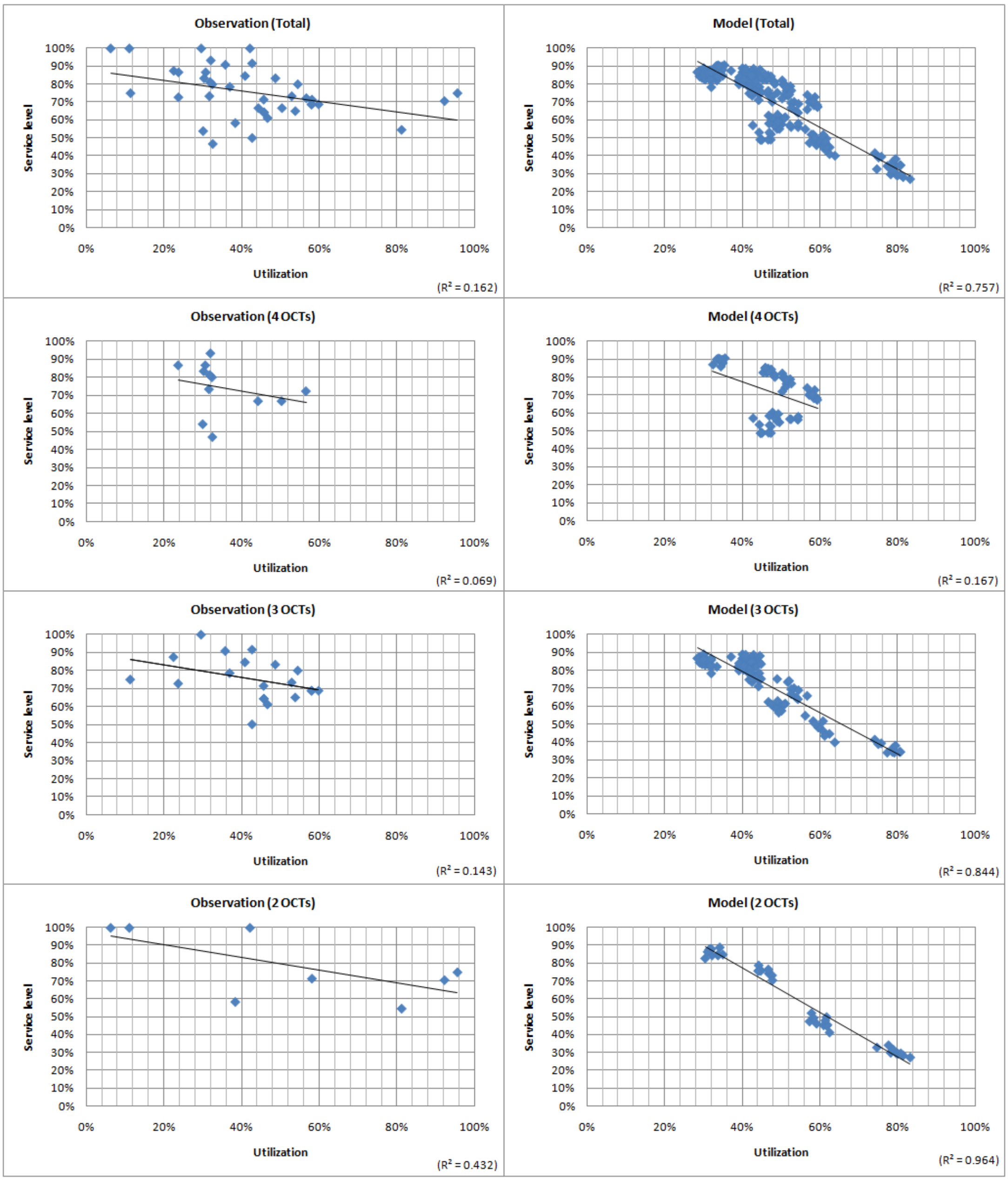

Figure 4.10: Service level vs. utilization performance per number of OCTs (Observation period vs. simulation model)

Overall performance

We find that the observation period is limited due to only 19 days of observations (38 shifts).The low scores for goodness of fit in terms of R^2 also confirm this statement. Therefore, it is hard to completely validate our model.

First, we expect that an increase in capacity results in higher performance in terms of service level. Figure 4.10 shows that the data from the observation period does not confirm this behavior: 2 OCTs perform better than 3 OCTs, and 3 OCTs perform better than 4 OCTs. However, our model does show the service level performance as expected.

Second, for each graph we expect that an increase in utilization results in a decrease of the service level (the percentage of patients that is served within 20 minutes waiting time). We find that each graph shows this pattern. Hereby, we find that the model results in a steeper decreasing linear function compared to the observation period.

For both aspects, we clarify the differences as a result of our modeling assumptions:

- *Stable work rate:* An important assumption in our model is that all OCTs have the same work rate. In practice, we find that the OCTs tend to work faster during peak moments. This means that when utilization increases, the service level decreases less steeply.

- *Postpone external tasks:* Chapter 2 and 4 describe the occurrence of external tasks that temporarily decrease the capacity. In practice we find that during peak moments, OCTs try to postpone external tasks to a moment with less cast room patients. This behavior is not part of our model. Furthermore, when only 2 OCTs are present, this behavior takes place earlier than when 4 OCTs are present.

- *Limitations in physical space in the cast room:* the physical space in the cast room is limited. Hereby, we refer to the report 'Analyserapportage gipskamer' (2009). An increase in capacity results in less workspace for the OCTs. In practice, less workspace results in a lower work rate for OCTs. This is not part of our model.

The lack of these factors in our model results in an equal utilization vs. service level rate for any level of capacity as Figure 4.10 shows.

Utilization range

The model graphs show a utilization range that starts around 30%. The utilization range ends almost at the same percentage (85%) as the observation period. Overall, the observation period shows lower utilization rates than our model. We clarify these differences as a result of the use of average patient numbers to determine the input of our model. Our observation period lasted four weeks, including two cycles. During a few shifts, very few patients were present. This results in a low utilization and a high service level. The graphs of the observation period include each individual shift during the observation period. However, as input to our model, we use the average number of patients present during a shift. For example, if the morning shift of Monday in week 1 had very few patients, and the morning shift of Monday in week 3 had many patients, we find an amount of patients in the middle of those two observation as input to Monday morning during odd weeks. The agenda system does not allow endless patients to be scheduled during a shift. Therefore, the maximum number of patients present during a shift in both the observation period and our model is comparable. This results in an equal end range of the utilization rate.

To conclude, we find several values that lie underneath the linear line for our model in Figure 4.10. This primarily occurs when the capacity is equal to 3 or 4 OCTs. These values have the same utilization rates as the values on or above the linear line, while the service level appears to differ. Figure 4.6 shows that the arrival rate of walk-in patients varies during any shift. When the arrival rate is smaller during a given moment, this results in a higher number of patients in the waiting area. A higher number of patients decreases the service level. In addition, the cast room situations encounters disturbances as well as unscheduled OCT unavailability. Therefore, we clarify the outliers under the linear line in Figure 4.10 as a result of moments with a higher walk-in arrival rate. Hereby, the utilization remains the same, but the service level decreases as a result of temporary peaks in the total number of patients waiting for treatment in combination with temporary decreases in capacity.

OUTPUT VALUES

As we simply have too few observations, we are not able to perform the validation process in more detail. Despite the few differences, which we clarified before, we assume that our model is valid for use in our experimentation. We evaluated the input parameters and concluded that our model results in a performance as we expect as well as the cast room stakeholders.

To conclude, we consider the output values of our model and compare these to the observation period. Table 4.12 shows the values for the key performance indicators patient waiting time, service level, and the overtime.

Key performance indicators	***Observation period***	***Simulation model***
Average waiting time per patient (SL%)	16.1 minutes (74%)	18.4 minutes (72.8%)
OCT AM overtime	3.7 minutes	3.3 minutes
OCT PM overtime	- 30.1 minutes	- 12 minutes

Table 4.12: Output values of the simulation model (20 replications of 1000 days) and the observation period (25 May – 19 June 2009, n=556 patients)

We find that the model performs slightly worse than the observation period for the key performance indicators regarding patient waiting time. This is a result of the worst case representation of the cast room situation (see Section 4.1), as described before. For overtime, we find that the OCT AM overtime is only 0.4 minutes less than during the observation period. However, the difference between OCT PM overtime between the observation period and the simulation model is still quite large with about 18 minutes. We clarify this difference by walk-in patients and second consults in our model. Walk-in patients can arrive till 4 PM in our model. These patients have an average duration of 27 minutes. Furthermore, second consults can enter the cast room as long as the OCTs are still present. However, during the observation period, none of the patients with a second consult arrived after 4 PM. We clarify that the combination of the arrival of walk-in patients and second consults at the end of the afternoon shift results in the lower value of OCT pm overtime in our model.

4.5 EXPERIMENTAL INTERVENTIONS

The overall goal of our research is to design and evaluate interventions to improve the current performance of the cast room. Hereby, the goal is to improve the performance in terms of our performance indicators service level and OCT overtime. Hereby, the service level contains both the percentage of patients served within 20 minutes as well as the average waiting time per patient. Furthermore, an important goal is to improve the quality of labor by balancing the workload during a shift. This balance also contributes to an increase in service level as explained in Section 2.3. Section 3.3 as well as the document 'Verbeteracties gipskamer' (2009) describe several recommendations to improve the current situation. We group our recommendations in three main interventions. The following list provides a global overview of our experiments:

- Base situation
- Intervention 1: Less invasive improvement actions
- Intervention 2: Redesign of the agenda system and of the appointment scheduling
- Intervention 3: More invasive improvement actions

The base situation represents the current cast room situation. Please note that we adjust the base situation to the validated situation as well (see Section 4.5.1). This is the result of new schedules that are in place since October 2009. In addition, we correct the number of patients according to annual figures.

The three main interventions include the recommendations of Section 3.3 and the document 'Verbeteracties gipskamer' (2009) as sub-interventions. We outline the specific sub-interventions in the remainder of this chapter. First, we explain the specific goal of each sub-intervention. Second, these sub-interventions require adjustments in the input parameters for our model compared to the current situation as described in Section 4.1 and 4.2. We describe these input alterations in detail. For the implementation of the (sub-)interventions in the current situation, we refer to Chapter 6.

4.5.1 BASE SITUATION

The base situation represents the current cast room situation. The cast room and Pediatric outpatient clinic use new rosters from October 2009. These vary from the rosters as used during the observation period. In order to present realistic results, we define the base situation as the representation of the current situation.

Adjusting the personnel schedules

First, we model the new OCT schedule. Table 4.13 shows the new OCT schedule for intervention 0. Please note that the Pediatric outpatient clinic presence is already subtracted in this table as well.

Number of OCTs scheduled per shift		Even weeks	Odd weeks
Monday	*a.m.*	3	3
	p.m.	3	3
Tuesday	*a.m.*	3	3
	p.m.	2	3
Wednesday	*a.m.*	3	3
	p.m.	3	3
Thursday	*a.m.*	4	4
	p.m.	3	4
Friday	*a.m.*	3	3
	p.m.	3	2

Table 4.13: OCT schedule (Outpatient clinic Orthopedics, Traumatology & Plastic Surgery, October 2009 – September 2010)

Second, we adjust the changes in the specialists' consulting hours schedule. Figure 4.11 shows the updated specialist consulting hours schedule. Hereby, there is one new specialist, namely CHP-Alge (16), who substitutes the patients and consulting hours of CHP-vanLoon.

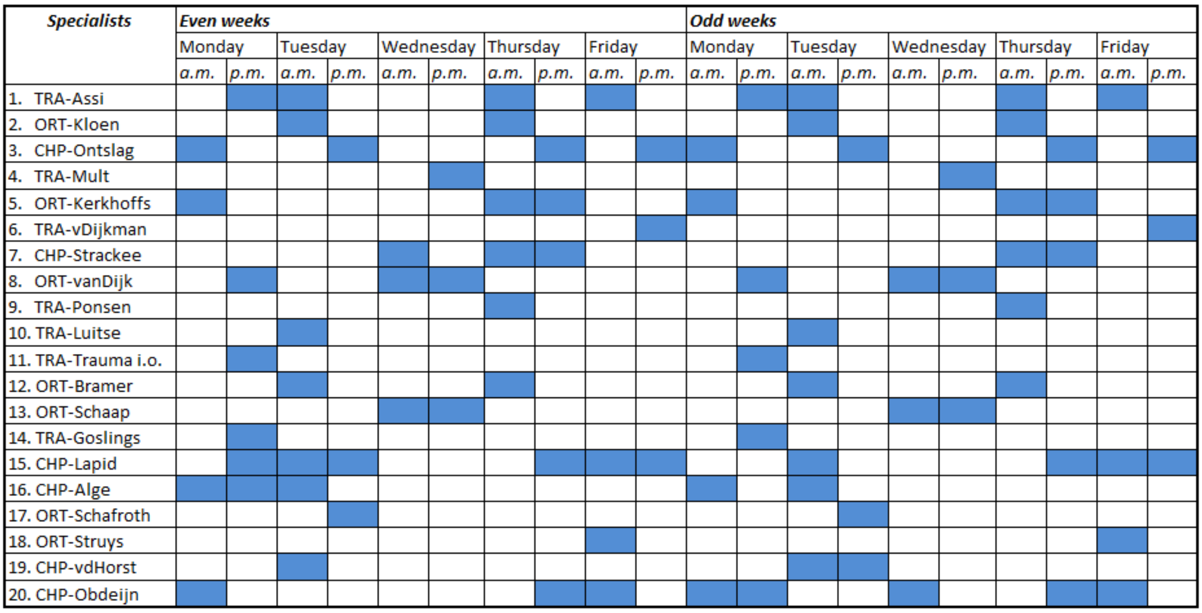

Figure 4.11: Specialist consulting hours schedule (Outpatient clinic Orthopedics, Traumatology & Plastic Surgery, October 2009 – September 2010)

The adjustments in the specialist schedule result in updated arrival rates for walk-in patients. Please note that the agenda times (see Table 4.2) or the consulting hours of the departments (see Table 4.3) do not change.

Adjusting the number of patients

We determine an annual adjustment factor in order to make sure that the number of patients during the observation period are not a consequence of a seasonal effect. We use this factor to correct the arrival rates of the patients in our model. We retrieve the number of cast room patients in the period September 2008 to August 2009 from the DBC-database. As the DBC-database does not distinguish 2nd consults, we do not take in account the 2nd consults of the observation period. Table 4.14 shows the number of patients per week for both the observation period and twelve months. Hereby, we calculate the annual adjustment factor.

Number of patients per week	
Observation period	134.75
September 2008 – August 2009	131.37
Annual adjustment factor	***1.03***

Table 4.14: Annual adjustment factor for patient arrival rates (Observation period , September 2008 – August 2009, N= 6831 patients)

We conclude that the observation period encountered a higher number of patients per week compared to the annual figures. We use the annual adjustment factor to adjust the arrival rates for appointment requests, same-day requests, and walk-in arrivals.

4.5.1 INTERVENTION 1: LESS INVASIVE IMPROVEMENT ACTIONS

Intervention 1 combines recommendations regarding improvements in communication and behavior of both the OCTs and the DAs. We regard these recommendations as less invasive compared to the sub-interventions of intervention 2 and 3 in the current situation. We describe the sub-interventions in arbitrary order.

OCT PUNCTUALITY

Section 2.3 describes the delay in the morning cast room start time. Furthermore, Figure 2.6 shows its effect on the average patient waiting time. The delay in start time results in immediate waiting time for patients at the start of the day which gradually increases during the day. By means of this sub-intervention, we propose to remove the OCT punctuality in our model. This means that the OCTs start with treatments exactly at 8.30 AM. The goal of this sub-intervention is to decrease the average patient waiting time as well as increase the service level.

INDIVIDUAL LUNCH BREAKS

Section 2.3 describes the delay in the afternoon cast room start time and Figure 2.6 shows its effect on the average patient waiting time. The OCTs have their lunch break together in the current situation. Therefore, they wait until everyone is finished, before they leave the cast room for lunch. OCTs do not always return on time for their afternoon shift, because of this behavior in combination with potential overtime in the morning. This sub-intervention proposes that each OCT starts his lunch break immediately after his treatment of the last patient of the shift. Hereby, the goal is to decrease the average patient waiting time as well as increase the service level.

CANCELLATIONS

In the current situation, no-shows appear to be cancellations for 80%. Cancellations occur by either a patient, specialist, or doctor's assistant. When a cancellation occurs, the patient is not always removed from the agenda system. However, the removal of these appointments results in free agenda slots to schedule same-day patients. We assume that a cancellation is known at latest at the start of the appointment day. At this moment, the model removes the appointments of cancellations from the agenda system. These free slots can be used to schedule same-day patients.

OPERATING ROOM CAPACITY BLOCKING

Temporary decreases in capacity during peak times result in an increase in patient waiting time. Scheduled OCT unavailability can be countered by blocking the agenda so that new patients cannot be scheduled during these times. The current situation does not use capacity blocking for treatments at the operating room. These treatments are known one week in advance. During an operating room treatment, we block the slots of one agenda to prevent further scheduling. Hereby, we reserve time for an OCT to perform the operating room treatment. Hereby, our goal is to increase the service level of patients.

IMPROVE PATIENT PRIORITIZATION

In the current situation, OCTs serve patients according to a 'first come first serve' policy. As patients arrive with various levels of punctuality, OCTs sometimes help patients before their appointment time. Furthermore, walk-in patients receive priority although scheduled patients are on time present for their own appointment. We propose to use a new patient prioritization rule: scheduled/same-day patients have priority if their appointment time has passed. Before the appointment time of scheduled/same-day patients, walk-in patients or second consults have priority. If patients have an equal priority, first, inpatients have priority over outpatients, and second, OCTs apply the first come first serve rule. The goal of this sub-intervention is to decrease the average patient waiting time as well as increase the service level, specifically for scheduled patients. Furthermore, an additional goal of this rule is that patients are seen in a sequence that is more fair compared to the former rule.

4.5.2 INTERVENTION 2: REDESIGN OF THE AGENDA SYSTEM AND APPOINTMENT SCHEDULING

The goal of intervention 1 is to decrease or remove delay in the cast room process. Hereby, we mean delay as a result of lack in communication between the OCTs and DAs, as well as timeliness of the OCTs. We expect that intervention 1 results in an increase of the patient service level. Section 2.3 describes the lack of workload balance for the OCTs. Figure 2.7 shows the number of patient minutes per OCT during the day, which is a indication of the cast room workload during the day. The figure shows a fluctuating pattern for any day. Section 2.3 describes the relation between workload and its impact on the patient service level. The goal of intervention 2 is to balance the workload for OCTs throughout the shift.

Workload is a result of the number of patients that visit the cast room during shifts. In order to balance the workload, we have to influence the arrival of the cast room patients. Chapter 2 describes patient types of the cast room. There are three main types, namely scheduled patients, same-day patients, and walk-in patients. We state that the cast room stakeholders can influence the arrival of scheduled patients that do not require a combination appointment as well as same-day patients. We propose to adjust the current way of scheduling appointments. Hereby, we are able to schedule the patients with no combination appointment requirements around peak moments of the current situation.

First, we outline a sub-intervention to schedule patients around the peak moments during a shift. Hereby, we redesign the current agenda system. Second, we introduce several rules of thumb regarding appointment scheduling to improve the cast room performance.

APPOINTMENT SCHEDULING AT NON PEAK MOMENTS

Figure 4.11 shows the expected workload for the cast room in terms of the combination of all patients for which we cannot influence the arrival pattern. These include the following patients:

- Scheduled patients with combination appointment requirements.
- Walk-in patients

Furthermore, we make the following assumptions in Figure 4.12:

- Scheduled/walk-in patients related to a specialist arrive evenly spread over the consulting hours of their specialist.
- Scheduled/walk-in patients not related to a specialist arrive evenly spread over the entire cycle.
- Each patient has the average treatment duration of 18.85 minutes.
- Disturbances during treatments nor internal waiting time for specialists Is taken into account.

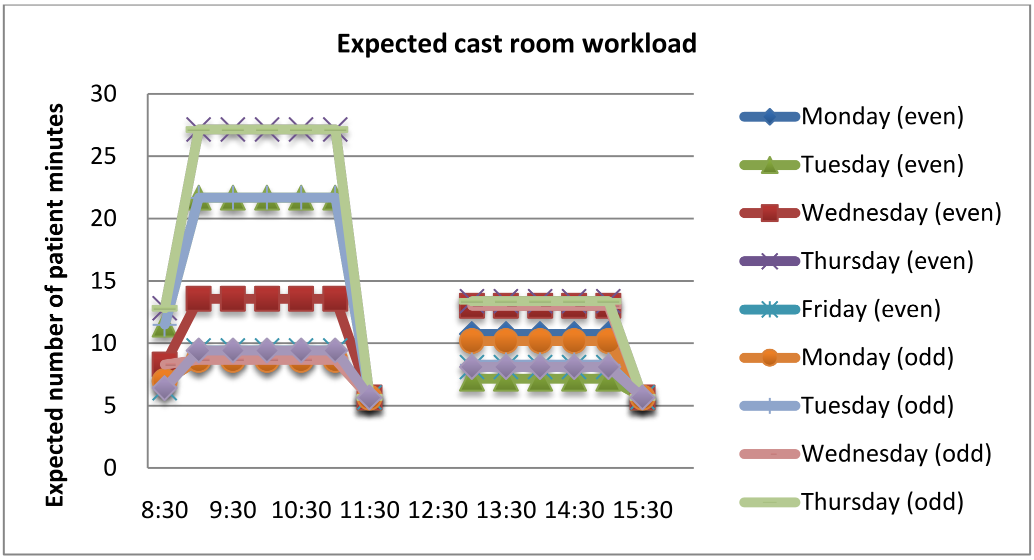

Figure 4.12: Expected workload for the cast room, excluding patients with no combination appointment requirements (Observation period 25 May – 19 June 2009, outpatient clinic schedules 2010)

We find that peak moments of the cast room on any day are during the consulting hours of the specialists. We want to influence the arrival pattern of patients to reduce those peak moments in OCT workload. Hereby, the goal is to shift patients to non peak moments to balance the overall workload. We find that we are able to influence the arrival of scheduled patients. We cannot influence the arrival of any scheduled patient, as 78% of the scheduled patients require a combination appointment during the specialists' consulting hours. Therefore, we propose to schedule appointment request that do not require a combination appointment during the non peak moments.

To illustrate our goal more clearly, we explain our goal by zooming in on one shift. Figure 4.13 shows the expected cast room workload (excluding non-combination appointments) for Tuesday morning (even weeks). The line indicates the expected workload in patient minutes during the shift. The top segment of the line indicates the peak in workload of the shift.

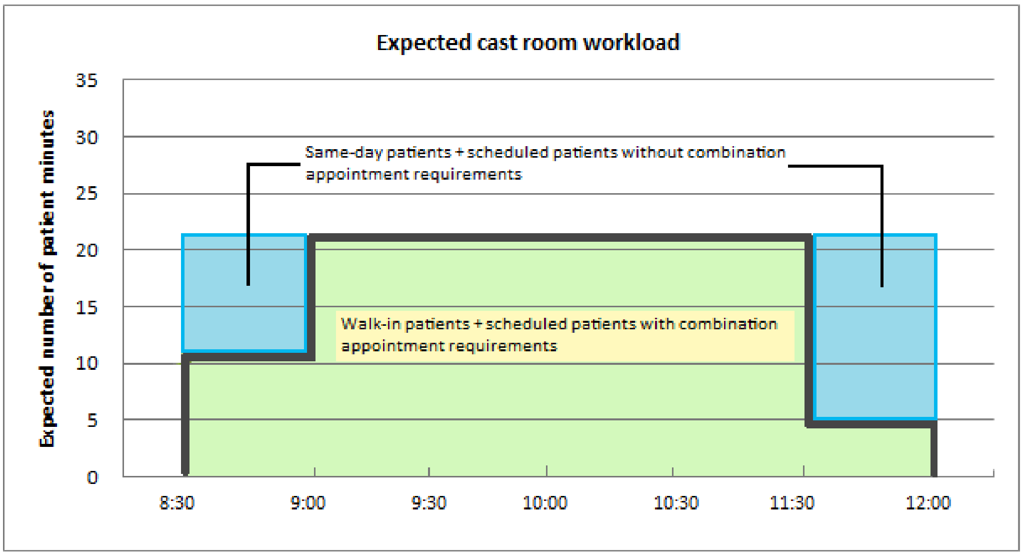

Figure 4.13: Expected cast room workload for Tuesday morning during even weeks (Observation period 25 May – 19 June 2009, outpatient clinic schedules 2010)

Figure 4.12 shows that non peak moments are every morning between 8.30-9.00AM and 11.30-12.00AM, and every afternoon from 3.30-4.00PM. Please note that the non-peak between 8.30-9.00AM is higher than 11.30-12.00AM, because the Orthopedic specialists start their consulting hours at 8.30AM instead of 9.00AM (Traumatology and Plastic Surgery).

This sub-intervention proposes to schedule appointment requests without combination appointment requirements primarily during these non peak moments. Furthermore, we propose to schedule appointment requests with combination requirements only during the peak moments. To be clear about the procedure, we now describe the exact steps in appointment scheduling for both possibilities:

Appointment request with combination appointment requirement

1- Find shift in which the required specialist is present.
2- Find free agenda slots:
    a. If AM: Find free agenda slots between 9.00-11.30AM in agenda 1.
    b. If PM: Find free agenda slots between 1.00-3.30PM in agenda 1.
3- If no available agenda slot is found:
    a. If AM: Find free agenda slots between 9.00-11.30AM in agenda 2.
    b. If PM: Find free agenda slots between 1.00-3.30PM in agenda 2.
4- If no available agenda slot is found:
    a. If AM: Find free agenda slots between 9.00-11.30AM in overbooking agenda.
    b. If PM: Find free agenda slots between 1.00-3.30PM in overbooking agenda.
5- If no available agenda slot is found, locate next shift in which the required specialist is present and go back to step 2.

Appointment request without combination appointment requirement

1- Find first available shift based on patient characteristics.
2- Find free agenda slots:
    a. Find free agenda slots between 8.30-9.00AM in agenda 1/2
    b. Find free agenda slots between 11.30-12.00AM in agenda 1/2.
    c. Find free agenda slots between 3.30-4.00PM in agenda 1/2.
3- If no available agenda slot is found:
    a. Find free agenda slots between 8.30-9.00AM in overbooking agenda.
    b. Find free agenda slots between 11.30-12.00AM in overbooking agenda.
    c. Find free agenda slots between 3.30-4.00PM in overbooking agenda.
4- If no available agenda slot is found:
    a. Find free agenda slots between 9.00-11.30AM in agenda 1/2.
    b. Find free agenda slots between 1.00-3.30PM in agenda 1/2.
5- If no available agenda slot is found:
    a. Find free agenda slots between 9.00-11.30AM in overbooking agenda.
    b. Find free agenda slots between 1.00-3.30PM in overbooking agenda.
6- If no available agenda slot is found, go to next day and go back to step 2.

Please note that we use the same agendas and agenda times as in the base situation (See description in Section 4.3).

RULES OF THUMB REGARDING APPOINTMENT SCHEDULING

In Section 3.3 and the document 'Verbeteracties gipskamer' (2009), we outline several recommendations regarding appointment scheduling. This section describes rules of thumb that we propose to improve the scheduling of appointments. The goal of these rules is to schedule specific treatment types together to minimize variability, that results in delay. Furthermore, we ensure that the impact of variability is as small as possible during the beginning of a shift. For instance, if a disturbance occurs during a treatment with high variability at the start of a shift, the potential impact on the average patient waiting time is more dramatic than when a disturbance occurs during a treatment with small variability.

Low-variance at the beginning of the shift (LVBEG)

We schedule patients with a required slot length B15 from the beginning of the shift (slot 1) towards the end (slot 14), and we schedule patients with a required slot length of B30-B90 from the end of the shift (slot 14) towards the beginning (slot 1). This results in a schedule where low-variance treatments meet the high-variance treatments in the middle. LVBEG scheduling applies for both combination appointments and non-combination appointments.

When the LVBEG-rule is applied in combination with scheduling during non-peak moment for appointment requests without combination appointment requirements, the model first determines in which agenda(s) to look for available agenda slots. Subsequently, the model uses the LVBEG-rule to find available slots in the agenda(s).

Adjusted dome-shaped scheduling

Dome-shaped scheduling gradually increase the appointment slot duration to the middle of the shift, after which the appointment slot duration decreases from the middle of the shift towards the end. Hereby, we adjust the LVBEG scheduling rule, so that treatments with an expected treatment duration longer than 15 minutes can only be scheduled to either 11.45 AM or 15.45 PM (Slot 13).

Please note that adjusted dome-shaped scheduling cannot be combined with either LVBEG or scheduling during peak moments during simulation.

Long expected treatment duration at the end of the day

We propose to schedule treatments with a long duration at the end of the day. We define a long duration as a duration longer than thirty minutes. It is possible that a patient with a long treatment duration requires a combination appointment. Therefore, we propose a distinction.

- *No combination appointment required:* Find available agenda slots from the end of the day.
- *Combination appointment required:* Find available agenda slots from the end of the shift in which the required specialist is present.

Hereby, we locate available agenda slots from the last agenda slot (of either the day or shift) towards the beginning of the shift.

Capacity reserving for inpatients

In consultation with the cast room stakeholders, we propose to reserve capacity for inpatients on every day. We use the observation period to determine the average amount of inpatient minutes per day. We find that we require on average one hour per day. We propose to divide this evenly over two shifts. Hereby, we reserve capacity in the morning for discharge inpatients between 10.00-10.30 AM. Furthermore, we reserve capacity in the afternoon for non-discharge patients between 3.30-4.00 PM.

Capacity reserving for same-day patients

In consultation with the cast room stakeholders, we propose to reserve capacity for same-day patients on every day. We use the observation period to determine the average amount of same-day patient minutes per day. We find that we require on average one and a half hour per day. We propose to divide this evenly over two shifts. Hereby, we reserve capacity in the morning for discharge inpatients at 10.00-10.45 AM. Furthermore, we reserve capacity in the afternoon for non-discharge patients at 3.15-4.00 PM.

Introduce planned slack in appointment scheduling

We find that disturbances as well as internal delays occur frequently during the day (see Section 2.3). This results in additional patient waiting time in combination with a decrease of the service level. We propose to include slack in appointment scheduling. Hereby, we design two alternatives.

- *Alternative 1:* Add 5 minutes of slack to treatments with an expected duration longer than 30 minutes.
- *Alternative 2:* Add 5 minutes of slack to any treatment.

4.5.3 INTERVENTION 3: MORE INVASIVE IMPROVEMENT ACTIONS

This section outlines intervention 3 with more invasive improvement actions. Hereby, we describe further alterations in the agenda system regarding the slot duration, improvement in communication regarding the lack in appointment scheduling of walk-in patients and same-day patients, reducing the percentage of no-shows and cancellations, and adjustments in the outpatient clinic capacity to further improve the performance of our interventions in the cast room.

INTRODUCTION OF THE B10 AGENDA SLOT

Section 4.2 describes the lack in the number of observations per treatment type (see Appendix C). However, we do have 108 observation of the treatment type *cast removal,* which shows an average duration of 7 minutes. This is remarkably, as DAs schedule these treatments in an agenda slot of 15 minutes (B15) in the current situation. In consultation with the cast room stakeholders we decide to adjust the minimum length of agenda slots to improve the fit with the actual treatment duration. Hereby, we propose to schedule cast removals in our model in an agenda slot of 10 minutes (Treatment 0). This results in the adjustments of the treatment duration in our model. First, we fit the observation period data regarding cast removals to a Weibull distribution. Second, we update the duration of Treatment 1 and Treatment 2 (see Tables 4.5 and 4.9). Furthermore, we update the probabilities per treatment type. Table 4.15 shows the updates in probability as well as the input parameters of the agenda slots per scheduled/same-day patient in our simulation model.

Treatment type	***Probability***	***Duration (in minutes) modeled by:***	***Z value < critical value***	
Treatment 0	27.5%	Weibull distribution: α=1.71, β=7.26	13.39 < 16.81	*Do not reject*
Treatment 1	38.9%	Weibull distribution: α=1.29, β=23.23	1.46 < 16.81	*Do not reject*
Treatment 2	33.6%	Weibull distribution: α=1.88, β=26.95	0.80 < 16.81	*Do not reject*
Treatment 3	0.9%	No changes	n.a.	
Treatment 4	0.9%	No changes	n.a.	
Treatment 5	0.2%	No changes	n.a.	

Table 4.15: Input parameters for treatment types (Update of tables 4.3 and 4.2)

Schedule cast removals at the start of the cast room consulting hours

In consultation with the cast room stakeholders, we propose a new rule of thumb regarding appointment scheduling. As an adjustment of the LVBEG-rule, we schedule the cast removals at the start of the consulting hours. Hereby, if a cast removal is required, the model tries to find an available slot from the start of the shift to the end. When a treatment is required with an expected duration of 15 minutes, the model tries to find available slots from the middle of the shift towards the beginning, When treatment is required with an expected duration longer than 15 minutes, the model tries to find an available slot from the end of the shift towards the beginning. Hereby, we make sure that the first agenda slots of a shift are kept free until the agenda is filled. Please note that it is possible that the rule of thumb regarding long treatments is in place to schedule treatments with a long expected duration (45 minutes or more) as discussed before.

OPTIMIZING THE FIT BETWEEN SCHEDULED AND ACTUAL TREATMENT DURATION

In the current situation, the actual treatment duration differs from the scheduled treatment duration (see also Appendix C). Cast room stakeholders indicate the possible improvement in clear communication by actually communicating the expected treatment duration rather than the treatment type. During this extension, we assume that OCTs are able to exactly estimate the actual treatment duration of a patient. Hereby, we use the input parameters as described in Section 4.2. The model assigns a treatment duration to a patient. We round up this actual processing time according to a minimum slot length of 5 minutes, and subsequently schedule the required slots in the agenda. This results in a best case scenario, as the scheduled duration is always more than the actual duration and includes slack for possible disturbances.

IMPROVED COMMUNICATION TO REDUCE THE PERCENTAGE OF WALK-IN PATIENTS

The report *'Optimalisatie logistiek gipskamer: Analyserapport'* (2009) shows that walk-in patients represent 30% of all patients during the observation period. Some of the walk-in patients require an appointment, but as a result of lack in communication between cast room personnel and outpatient clinic personnel, the appointment is not scheduled. Table 4.16 shows the types of walk-in patients.

Walk-in patients	***%***
Combination – ad hoc	58%
Cast problems	13%
Cast replacement	19%
Cast removal	3%
Emergency – ad hoc	2%
Unknown	5%

Table 4.16: Types of walk-in patients (Observation period 25 May – 19 June 2009, N=254 patients)

Cast room stakeholders indicate that part of the walk-in patients with the type *Combination – ad hoc,* and all of the walk-in patients with the types *Cast replacement,* and *Cast removal* should receive a appointment beforehand. As there is no exact indication what part of the *Combination – ad hoc* walk-in patients should receive an appointment, we assume this part equals 50% (of 58%). According to these expert opinions, we set the total percentage of walk-in patients that receive an appointment to 41% (=*0.5*58+19+3*). Therefore, we use the same arrival rates as for the current situation, however, we schedule an appointment for 41% of these walk-in patients. For appointment scheduling, these patients require the attributes specialist, treatment week and treatment duration. We assume that it is possible that these patient require a combination appointment.

To determine this requirement, we derive probabilities for the specialists. We base these probabilities on the walk-in patients during the observation period. Table 4.17 shows the probabilities.

#	Specialist	P	#	Specialist	P	#	Specialist	P
0.	No specialist required	47.7%	**7.**	CHP-Strackee	9.2%	**14.**	TRA-Goslings	0.0%
1.	TRA-Assi	6.6%	**8.**	ORT-vanDijk	3.3%	**15.**	CHP-Lapid	0.7%
2.	ORT-Kloen	7.3%	**9.**	TRA-Ponsen	2.6%	**16.**	CHP-vanLoon	1.3%
3.	CHP-Ontslag	1.3%	**10.**	TRA-Luitse	4.0%	**17.**	ORT-Schafroth	0.7%
4.	TRA-Mult	3.3%	**11.**	TRA-Traumatoloog i.o.	0.0%	**18.**	ORT-Struys	0.7%
5.	ORT-Kerkhoffs	3.3%	**12.**	ORT-Bramer	2.6%	**19.**	CHP-vdHorst	0.1%
6.	TRA-vDijkman	1.3%	**13.**	ORT-Schaap	1.3%	**20.**	CHP-Obdeijn	0.1%

Table 4.17: Specialist requirement probabilities for walk-in patients (Observation period 25 May – 19 June 2009, N=151 patients)

Furthermore, we determine the required agenda slot length based on the duration of the treatment. Hereby, we round up to a multiple of the minimum slot length of 15 minutes. To assign the treatment week, we use the probabilities of Table 4.6.

IMPROVE COMMUNICATION BETWEEN INPATIENT CLINIC AND CAST ROOM

In the current situation, the inpatient clinic calls to the cast room to make an appointment for an inpatient. If possible, this appointment is on the same-day, if not, the OCTs schedule the appointment on the following day. Cast room stakeholders indicate that the treatment procedure of inpatients is known beforehand. This means that their appointments can be scheduled beforehand like scheduled outpatients. However, there is uncertainty about the discharge of an inpatient from the hospital. Before a cast room inpatients is discharged, this patient receives a new plaster cast. We assume that 50% of the inpatients at the cast room can be scheduled like outpatients. During this sub-intervention, we use the same arrival rates for same-day patients as in the current situation. However, 50% of the inpatients receives an appointment. Hereby, we assume the required attribute week as equal to one, and the attribute specialist equal to zero (no combination appointment required). Furthermore, we determine the required agenda slot length based on the duration of the treatment. Hereby, we round up to a multiple of the minimum slot length of 15 minutes.

REDUCE PERCENTAGE OF NO-SHOWS AND CANCELLATIONS

In the current situation, the cast room encounters a high percentage (9.3%) of no-shows. Part of these no-shows are cancellations by either the patient, DA, or a specialist. During this sub-intervention, we evaluate the reductions in the percentage of no-shows while the cast room workload remains the same. Hereby, we mean that a decrease in the no-show percentage results in an adjusted arrival rate of scheduled patients in order to keep the same total number of patients. We assume one situation for this sub-intervention in which we reduce the no-show percentage with 50% to 4.65%. Please note that as in the current situation, 80% of the no-shows remains a cancellation.

ELIMINATION OF OCT UNAVAILABILITY

Section 2.3 as well as the report 'Analyserapporage gipskamer' (2009) describe the impact of fluctuations in capacity during a shift on the overall performance. OCT unavailability occurs both scheduled as unscheduled. The goal of this sub-intervention is to show the potential improvement in performance when the cast room is able to improve the coordination of the OCT unavailability. Therefore, we assume that we can eliminate all types of OCT unavailability, except for the lunch break and treatments at the operating room.

ELIMINATION OF DISTURBANCES DURING TREATMENT

Section 2.3 as well as the report 'Analyserapporage gipskamer' (2009) describe the impact of disturbances during the treatment of cast room patients. The goal of this sub-intervention is to show the potential improvement in performance when disturbances during treatment do not occur. Hereby, we eliminate the occurrence of disturbances during treatment from our model.

REDUCE SPECIALIST WAITING TIME

Section 2.3 as well as the report 'Analyserapporage gipskamer' (2009) describe the impact of internal waiting time for specialists. The goal of this sub-intervention is to show the potential improvement in performance when the specialist waiting time is reduced. Hereby, we reduce the specialist waiting time with 50%.

DOCTOR'S ASSISTANT IN THE CAST ROOM

Section 2.3 indicates the disturbances and problems of the cast room process. Cast room stakeholders indicate the added value of placing a doctor's assistant in the cast room. The presence of a doctor's assistant (DA) in the cast room is able to remove bottlenecks in the process. We define the following tasks for a doctors' assistant when present in the cast room. Currently, the OCTs pick up patients or specialists, and deal with disturbances. The DA is able to perform these tasks, while the OCTs continue with the treatment of patients. Also, the DA is able to assist an OCT instead of another OCT. Based on expert opinions from the stakeholders in the cast room process, we propose two possible improvement situations by placing a DA in the cast room, which Table 4.18 summarizes.

Improvement aspects	***Alternative 1: Limited use of DA***	***Alternative 2: Extensive use of DA***
Treatment setup time + registration	DA performs 75% of these tasks	DA performs 100% of these tasks
Disturbances	DA deals with 50% of disturbances	DA deals with 100% of disturbances
Specialist waiting time	Specialist waiting time is 75%	Specialist waiting time is 50%
OCT assistance	OCT assistance duration is 50%	OCT assistance duration is 50%

Table 4.18: Effects of placing a DA in the cast room

SPREAD OF THE SPECIALIST CONSULTING HOURS SCHEDULE

Figure 2.4 shows the average number of patients per shift. As a result of the specialist consulting hours scheduler, the total number of patients per shift fluctuates. Our goal is to balance the total number of patients per shift during a cycle. Hereby, we are able to balance capacity accordingly.

According to the observation period data, we derive the total impact per hour per specialist. Hereby, we use impact as the total number of patients at the cast room that combines an appointment with specialist. These combined appointments include both scheduled combination appointments as well as walk-in referrals. Table 4.19 shows the impact per specialist in combination with the required number of consulting hours per cycle.

Specialist	Impact	Shifts	Specialist	Impact	Shifts	Specialist	Impact	Shifts
TRA-Assi	1.37	8	ORT-vanDijk	0.8	5	CHP-Lapid	0.22	7
ORT-Kloen	2.58	4	TRA-Ponsen	1.22	2	CHP-vanLoon	1	5
CHP-Ontslag	0.53	8	TRA-Luitse	1.11	2	ORT-Schafroth	0.09	1
TRA-Mult	2.17	2	TRA-Traumatoloog i.o.	1.33	2	ORT-Struys	0.67	4
ORT-Kerkhoffs	0.88	5	ORT-Bramer	0.18	5	CHP-vdHorst	0.33	3
TRA-vDijkman	1.67	2	ORT-Schaap	0.19	4	CHP-Obdeijn	0.17	9
CHP-Strackee	1.13	5	TRA-Goslings	0.67	2			

Table 4.19: Impact per shift, and required number of shifts for each specialist (Observation period 25 May – 19 June 2009, N=19 days)

We combine the specialist's consulting hours schedule (see Appendix B) with the impacts to determine the total impact per day in number of expected patients per hour. Table 4.20 shows the results.

Even weeks										***Odd weeks***									
Monday		*Tuesday*		*Wednesday*		*Thursday*		*Friday*		*Monday*		*Tuesday*		*Wednesday*		*Thursday*		*Friday*	
a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.
1.9	3.4	3.2	3.9	0.9	2.8	7.7	3.0	4.0	1.0	1.6	3.2	6.3	1.3	0.3	2.8	6.3	4.4	4.1	1.2

Table 4.20: Total impact per shift during a cycle (Observation period 25 May – 19 June, N=19 days, N=19 specialists)

Table 4.19 shows fluctuations in total impact, just like figure 2.4. To balance the impact over all days, we formulate an integer linear programming problem. Hereby, we solve the problem by rescheduling the consulting hours according to the required number of consulting hours per week. We formulate the problem to minimize the maximum total impact for any day during the shift. We include the ILP problem formulation in Appendix E. Table 4.21 shows the results of the optimal solution and the improved balance over the shifts, whereas Figure 4.14 shows the update specialist's consulting hours schedule.

Even weeks										***Odd weeks***									
Monday		*Tuesday*		*Wednesday*		*Thursday*		*Friday*		*Monday*		*Tuesday*		*Wednesday*		*Thursday*		*Friday*	
a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.
3.2	3.3	3.2	3.2	3.3	3.3	3.3	3.2	3.3	3.2	3.3	3.2	3.3	3.2	3.2	3.3	3.3	2.7	2.4	3.2

Table 4.21: Total impact per shift during a cycle (Solution of ILP problem for specialist's consulting hours schedule, see Appendix E)

Section 4.2 describes the impact of the specialist's presence during a shift on the walk-in arrival rate. According to the updated impacts and specialist's schedule, we alter these arrival rates.

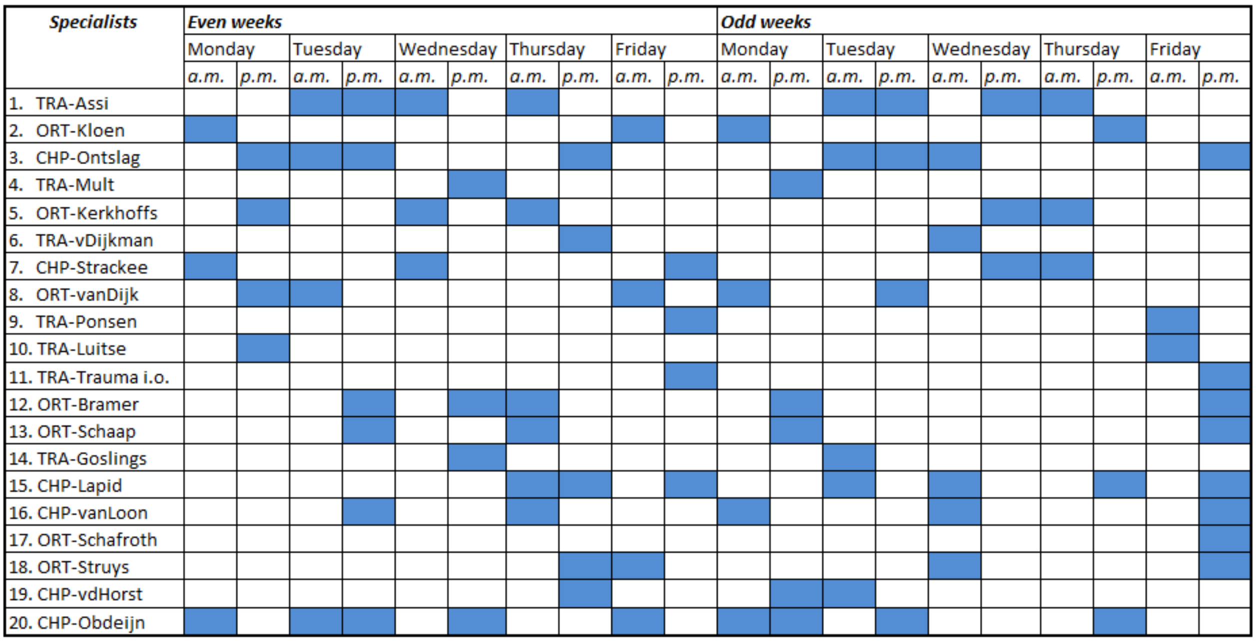

Figure 4.14: Specialist consulting hours schedule optimal (Appendix E)

The former OCT schedule was based on the expected number of patients per shift. The spread of the specialists' consulting hours schedule results in a spread of the expected number of patients per shift. Therefore, we propose to reschedule the number of OCTs per shift. We use the sum of the current OCT capacity (see Table 4.13) and divide this number evenly over the total number of shifts. The sum equals 61, which results in 3.05 OCTs per shift. We schedule 3 OCTs to every shift and have one OCT left to schedule. In the former schedule, only Thursday morning (both even/odd weeks) and Thursday afternoon (odd weeks) did have an OCT shift capacity of 4. We propose to schedule the additional OCT to the shift with the highest expected number of patients. We find that this is Thursday morning (even weeks). Table 4.22 shows the OCT schedule for this sub-intervention.

OCT capacity per shift		Even weeks	Odd weeks
Monday	*a.m.*	3	3
	p.m.	3	3
Tuesday	*a.m.*	3	3
	p.m.	3	3
Wednesday	*a.m.*	3	3
	p.m.	3	3
Thursday	*a.m.*	4	3
	p.m.	3	3
Friday	*a.m.*	3	3
	p.m.	3	3

Table 4.22: OCT schedule (Sub-intervention spread of specialists' consulting hours)

CHAPTER 5 - RESULTS OF THE SIMULATION STUDY

Chapter 5 discusses the results of our simulation study. We present and discuss the results for the interventions and their sub-interventions. Hereby, we follow the structure of Section 4.5. Please remind that we perform 10 replications per (sub-)intervention, each of 1,000 days (see Section 4.4).

5.1 BASE SITUATION

The base situation represents the current cast room situation. We use the base situation to compare with our (sub-)interventions. Hereby, we use the key performance indicators as described in Section 2.3. The most important performance indicator is service level. The service level indicates the percentage of patients seen in the cast room within a waiting time of 20 minutes. In addition, we use the average patient waiting time (PWT). A.M. overtime is the overtime for OCTs between the last treatment in the morning and the end of the morning shift (12.15 AM). P.M. overtime is the overtime for OCTs between the last treatment in the afternoon and the end of the afternoon shift (4.30 PM). Please note that we show undertime as negative overtime. To conclude, we also show the percentage of patients scheduled on the earliest possible appointment date to compare the sub-interventions.

OVERALL PERFORMANCE

Table 5.1 shows the performance of the base situation.

Base situation	***Service level (Mean)***	***Service level (St. Dev)***	***PWT (Mean)***	***PWT (St. Dev)***	***A.M. overtime***	***P.M. overtime***	***Earliest date (%)***
Base situation	72.2%	0.8%	17.7 min.	0.8 min.	+4.3 min.	-7.6 min.	89.6%

Table 5.1: Results of the base situation

We find that the base situation has a service level of 72.2% in combination with an average patient waiting time of 17.7 minutes. Section 2.3 states our target service level of at least 95%. The next sections zoom in on the performance of the base situation regarding our performance indicators.

SERVICE LEVEL

First, we break down the service level for scheduled and walk-in patients. Table 5.2 shows these service level percentages.

Base situation	***Service level (Mean)***	***Service level (St. Dev)***	***Service level (scheduled) (Mean)***	***Service level (walk-in) (Mean)***
Base situation	72.2%	0.8%	73.7%	69.4%

Table 5.2: Service level for scheduled patients and walk-in patients in the base situation

Table 5.2 shows that scheduled patients have a higher service level than walk-in patients. This results from the punctuality of scheduled patients at the start of a shift. Scheduled patients arrive earlier than walk-in patients. Hereby, the use of the first come first serve-rule in the current situation benefits the scheduled patients at the start of shifts.

Second, Table 5.3 provides insight in the service level per shift in the current situation.

Shift service levels		***Even week***					***Odd week***				
		Mo	*Tu*	*We*	*Th*	*Fr*	*Mo*	*Tu*	*We*	*Th*	*Fr*
Base situation	*a.m.*	85%	73%	89%	82%	92%	70%	73%	92%	85%	91%
	p.m.	44%	33%	85%	63%	87%	56%	47%	86%	66%	67%

Table 5.3: Service levels per shift for the base situation

Table 5.3 shows that the service levels fluctuate per shift. Overall, the morning shifts have a higher service level than the afternoon shifts. In addition, we find that some shifts have a very low performance (<50%) compared to the average service level (72%).

First, the differences in service level between morning and afternoon result from the OCT overtime in the morning in combination with the shared lunch breaks. In addition, we find that the agendas actually contain appointments at the start of the shift. Therefore, patients are actually present at the start of a shift and encounter the waiting time that results from the delay in shift start time. Figure 5.1 emphasizes the impact of the delay at the start of shifts.

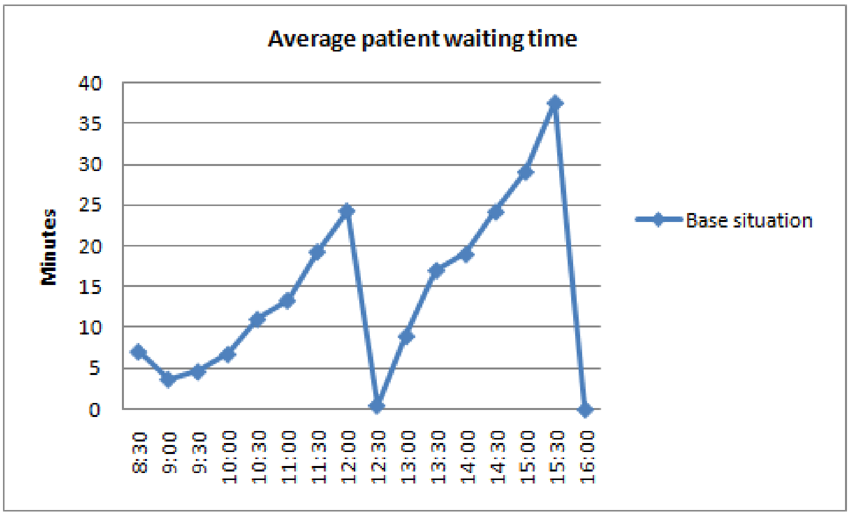

Figure 5.1: Average patient waiting time per 30 minutes (Base situation)

Figure 5.1 confirms that the service level is lower in the afternoon. Furthermore, Figure 5.1 shows that the cast room immediately starts with waiting time that gradually increases during the shift. This corresponds with our description in Section 2.3.

Second, the shifts with a very low performance in service level (<50%) experience additional Pediatric outpatient clinic capacity requirements. The decrease in capacity during those shifts results in the decrease of the shift service level. We find that this corresponds with the results of our observation period.

Overall, we find that delays in shift starting time, temporary OCT unavailability, disturbances (or internal delays) during treatments, and variance in treatment duration contribute to the service levels lower than the target of 95%. In the following paragraphs of this chapter, we evaluate the performance of our (sub-)interventions compared to the performance of the base situation. The overall goal of these (sub-)interventions is to increase the service level per shift to at least 95%. Hereby, an important additional goal is to balance the workload of OCTs during a shift.

OCT OVERTIME

The average OCT overtime does not show the frequency in which OCT overtime actually occurs. Table 5.4 provides insight in these frequencies for both the morning and the afternoon shift.

Base situation	***Average AM overtime***	***% AM overtime of total AM shifts***	***Average PM overtime***	***% PM overtime of total PM shifts***
Base situation	+4.3 min.	61.2%	-7.6 min.	37.3%

Table 5.4: OCT overtime for the base situation

Table 5.4 shows that AM overtime occurs regularly with 61.2% of all shifts. However, the average AM overtime is only 4.3 minutes. Overtime in the afternoon does not occur as frequently as in the morning with 37.3%. This also results in the average PM undertime of nearly 8 minutes. The differences between the morning and afternoon shift result from the available agenda slots near the end of the shift. The agenda allows appointments up to 15 minutes before the end time of the morning shift. In the afternoon, this is 30 minutes.

APPOINTMENT SCHEDULING

Our model schedules appointment requests based on the patient attributes required week, specialist, and treatment type. Hereby, the preferred situation is that patients receive their appointment on the earliest appointment date or as close to the earliest possible appointment date as possible. The model determines this date by the combination of the appointment request date and the patient attributes week and specialist. Subsequently, sufficient agenda slots should be available to actually schedule the appointment. Table 5.5 shows the percentage of scheduled patients that are scheduled on the earliest possible date as well as the percentage of scheduled patients that is scheduled within five days of the earliest possible date.

Base situation	***% scheduled on earliest possible date***	***% scheduled within five days of earliest possible date***
Base situation	89.6%	100.0%

Table 5.5: Appointment scheduling performance for the base situation (N=18,058)

Table 5.5 shows that nearly 90% of the patients with an appointment receives the appointment on the earliest possible date. Every patient with an appointment receives this appointment within five days of the earliest possible appointment date. We require that any of our (sub)-interventions should be equal or higher than to percentage of 89.6% of patients scheduled on the earliest possible date. Treatments of cast room patients follow a specific procedure and time duration (in weeks/months).

BASE SITUATION VS. (SUB)-INTERVENTIONS

The following sections describe the performance for the (sub)-interventions. Hereby, we show the performance for each sub-intervention for the performance indicators service level percentage, average patient waiting time, and OCT overtime (AM/PM). We indicate if any differences for the service level percentage are statistically significant based on a confidence interval of 95%. Hereby, we use the paired-t approach as described by Robinson (2004). Hereby, we determine the confidence interval according to the mean difference and standard deviation of the differences between each sub-intervention and the base situation regarding the service level. Furthermore, we use symbols to show if the average values of the sub-interventions differ from the base situation, but only if the service level changes significantly compared to the base situation. We use the following symbols:

- the "✔" symbol indicates a significant improvement in performance.
- the "✖" symbol indicates a significant deterioration in performance.
- the "⊖" symbol indicates that there are no significant changes in performance.

Furthermore, at the end of each intervention, we combine the sub-interventions to evaluate the overall intervention performance improvement. First, we determine the best combination of sub-interventions. Second, we show and describe the results of the best combination of sub-interventions in more detail as we did for the base situation. Please note that we use the most successful combination of sub-interventions for further experimentation with subsequent (sub)-interventions.

5.2 INTERVENTION 1: LESS INVASIVE IMPROVEMENT ACTIONS

This section describes and discusses the results of the sub-interventions of intervention 1. The goal of intervention 1 is to improve the communication between OCTs and the DAs, as well as the timeliness of OCTs. These improvements concern adjustments in the behavior of both OCTs and DAs of the outpatient clinic.

First, we present and discuss the results of each individual sub-intervention. Second, we combine the sub-interventions and evaluate the overall improvement in performance. Based on the individual performance, we decide to include or exclude sub-interventions in the combination. Please note that we do not show the performance of the individual sub-interventions as detailed as Section 5.1.

5.2.1 RESULTS OF THE INDIVIDUAL SUB-INTERVENTIONS OF INTERVENTION 1

Table 5.6 summarizes the results of the performance of the individual sub-interventions for intervention 1.

Intervention 1: Less invasive improvement actions	*Service level (Mean)*	*Service level (St.Dev)*	*Stat. signif. (95%)*	*PWT Mean (min.)*	*PWT St.Dev (min.)*	*A.M. overtime (min.)*	*P.M. overtime (min.)*	*Earliest date (%)*
Base situation	72.2%	0.8%	n.a.	17.7	0.8	+4.3	-7.6	89.6%
1. OCT punctuality	74.0% ✔	0.7%	Yes	16.5 ✔	0.6	+4.0 ✔	-8.2 ✔	89.6%
2. Individual lunch breaks	75.3% ✔	0.6%	Yes	15.1 ✔	0.4	+4.0 ✔	-11.7 ✔	89.6%
3. Cancellations	72.4% ⊖	0.6%	No	17.6 ⊖	0.7	+4.0 ⊖	-8.2 ⊖	89.5%
4. Capacity blocking	72.7% ⊖	0.4%	No	17.4 ⊖	0.4	+3.7 ⊖	-8.7 ⊖	89.5%
5. Improve patient prioritization	72.9% ⊖	0.9%	No	17.9 ⊖	1.0	+4.4 ⊖	-7.2 ⊖	89.6%

Table 5.6: Results of intervention 1: sub-interventions individually (10 replications of 1000 days)

We discuss the results for each sub-intervention in the remainder of this section.

OCT PUNCTUALITY

The goal of this sub-intervention is to decrease the high waiting time for patients at the start of the day (see Figure 2.6 and 5.1). The removal of delay by OCT punctuality results in an increase of the service level percentage as well as a decrease of the average patient waiting time. We expect the increase in service level performance as the delay at the start of the morning shift is removed. Patients with a scheduled appointment at 8.30 AM do not encounter waiting time anymore, which results in the improvement in the service level. As a result of starting on time, the results confirm our expectations regarding the decrease in overtime. The OCTs are finished earlier in the morning compared to the base situation. This also results in less PM overtime, as the OCTs start earlier with their afternoon shift as well.

INDIVIDUAL LUNCH BREAKS

The goal of the individual lunch breaks is to decrease the high waiting time for patients at the start of the afternoon shift (see Figure 2.6 and 5.1). This sub-intervention results in an increase of service level and a decrease of average patient waiting time. Like the previous sub-intervention, the individual lunch breaks reduce the delay in starting time of the afternoon shift. Therefore, the improvement in service level matches our expectations. The improvement in service level is larger than when removing OCT punctuality in the morning. Apparently, the delay of shared lunch breaks has a longer duration than the morning punctuality. In the morning, the OCTs are present in the cast room and thus, they are aware that patients are waiting for treatment. During the lunch break, they are not present in the cast room and they want to have sufficient time to lunch. Remarkably, the individual lunch breaks increase the OCT morning overtime with 0.3 minute for what we do not have an explanation. We find that our expectations regarding OCT afternoon overtime are met with a decrease to 11.7 minutes undertime.

CANCELLATIONS

Apparently, cancellations do not result in a significant improvement of the service level performance. We would expect a small increase in performance as same-day patients can be scheduled during cancelled appointments. In the current situation, DAs schedule same-day outpatients during free agenda slots. This has the same result as our sub-intervention. In addition, OCTs schedule same-day inpatients during moments that they expect few cast room patients. Our model does not model the same-day inpatients according to this method. Therefore in practice, we expect a clear improvement for this sub-intervention. We further comment on this aspect and the implementation in Chapter 6. In addition, we find that 88% of the same-days patients are inpatients. These patient receive a B30 agenda slot. However, the most common treatment slot is 15 minute. This means that if an cancellation occurs, this is in most cases a B15 slot. This slot is not large enough to schedule a same-day inpatient with B30 agenda slot requirements. Therefore, this sub-intervention does not show the significant improvement that we expected.

OPERATING ROOM CAPACITY BLOCKING

Capacity blocking results in the reservation of capacity to cope, in this instance, with unscheduled OCT unavailability. Hereby, we temporarily decrease the workload proportionate to the temporary decrease in capacity. For this reason, we expect that this sub-intervention results in an increase of service level. We find that the service level slightly improves, but this is not significant. We clarify this as a result of appointment scheduling. Section 4.2 shows that most patients receive their appointment at least one week in advance, while the capacity blocking occurs exactly one week in advance. Table 4.6 shows that at least 46% of the scheduled patients receive an appointment more than one week in advance. The remaining 54% receive an appointment on earliest between 5-9 days depending on specialist requirements. We expect that the service level improves if the OR treatments are known more than a week in advance.

IMPROVE PATIENT PRIORITIZATION

In the current situation, the OCTs treat patient according to a “first come, first serve”-rule. Due to high levels of punctuality, it occurs that patients that arrive on time for their appointment have to wait for patients that arrived too early for their appointment. Also, walk-in patients contribute to this occurrence. Therefore, we evaluate a patient prioritization rule that avoids this occurrence. Hereby, we expect that the service level increases, especially for scheduled patients. Table 5.6 shows no significant improvement in overall service level. Therefore, Table 5.7 shows the service level for scheduled and walk-in patients for the base situation as well as this sub-intervention.

Intervention 1: Less invasive improvement actions	***Service level (Mean)***	***Service level (St. Dev)***	***Service level (scheduled) (Mean)***	***Service level (walk-in) (Mean)***
Base situation	72.2%	0.8%	73.7%	69.4%
Improve patient prioritization	72.9%	0.9%	76.3%	67.5%

Table 5.7: Service level results for sub-intervention improve patient prioritization

Table 5.7 confirms that the patient prioritization rule does improve the service level for scheduled patients. Hereby, the service level for walk-in patients decreases, which is the result of the priority of scheduled patients after their appointment time over walk-in patients. Therefore, we conclude that we achieve the goal of this sub-intervention, although the improvement is not immediately clear based on the overall service level.

5.2.2 INTERVENTION 1: COMBINATION OF THE SUB-INTERVENTIONS

We combine our sub-interventions to evaluate the overall performance of intervention 1. We include OCT punctuality and individual lunch breaks in each combination as both individually improve the overall performance. We are not sure about the performance of the other sub-interventions. Therefore, we design the following combinations:

- *Combination 1:* OCT punctuality, individual lunch breaks, and cancellations.
- *Combination 2:* OCT punctuality, individual lunch breaks, cancellations, and OR blocking.
- *Combination 3:* OCT punctuality, individual lunch breaks, cancellations, and improve patient prioritization.
- *Combination 4*: OCT punctuality, individual lunch breaks, cancellations, improve patient prioritization, and OR blocking.

We expect an improvement in performance by using a combination of sub-intervention. This expectation results from the individual performances of the sub-interventions that are included in each combination. Furthermore, we expect that although some sub-interventions showed better performance than others, the overall increase in performance will not be equal to the sum of the individual improvements. This is because the sub-interventions impact each other as well. Table 5.7 show the results for the combinations of intervention 1.

Intervention 1: Less invasive improvement actions	***Service level (Mean)***	***Service level (St.Dev)***	***Stat. signif. (95%)***	***PWT Mean (min.)***	***PWT St.Dev (min.)***	***A.M. overtime (min.)***	***P.M. overtime (min.)***	***Earliest date (%)***
Base situation	72.2%	0.8%	n.a.	17.7	0.8	+4.3	-7.6	89.6%
Combination 1 (1,2,3)	76.7%	1.0%	Yes	14.0	0.8	+4.3	-11.3	89.6%
Combination 2 (1,2,3,4)	77.1%	0.9%	Yes	13.9	0.7	+3.8	-11.5	89.7%
Combination 3 (1,2,3,5)	76.9%	0.5%	Yes	13.8	0.5	+4.0	-11.7	89.6%
Combination 4 (1,2,3,4,5)	77.7%	0.8%	Yes	13.9	0.5	+4.3	-11.1	89.7%

Table 5.8: Results of intervention 1: combination of the sub-interventions

Table 5.7 shows that combination 4 results in the best performance. Combination 4 includes every sub-intervention. We find that cancellations, OR blocking and improve patient prioritization do result in performance improvement in combination with the other sub-interventions. Hereby, we show that by implementation of less invasive improvement actions, we improve the average patient waiting time with nearly 4 minutes, which is an improvement of 21%.

We use combination 4 as representation of intervention 1 in further experimentation. First, we evaluate the performance of intervention 1 in more detail.

SERVICE LEVEL

Table 5.8 shows the service level for both scheduled and walk-in patients.

Intervention 1: Less invasive improvement actions	***Service level (Mean)***	***Service level (St. Dev)***	***Service level (scheduled) (Mean)***	***Service level (walk-in) (Mean)***	***Service level (same-days) (Mean)***
Base situation	72.2%	0.8%	73.7%	69.4%	69.9%
Combination 4 (1,2,3,4,5)	77.7% ✓	0.8%	80.2% ✓	73.2% ✓	66.1% ✗

Table 5.9: Service level for scheduled patients and walk-in patients in intervention 1 compared to the base situation

Like the overall service level improvement, the service level for both scheduled patients and walk-in patients increases as well. We find that the increase for scheduled patients is much higher than the increase for walk-in patients. We clarify this behavior as a result of the sub-interventions OCT punctuality and individual lunch breaks that result in improvements at the start of shifts. Scheduled patients are immediately present at the start of a shift, as they receive an appointment from 8.30AM or 1.00PM. Walk-in patients arrive during shifts for which the improvements apply less than at the beginning.

In addition, Table 5.10 shows the service level per shift for both the base situation and combination 4 of intervention 1.

Shift service levels		***Even week***					***Odd week***				
		Mo	*Tu*	*We*	*Th*	*Fr*	*Mo*	*Tu*	*We*	*Th*	*Fr*
Base situation	*a.m.*	85%	73%	89%	82%	92%	70%	73%	92%	85%	91%
	p.m.	44%	33%	85%	63%	87%	56%	47%	86%	66%	67%
Intervention 1	*a.m.*	89%	75%	92%	84%	94%	73%	75%	95%	88%	93%
	p.m.	46%	42%	87%	77%	91%	61%	57%	88%	78%	75%

Table 5.10: Service level per shift (Base situation vs. intervention 1)

Table 5.10 shows that we increase the service level per shift proportionate to the overall increase in service level percentage. The main goal of the sub-interventions OCT punctuality and individual lunch breaks is to reduce the high waiting time for patients at the start of a shift. Figure 5.2 shows the result of intervention 1 for the average patient waiting time during the day.

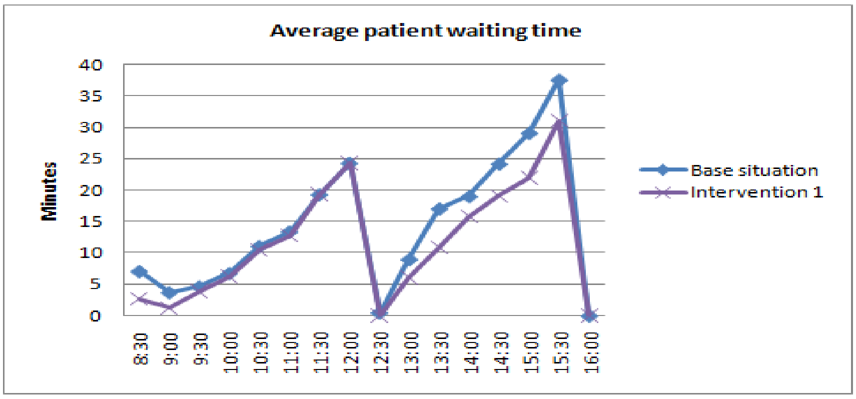

Figure 5.2: Average patient waiting time (Base situation vs. intervention 1)

Figure 5.2 confirms that intervention 1 improve the patient waiting time at the start of shifts. Hereby, as discussed before, the individual lunch breaks result in the best improvement. We conclude that in addition to the service level improvement, we actually achieve the main goal of our sub-interventions.

OCT OVERTIME

Table 5.11 shows the OCT performance for intervention 1 compared to the base situation.

Intervention 1: Less invasive improvement actions	***Average AM overtime***	***% AM overtime of total AM shifts***	***Average PM overtime***	***% PM overtime of total PM shifts***
Base situation	+4.3 min.	61.2%	-7.6 min.	37.3%
Combination 4 (1,2,3,4,5)	+4.3 min. ⊖	60.8% ✓	-11.1 min. ✓	34.0% ✓

Table 5.11: OCT overtime for intervention 1 compared to the base situation

Table 5.11 shows that we decrease the percentage of overtime in the morning as well as the afternoon. However, the overtime in the morning does not change, whereas the overtime in the afternoon decreases. The improvements results mainly from sub-interventions OCT punctuality and individual lunch breaks. Starting on time results in finishing on time and thus fewer occurrences of OCT overtime.

APPOINTMENT SCHEDULING

Table 5.12 shows the performance of appointment scheduling regarding percentages of patients that receive their appointment close to the earliest possible date.

Intervention 1: Less invasive improvement actions	***% scheduled on earliest possible date***	***% scheduled within five days of earliest possible date***
Base situation	89.7%	100.0%
Combination 4 (1,2,3,4,5)	89.7% ⊖	100.0% ⊖

Table 5.12: Appointment scheduling performance for intervention 1 compared to the base situation (18,058)

As intervention 1 does not introduce changes in the appointment scheduling process, we do not find any changes compared the base situation.

5.3 INTERVENTION 2: REDESIGN OF THE AGENDA SYSTEM AND APPOINTMENT SCHEDULING

Figure 2.7 shows the fluctuation in workload during shifts in the current situation. The goal of intervention 2 is to balance the workload of the OCTs. In Section 2.3, we outlined the direct relation between workload and the performance indicators regarding service level. Intervention 2 contains adjustments in the agenda system as well as rules of thumb for appointment scheduling to increase the balance in workload during shifts. Hereby, we consider intervention 1 to be a essential precondition in order for intervention 2 to be successful. Therefore, we use the best combination of the intervention 1 during the evaluation of intervention 2, as indicated before.

5.3.1 RESULTS OF THE SUB-INTERVENTIONS OF INTERVENTION 2

First, Table 5.13 shows the results in performance for the individual rules of thumb in combination with the sub-interventions of intervention 1.

Intervention 2: Redesign of the agenda system and of the appointment scheduling	*Service level (Mean)*	*Service level (St. Dev)*	*Stat. signif. (95%)*	*PWT Mean (min.)*	*PWT St.Dev (min.)*	*A.M. overtime (min.)*	*P.M. overtime (min.)*	*Earliest date (%)*
Intervention 1	77.7%	0.8%	Yes	13.9	0.5	+4.3	-11.1	89.7%
1. Schedule around peak moments	78.1% ⊖	0.5%	No	13.8 ⊖	0.5	+3.2 ⊖	-22.8 ⊖	99.0%
2. Low variance at the beginning	78.7% ✓	0.4%	Yes	12.8 ✓	0.4	+7.5 ⊗	-7.9 ⊗	89.5%
3. Adjusted dome-shaped scheduling	77.4% ⊖	0.5%	No	13.8 ⊖	0.5	+4.9 ⊖	-13.1 ⊖	89.8%
4. Long treatments at the end of the day	77.3% ⊖	0.7%	No	13.7 ⊖	0.4	+4.6 ⊖	-10.8 ⊖	89.1%
5. Capacity reserving for inpatients	77.3% ⊖	0.6%	No	14.0 ⊖	0.5	+5.0 ⊖	-12.3 ⊖	89.5%
6. Capacity reserving for same-days	77.0% ⊖	0.7%	No	14.2 ⊖	0.6	+5.4 ⊖	-14.5 ⊖	89.6%
7. Limited planned slack	77.7% ⊖	0.8%	No	13.6 ⊖	0.5	+3.6 ⊖	-12.9 ⊖	89.6%
8. Extensive planned slack	77.9% ⊖	1.1%	No	13.4 ⊖	0.8	+3.3 ⊖	-13.9 ⊖	89.0%

Table 5.13; Results for the rules of thumb regarding appointment scheduling

We discuss the results for each rule of thumb individually in the remainder of this section (5.3.1).

SCHEDULE AROUND PEAK MOMENTS

We reduce the number of scheduled patients during peaks. Hereby, the model schedules patients with no specialist requirements during non peak moments. Hereby, we increase the workload balance during a shift. We expect that the increase of workload balance during shifts results in an increase of service level. Furthermore, we expect that the OCT undertime increases as we schedule more patients at the end of the shift compared to the current situation.

Table 5.13 shows that this sub-intervention does not result in a significant improvement regarding service level. We do find that the overtime in the afternoon decreases with about 10 minutes. Although we also scheduled patients without combination appointment requirements at the end of shift, the probability that patients with combination appointment requirements are scheduled at the end of a peak moment is smaller. In combination with the punctuality of patients, patients without combination appointment requirements could be served earlier than scheduled, which results in less overtime.

To conclude, this sub-intervention increases the percentage of patients scheduled on the earliest possible appointment date to nearly 100%. As we schedule patients without combination appointment requirements primarily around peak moments, we more or less reserve agenda slots during peak moments for the patients with combination appointments. The increase in available slots for these patients contributes to the increase in percentage of patients scheduled on the earliest appointment date.

LOW-VARIANCE AT THE BEGINNING

The LVBEG-rule groups patients with a small treatment duration and variability at the beginning of shifts. Hereby, disturbances have a smaller impact than when a patient with a long treatment duration is treated at the start of shift. Therefore, we expect an increase in service level. Furthermore as we schedule long treatment at the end of a shift, we would expect that the OCT overtime increases.

Table 5.13 confirms our expectations. The service level percentage increases to 78.7% in combination with an average patient waiting time of 12.8 minutes. Furthermore, we find that the OCT overtime indeed increases for both shifts.

ADJUSTED DOME-SHAPED SCHEDULING

The adjusted dome-shaped scheduling rules does not differ that much from the LVBEG-rule. The only difference is that we also schedule patients with a short treatment duration at the end of shifts. Therefore, we expect that this results in a decrease of OCT overtime. However, as we schedule short treatments after long treatments, disturbances do impact these small treatments. Therefore, we expect an increase in service level though smaller than the LVBEG-rule.

Surprisingly, Table 5.13 does not confirm our expectations regarding the service level, which decreases compared to performance of intervention 1. However, the change is not significant in comparison with intervention 1. The goal of treatments with a short treatment at the beginning of a shift is to minimize the impact of disturbances on these patients. However, as we also schedule patients with a short treatment duration at the end of the shift, the impact of disturbances is higher for these patients. We clarify that the combination of these aspects that cancel each other out, which results in a service level that is not significantly different compared to intervention 1. Furthermore, we find that the OCT morning overtime increases slightly to 4.9 minutes. This increase is much smaller than the increase in OCT morning overtime when we use the LVBEG-rule. The OCT afternoon overtime decreases to 13.1 minutes of undertime. This confirms our expectations.

LONG EXPECTED TREATMENT DURATION AT THE END OF THE DAY

This rule of thumb is related to the LVBEG-rule. However, this rule specifies long treatments as treatments with a duration of 45 minutes of longer, whereas LVBEG also schedules treatments with 30 minutes at the end of the shift. Therefore, the appointment scheduling of patients with an expected treatment duration shorter than 45 minutes does not change in this sub-intervention. Another change compared to the LVBEG-rule is that when no specialist is required, this rule of thumb tries to schedule treatments with a long expected duration at the end of the day. The goal of this rule is to increase the service level percentage. As long treatments are scheduled at the end of the day, they do not cause long waiting times for short treatment duration patients that are waiting for treatment at the same moment. Hereby, if a disturbance occurs, the overall impact is smaller, because the probability that patients are waiting is smaller. Therefore, we expect to find a small increase in service level. However, we expect that the OCT undertime decreases, especially for the afternoon.

Table 5.13 shows that the service level does not change significantly. Therefore, we do not find a confirmation of our expectations regarding service level. This rule is in place for patients with an expected treatment duration of 45 minutes or longer. Table 4.5 indicates that this applies for only 2% of all scheduled patients

(Type 3,4, and 5). The other 98% of scheduled patients still receives a random slot in the agenda. Hereby, the probability is high that these patients with an expected treatment duration of 30 minutes or less receive an appointment near the end of a shift or day before an appointment request for a long treatment arrives. Therefore, the benefit of this rule does not apply yet. We clarify that there is no significant change in service level as a result of the small percentage of appointment requests for treatments with a long expected treatment duration. Furthermore, we find that the OCT overtime slightly increases, which confirms our expectation.

CAPACITY RESERVING FOR INPATIENTS

This rule of thumb uses capacity reserving. Although it is meant for potential inpatients, capacity reserving also results in an additional buffer during the shift to cope or reduce the effect of delays that occurred during the shift. Therefore, we expect that the service level improves. Furthermore, we might expect a slight increase in morning OCT overtime, as patients have to be scheduled around the capacity reserving of the morning. In addition, we expect a decrease in afternoon OCT overtime, because of our capacity reserving at 3.30 PM.

Table 5.13 does not confirm our expectations regarding service level. We do find a small increase in service level, but the average patient waiting time decrease. However, both changes are not significant compared to intervention 1. We do not have an explanation for this behavior.

We find that Table 5.13 does confirm our expectations regarding OCT overtime. Overtime in the morning slightly increases as a result of scheduling patients after the reserved capacity. Furthermore, the afternoon overtime decreases as we schedule fewer patient near the end of the day.

The main goal of this sub-intervention is not visible in terms of the service level. Namely, the goal is to see inpatients on shorter notice by reserving capacity for these patients. Table 5.14 shows the percentage of inpatients that receives an appointment on the same-day as the appointment request.

Capacity reserving for inpatients	***Earliest date (inpatients)***
Base situation	99.4%
Capacity reserving for inpatients	100.0%

Table 5.14: Service level for inpatients (intervention 1 vs. capacity reserving for inpatients)

We find that the base situation already shows a percentage of nearly 100% for inpatients scheduled on the earliest appointment date. This intervention does improve the percentage to 100%. We clarify the high initial percentage as a result of the arrival time of inpatient requests. Most inpatient requests arrive before a shift (either morning or afternoon). Hereby, there are enough agenda slots to schedule the inpatients during the morning or afternoon shift also because of the overbooking agenda. The main goal of this sub-intervention is not directly visible in this percentage or the service level. Discharge patients should be seen as soon as possible to free capacity in the inpatient clinic. The reservation of agenda slots in the middle of the morning shift contributes to this desire. Therefore, we expect that the actual benefit of this sub-intervention is visible in practice.

CAPACITY RESERVING FOR SAME-DAY PATIENTS

This rule of thumb also uses capacity reserving. Although it is meant for potential same-days, capacity reserving also results in an additional buffer during the shift to cope or reduce the effect of delays that occurred during the shift. Therefore, we expect that the service level improves. Furthermore, we might expect a slight increase in morning OCT overtime, as patients have to be scheduled around the capacity reserving of the morning. In addition, we expect a decrease in afternoon OCT overtime, because of our capacity reserving at 3.30 PM. Overall, we expect that the implementation of this rule yields better results than the rule capacity reserving for inpatients, as we create a larger buffer.

Table 5.13 does not confirm our expectations regarding service level. We find deteriorations in both the service level as well as the average patient waiting time. However, this change is not significant compared to intervention 1. We do not have an explanation for this behavior.

We find that Table 5.13 does confirm our expectations regarding OCT overtime. Overtime in the morning slightly increases as a result of scheduling patients after the reserved capacity. Furthermore, the afternoon overtime decreases as we schedule fewer patient near the end of the day. The impact for both the morning and afternoon overtime is indeed larger than during the use of the capacity reserving for inpatients rule.

The main goal of this sub-intervention is not visible in terms of the service level. Namely, the goal is to see inpatients on shorter notice by reserving capacity for these patients. Table 5.15 shows the percentage of inpatients that receives an appointment on the same-day as the appointment request.

Capacity reserving for same-days	***Earliest date (same-days)***
Base situation	99.3%
Capacity reserving for inpatients	100.0%

Table 5.15: Service level for same-day patients (intervention 1 vs. capacity reserving for same-days)

We find that the base situation already shows a percentage of nearly 100% for same-day patients scheduled on the earliest appointment date. This intervention does improve the percentage to 100%. We clarify the high initial percentage as a result of the arrival time of same-day requests. Most same-day request are inpatient requests that arrive before a shift (either morning or afternoon). Hereby, there are enough agenda slots to schedule these inpatients during the morning or afternoon shift also because of the overbooking agenda.

We conclude that this sub-intervention and the previous sub-intervention individually do not look like an addition to the current situation. However, we described the benefit for discharge inpatients in practice. Furthermore, we expect that the reservation of capacity in combination with the other rules of thumb regarding appointment scheduling results in further improvement regarding service level.

PLANNED SLACK IN APPOINTMENT SCHEDULING

The introduction of slack into appointment scheduling tries to counteract process delays as a result of disturbances and specialists' waiting time. We expect that the service level increases for both situations (limited vs. extensive). Furthermore, we expect that the OCT overtime decreases as we schedule patients with a longer duration in the agenda, which results in an overall decrease of the number of patients per shift. In addition to this, we expect that the percentage of patients scheduled on the earliest appointment date decreases as we have fewer space in the agendas left.

Table 5.13 shows that the service level does not improve significantly for either situation. Although we provide patients with additional slack in the appointment duration, we clarify this behavior as a result of the variance in actual treatment duration. Patients with an actual treatment duration of 30 minutes, but with a scheduled duration of 15 minutes, still disturb the service level. The sub-intervention slack is not able to counteract those occurrences. Furthermore, we find that Table 5.13 confirms our expectations regarding overtime and the earliest appointment date percentage.

5.3.2 INTERVENTION 2: COMBINATION OF THE SUB-INTERVENTIONS

The individual rules of thumb did not result in clear service level improvements, save the LVBEG-rule. Therefore, we evaluate several combinations in which the LVBEG-rule is always included. Chapter 4 describes that the LVBEG-rule cannot be combined with the adjusted dome-shaped scheduling rule. Therefore, we do not include that rule in our combinations. We design the following combinations:

- *Combination 1:* LVBEG, and capacity reserving for same-day patients
- *Combination 2:* LVBEG, capacity reserving for same-day patients, and peak moments.
- *Combination 3:* LVBEG, capacity reserving for same-day patients, and long treatments.
- *Combination 4:* LVBEG, capacity reserving for same-day patients, peak moments, and long treatments.
- *Combination 5:* Limited buffer, LVBEG, and capacity reserving for same-day patients
- *Combination 6:* Limited buffer, LVBEG, capacity reserving for same-day patients, and peak moments.
- *Combination 7:* Limited buffer, LVBEG, capacity reserving for same-day patients, and long treatments.
- *Combination 8:* Limited buffer, LVBEG, capacity reserving for same-day patients, peak moments, and long treatments.

Please note that we the combinations do not include the extensive buffer. We find that the percentage of patients scheduled on the earliest possible appointment date is lower that the base situation when the extensive buffer is in place. Therefore, we cannot allow this sub-intervention in our combinations. We expect each combination to result in a better performance than intervention 1. Also, we expect that the combination of some rules will result in performance improvements, rather than when we use a rule individually. Table 5.16 summarizes the results for the combinations of intervention 2.

***Intervention 2:** Redesign of the agenda system and of the appointment scheduling*	***Service level** (Mean)*	***Service level** (St. Dev)*	***Stat. signif.** (95%)*	***PWT Mean** (min.)*	***PWT St.Dev** (min.)*	***A.M. overtime** (min.)*	***P.M. overtime** (min.)*	***Earliest date** (%)*
Intervention 1	77.7%	0.8%	Yes	13.9	0.5	+4.3	-11.1	89.7%
Combination 1 (2,6)	78.3%	0.7%	No	13.0	0.4	+8.3	-9.2	89.7%
Combination 2 (1,2,6)	80.6%	0.5%	Yes	11.9	0.4	+13.7	-0.6	98.3%
Combination 3 (2,4,6)	78.0%	0.8%	No	13.2	0.4	+7.8	-8.7	88.9%
Combination 4 (1,2,4,6)	80.7%	0.6%	Yes	11.9	0.5	+13.0	-0.6	98.3%
Combination 5 (2,6,7)	78.0%	1.0%	No	13.1	0.7	+7.8	-8.0	89.6%
Combination 6 (1,2,6,7)	80.8%	0.9%	Yes	11.7	0.7	+13.2	-0.5	98.3%
Combination 7 (2,4,6,7)	77.9%	0.7%	No	13.4	0.5	+7.8	-8.3	88.8%
Combination 8 (1,2,4,6,7)	81.3%	0.7%	Yes	11.4	0.6	+13.7	-0.6	98.2%

Table 5.16: Results for intervention 2: agenda system adjustments in combination with rules of thumb regarding appointment scheduling

Table 5.16 confirms our expectations in which we find that combination 8 outperforms the other combinations in terms of service level. Overall, the OCT overtime increases for both shifts. We find that while combined, our rules of thumb regarding appointment scheduling yield the best performance for the cast room in terms of service level. Hereby, it is interesting to see that the combined improvement is larger than the sum of the individual improvements which mainly results from the combination of the LVBEG-rule and scheduling during non peaks for patients without combination appointment requirements. We conclude that we use combination

8 as representation of intervention 2 in further experimentation. First, we evaluate the performance of intervention 2 in more detail.

SERVICE LEVEL

Table 5.17 shows the service level for both scheduled patients for intervention 2.

Intervention 2: Redesign of the agenda system and appointment scheduling	*Service level (Mean)*	*Service level (St. Dev)*	*Service level (scheduled) (Mean)*	*Service level (walk-in) (Mean)*
Intervention 1	77.6%	0.9%	80.2%	72.9%
Combination 8 (1,2,4,6,7)	81.3% ✓	0.7%	83.5% ✓	77.4% ✓

Table 5.17: Service level for scheduled patients and walk-in patients in intervention 1 compared to intervention 2

Table 5.17 shows that both the service level for scheduled and walk-in patients increases. Remarkably, the service level of walk-in patients (+4.5%) increases more than the service level of scheduled patients (+3.3%). We conclude that the workload balance that we stimulate in intervention 2 results fewer waiting time for walk-in patients. Table 5.18 shows the service level per shift.

Shift service levels		***Even week***					***Odd week***				
		Mo	*Tu*	*We*	*Th*	*Fr*	*Mo*	*Tu*	*We*	*Th*	*Fr*
Intervention 1	*a.m.*	89%	75%	92%	84%	94%	73%	75%	95%	88%	93%
	p.m.	46%	42%	87%	77%	91%	61%	57%	88%	78%	75%
Intervention 2	*a.m.*	91%	76%	91%	86%	92%	79%	78%	93%	87%	91%
	p.m.	70%	45%	81%	81%	88%	81%	59%	86%	83%	69%

Table 5.18: Shift service levels (intervention 1 vs. intervention 2)

For most shifts, intervention 2 results in further improvement of the service level per shift. However, we find remarkable changes in the shaded shifts. Monday afternoon (odd/even) encounters a large improvement in service level compared to the other improvements. Furthermore, Wednesday afternoon (even) and Friday afternoon (odd) show a deterioration of more than 5% in service level. During only Wednesday and Friday, agenda 2 is not available for appointment scheduling (see Table 4.2). Furthermore, the best combination includes the sub-intervention of capacity reserving for same-day patients. When a patient request with a duration of 30 minutes or longer arrives, both the LVBEG-rule and long treatments at the end of the day first look at the end of agenda 1 before filling up the second agenda, in this case overbooking. Hereby, the probability is higher that a patient with a long expected treatment duration receives an appointment in the middle or towards the beginning of the afternoon shift. This results in a decrease of service level for the afternoon shifts of Wednesday and Friday. Table 5.18 shows that this is also the case for the morning shifts of these days.

Intervention 2 focuses on the spread of workload during a shift. During Monday afternoon, we find that OCTs have the highest probability and duration of additional Pediatric outpatient clinic presence. This results in temporary OCT unavailability from the beginning of the shift. During the shift, the OCT returns to the cast room. As the workload is spread, this OCT contributes to the increase in service level. Before intervention 2, the probability that a peak in workload occurs during the unavailability of the OCT is higher, which results in a smaller service level.

Figure 5.3 shows the average patient waiting time for intervention 2 compared to the base situation.

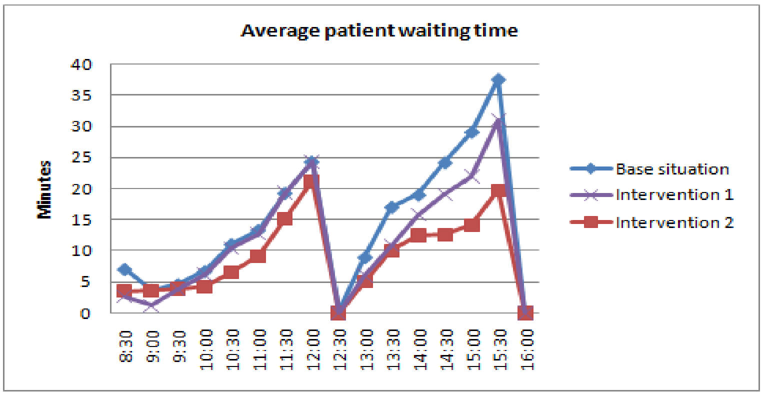

Figure 5.3: Average patient waiting time per 30 minutes (Base situation vs. intervention 2)

Figure 5.3 shows that we improve the average patient waiting time during the day. Furthermore, we find that the average waiting is lower at the start of the shift and is more balanced during the shift. However, there is still a peak in waiting time at the end of the shift. We clarify that this peak results from the combination of disturbances, internal waiting time, OCT unavailability, and treatment variance that builds up towards the end of a shift.

OCT OVERTIME

Table 5.19 shows the OCT performance for intervention 1 compared to the base situation.

Intervention 2: Redesign of the agenda system and appointment scheduling	*Average AM overtime*	*% AM overtime of total AM shifts*	*Average PM overtime*	*% PM overtime of total PM shifts*
Intervention 1	+4.1 min.	60.5%	-11.4 min.	33.8%
Combination 4 (1,2,4,6,7)	+13.7 min. ⊗	76.6% ⊗	-0.6 min. ⊗	46.9% ⊗

Table 5.19: OCT overtime for intervention 2 compared to intervention 1

We find that the rules of thumb regarding appointment scheduling decrease the quality of labor as both the average overtime as well as the occurrence of OCT overtime increases compared to intervention 1 as well as the base situation. The increase in overtime results mainly from the spread in workload as patients receive appointments until the end of the shift. In addition, the variance in actual treatment duration contributes to the increase of overtime.

APPOINTMENT SCHEDULING

Table 5.20 shows the performance of appointment scheduling regarding percentages of patients that receive their appointment close to the earliest possible date.

Intervention 2: Redesign of the agenda system and appointment scheduling	*% scheduled on earliest possible date*	*% scheduled within five days of earliest possible date*
Intervention 1	89.7%	100.0%
Combination 4 (1,2,4,6,7)	98.2% ✓	100.0% ⊖

Table 5.20: Appointment scheduling performance for intervention 1 compared to the base situation (18,058)

We conclude that we increase the percentage of patients that receive an appointment on the earliest possible appointment date to almost 100%. This is a result of our appointment scheduling rules that locate available agenda slots one by one, rather than picking a random agenda slot as occurs during the base situation and intervention 1. Hereby, we eliminate potential gaps between scheduled appointments and thus increase the percentage of patients scheduled on the earliest possible date. Furthermore, the rule schedule around peak moments contributes to this percentage as patients with combination appointment requirements have a higher probability to receive an appointment on the earliest appointment date.

5.4 INTERVENTION 3: MORE INVASIVE IMPROVEMENT ACTIONS

Section 2.3 describes the impact of fluctuations in OCT availability as well as potential improvements in communication regarding the scheduling of appointment requests for patients that do not receive an appointment in the current situation. The goal of this intervention is to further improve the service level for these matters. Furthermore, we evaluate changes in the agenda system regarding the length of agenda slots.

5.4.1 RESULTS OF THE SUB-INTERVENTIONS OF INTERVENTION 3

First, Table 5.16 shows the results of the individual sub-interventions of intervention 3, as describes in Section 4.5.4.

Intervention 3: More invasive improvement actions	***Service level (Mean)***	***Service level (St. Dev)***	***Stat. signif. (95%)***	***PWT Mean (min.)***	***PWT St.Dev (min.)***	***A.M. overtime (min.)***	***P.M. overtime (min.)***	***Earliest date (%)***
Intervention 2	81.3%	0.7%	n.a.	11.4	0.6	+13.7	-0.6	98.2%
1a. B10 introduction (LVBEG)	81.3%	0.5%	No	11.7	0.4	+12.7	-4.2	99.0%
1b. B10 introduction (cast removals)	78.6%	0.3%	Yes	13.7	0.3	+7.8	-19.7	98.7%
2a. Optimize fit (LVBEG)	80.0%	0.4%	Yes	12.4	0.4	+9.0	-15.6	98.8%
2b. Optimize fit (cast removals)	78.5%	0.6%	Yes	13.1	0.3	+2.8	-29.5	97.1%
3. Improve communication (walk-ins)	80.2%	0.4%	Yes	11.8	0.3	+15.5	-2.9	87.2%
4. Improve communication (inpatients)	80.7%	0.6%	No	11.8	0.5	+14.6	-4.8	95.6%
5. Improve communication (no-shows)	80.4%	1.0%	Yes	12.2	0.7	+14.3	0.0	98.5%
6. Elimination of OCT unavailability	85.7%	0.4%	Yes	8.3	0.2	+12.9	-5.8	98.1%
7. Elimination of treatment disturbances	81.8%	0.5%	Yes	10.9	0.3	+13.5	-2.0	98.1%
8. Reduce specialist waiting time	82.9%	0.8%	Yes	10.1	0.5	+12.4	-4.1	98.0%
9a. Limited use of a DA	88.5%	0.4%	Yes	6.4	0.2	+8.8	-10.8	98.1%
9b. Extensive use of a DA	90.8%	0.4%	Yes	5.1	0.1	+7.0	-14.9	98.1%
10. Spread of specialist consulting hours	81.0%	0.6%	No	10.6	0.4	+14.1	+0.4	99.8%

Table 5.21: Results of intervention 3: individual sub-interventions

We discuss the results for each sub-intervention individually in the remainder of this section (5.4.1).

B10 INTRODUCTION

We proposed to allow slot lengths shorter than the current minimum of 15 minutes in the agenda system. Hereby, we evaluate the introduction of the B10 agenda slot, which we use for the treatment of cast removals. We use this B10 introduction with intervention 2, but we also design a adjusted version of the LVBEG-rule, namely the rule to schedule cast removals at the beginning of a shift. We discuss the results for both alternatives in this section.

Our expectations for both rules are the same. The introduction of the B10 agenda slot results in a better fit between the slot length and the actual treatment duration of cast removals. As we schedule a shorter treatment duration in the agenda, there is room for additional patient appointments. In addition, the reduced slot length for cast removals results in a decrease of slack that can be used to cope with potential variability and disturbances. Therefore, we have both less slack as well as an increase of patient appointments during a shift. However, this removal of slack is placed at the start of a shift by using our appointment scheduling rules. Therefore, disturbances have less impact. Therefore, we expect an increase in service level. As we schedule patients more tightly from the beginning of a shift, we expect a decrease in OCT overtime for both the morning and afternoon shift.

B10 in combination with LVBEG

Table 5.21 shows that there is no significant change in service level compared to intervention 2. Although we exclude cast removals to B10 agenda slots, we find that the cast removals still receive combinations at the beginning of a shift as a result of the LVBEG-rule. Furthermore, we find that Table 5.21 confirms our expectations regarding the decrease in OCT overtime. To conclude, we find that the use of smaller agenda slots results in a slight increase of the percentage patients scheduled on the earliest appointment date.

B10 in combination with the 'cast removals at the beginning'-rule

Remarkably, Table 5.21 shows a significant decrease of the service level. This rule first schedules cast removals, and subsequently patients with a required agenda of B15, B30, and so forth. We conclude that the combination of B10 and B15 agenda slots, as happens with the LVBEG-rule, results in a better performance. Furthermore, we find that Table 5.21 confirms our expectations regarding overtime. To conclude, we find that the use of smaller agenda slots results in a slight increase of the percentage patients scheduled on the earliest appointment date.

OPTIMIZING THE FIT BETWEEN SCHEDULED AND ACTUAL TREATMENT DURATION

By optimizing the fit between scheduled and actual treatment duration, we schedule patients close to each other while eliminating potential slack to deal with disturbances or temporary OCT unavailability. Therefore, we expect that the service level decreases for both the LVBEG-rule as well as the rule to schedule cast removals at the beginning. Furthermore, as we schedule appointments for the exact treatment duration, we decrease the probability of scheduling patients for a too short period. Therefore, we expect that the OCT overtime decrease for both the morning and afternoon.

To conclude, we expect that the introduction of this individual sub-intervention results in a decrease in performance regarding service level and average patient waiting time. However, we expect that the combination of this sub-intervention with the reduction of disturbances and internal waiting time as well as improved coordination of the OCT unavailability results in the improvement of performance. Section 5.4.2 provides a description and discussion of the combination of the sub-interventions in this section.

Optimize fit in combination with LVBEG

Table 5.16 does confirm our expectations regarding service level and OCT overtime when we use the LVBEG-rule. Furthermore, we find that the OCT overtime decreases for both the morning and afternoon. The removal of slack results in a deterioration of the service level performance as disturbances and temporary OCT unavailability frequently occur.

Optimize fit in combination with the 'cast removals at the beginning'-rule

Table 5.16 does confirm our expectations regarding service level and OCT overtime when we use the cast removals at the beginning rule. Furthermore, we find that the OCT overtime decreases for both the morning and afternoon. The removal of slack results in a deterioration of the service level performance as disturbances and temporary OCT unavailability frequently occur.

We conclude that the LVBEG-rule outperforms the 'cast removals at the beginning'-rule during both sub-intervention 1 and 2 of intervention 3.

IMPROVE COMMUNICATION TO REDUCE THE PERCENTAGE OF WALK-IN PATIENTS

The improvement in communication results in prescheduled appointments for 41% of the walk-in patients. This means that we are able to influence the arrival pattern of more patients. Hereby, we are able to increase the balance in workload of OCTs. Therefore, we expect that this contributes to an increase in patient service level. Furthermore, as we have the same number of patients in our model, we expect no changes in OCT overtime.

Table 5.16 does not confirm our expectations regarding service level. We find that the service level decreases, but this decrease is not significant. We find that the percentage of patients scheduled on the earliest appointment date drops to 87.2%. Hereby, we find that this sub-intervention requires more appointments in the overbooking agenda compared to intervention 2. We clarify that this increase in patients at the same time results in no significant change regarding service level. Furthermore, we find that there is a substantial change in OCT afternoon overtime with a decrease of nearly 6 minutes. We clarify this improvement as a result of the slot size of 15 minutes in combination with the rules of thumb of intervention 2. Hereby, we schedule patients with a short expected treatment duration at the beginning of a shift, which results in an increase in undertime in the afternoon.

IMPROVE COMMUNICATION BETWEEN INPATIENT CLINIC AND CAST ROOM

Although we improve the communication between the inpatient clinic and the cast room, we do not expect improvements in performance level as a result of this sub-intervention. In the current situation, the inpatients are scheduled for the same-day if possible, but only during available slots. This sub-intervention still schedules these inpatients during available slots, however the scheduling is done at least one week in advance.

Table 5.16 shows that there is a minor increase in patient service level, which is not a significant change. Furthermore, there is an increase in OCT undertime for both the morning and afternoon shifts. Hereby, the improvement in afternoon overtime is higher than for the morning overtime. We clarify this as a result of the capacity reserving for same-days/inpatients. At the end of the day, we reserve 45 minutes in agenda 1 for same-day patients. However, this sub-intervention changes 50% of the same-day inpatients into scheduled inpatients, which results in less patients at the end of the day. Therefore, the decrease in OCT overtime is higher in the afternoon than in the morning.

REDUCE THE PERCENTAGE OF NO-SHOWS AND CANCELLATIONS

No-shows results in a unexpected decrease in workload. Hereby, a no-show results in a buffer to deal with any delay that is present at the point of the no-show. Section 2.3 describes the cast room performance and the presence of disturbances and patient waiting time. By reducing no-shows and no other sub-interventions in place, these unexpected buffers are removed, which should decrease the performance. On the other hand, as there are fewer no-shows, there are fewer appointment requests resulting in fewer expected workload overall. However, as the rules of thumb in appointment scheduling schedule appointments in close sequence, this does not result in an improvement in service level. Therefore, we expect a deterioration in service level and patient waiting time. Furthermore, as the total number of patients does not vary, we do not expect significant changes in OCT overtime for either the morning or afternoon.

Table 5.16 confirms our expectations. Both the service level and the average patient waiting time deteriorate as a result of reducing no-shows and cancellations. Furthermore, the OCT overtime does not result in significant changes.

ELIMINATION OF OCT UNAVAILABILITY

In Section 2.3 as well as in Chapter 4, we indicate the impact of OCT unavailability on the overall performance of the cast room. The removal of unscheduled OCT unavailability (except for OR-treatments) results in fewer capacity fluctuations during a shift. Thus overall, the cast room has more capacity available to treat patients. Therefore, we expect that the performance improves for all performance indicators.

Table 5.16 confirms our expectations. The impact of OCT unavailability on the overall cast room performance is very large, as we improve the service level to 85.7%. Furthermore, both the morning and afternoon OCT overtime decrease. We conclude that OCT unavailability is one of the major deteriorating factors in the current cast room performance. This results of this sub-intervention emphasize the need to improve the coordination of the OCT unavailability.

ELIMINATION OF DISTURBANCES DURING TREATMENT

Section 2.3 as well as the report ‘Analyserapporage gipskamer’ (2009) describe the impact of disturbances during the treatment of cast room patients. We expect that the elimination of disturbances during treatment improves the overall performance in terms of all performance indicators. The actual treatment duration is shorter which results in a decrease of patient waiting time. Furthermore, the decrease in actual treatment duration results in a decrease of the treatment time overall. This contributes in a decrease in OCT overtime for both shifts.

We find that Table 5.16 confirms our expectations as the service level increases to 81.8%, which is a significant change. Although the service level increases, we expected a higher improvement as the average duration of disturbances is 5.9 minutes. However, as we spread the occurrences of disturbances by means of a Poisson process over the total process, the overall impact proves to be smaller than expected. Furthermore, we find that the OCT overtime in the morning and afternoon decrease as a result of this sub-intervention.

REDUCE SPECIALIST WAITING TIME

Section 2.3 as well as the report ‘Analyserapporage gipskamer’ (2009) describe the impact of internal waiting time for specialists. Internal waiting time increase the total duration of a patient present in the cast room. Hereby, capacity is blocked by this patient. A decrease in this total duration results in less blocking of capacity. Therefore, we expect that the reduction of internal waiting time for specialists during treatment improves the overall performance in terms of all performance indicators.

Table 5.16 confirms our expectations. The impact of the internal waiting time on the overall cast room performance is significant: the adjustment results in a service level of 82.9%. Furthermore, this results in a decrease in OCT overtime for both shifts.

DOCTOR'S ASSISTANT IN THE CAST ROOM

The placement of a doctors' assistant results in a decrease or even elimination of disturbances and internal waiting time for patients (see Section 4.5). We expect that both alternatives (limited and extensive use of a DA) result in a clear improvement of performance in terms of the service level as well as OCT overtime.

Table 5.16 confirms our expectations. The improvement in performance is obvious in terms of all the performance indicators.

SPREAD OF CONSULTING HOURS SCHEDULE

The spread of the specialist's consulting hours is a complex sub-intervention. On one hand, we spread the total impact of specialists over a cycle of two weeks. Furthermore, we spread the total OCT capacity over a shift. Hereby, we balance the total number of patients over the shifts in a cycle. We combine this balance in patients with a balance in present OCTs. We assume that the spread of capacity is sufficient to deal with the spread of patients. Therefore, we expect that the service level increases. Furthermore, we do not expect significant changes in OCT overtime.

Table 5.16 shows that the improvement in service level is not significant, although the average patient waiting time does decrease with 0.8 minutes. Furthermore, we find that the OCT overtime does not change much for both morning (+0.5 minute) and afternoon (-1.0 minute). To evaluate if we meet the goal of spreading the impact, Table 5.22 shows the average number of patients per shift for both intervention 2 and this sub-intervention.

Average number of patients per shift		***Even week***					***Odd week***				
		Mo	*Tu*	*We*	*Th*	*Fr*	*Mo*	*Tu*	*We*	*Th*	*Fr*
Intervention 2	*a.m.*	13.8	18.8	13.1	23.5	14.0	14.1	18.2	12.0	22.6	13.9
	p.m.	12.2	11.3	13.0	12.1	10.4	12.3	10.7	11.8	12.1	10.8
Spread of CHS	*a.m.*	16.0	17.6	14.5	16.3	17.3	14.1	18.2	14.2	15.6	15.4
	p.m.	12.8	10.2	13.0	12.5	13.7	11.6	10.6	14.1	12.2	14.0

Table 5.22: Average number of patients per shift (Intervention 2 vs. sub-intervention spread of consulting hours schedule)

Table 5.22 confirms that the balance between the shifts increases. Hereby, we find that the morning shifts have a higher number of patients than the afternoon shifts. This is a result of the consulting hours in the morning and in the afternoon. The morning has 3.5 hours, while the afternoon has 3.0 hours. Therefore, we allow the morning shifts to have a higher number of patients than the afternoon, as more capacity in terms of OCT minutes available in the morning compared to the afternoon.

To conclude, Table 5.23 shows the service level per shift for this sub-intervention.

Shift service levels		***Even week***					***Odd week***				
		Mo	*Tu*	*We*	*Th*	*Fr*	*Mo*	*Tu*	*We*	*Th*	*Fr*
Intervention 2	*a.m.*	91%	76%	91%	86%	92%	79%	78%	93%	87%	91%
	p.m.	70%	45%	81%	81%	88%	81%	59%	86%	83%	69%
Spread of CHS	*a.m.*	87%	83%	88%	94%	84%	78%	81%	90%	87%	87%
	p.m.	67%	76%	80%	83%	75%	76%	66%	79%	71%	78%

Table 5.23: Shift service levels (Intervention 2 vs. sub-intervention spread of consulting hours schedule)

Although Table 5.22 confirms the balance in the number of patients per shifts, Table 5.23 does not show a clear balance in service level per shift. This also contributes to the overall service level which does not improve significantly compared to intervention 2. The shaded shifts represent shift during which additional Pediatric outpatient clinic might be required. As this sub-intervention uses the same capacity for each shift (Thursday a.m. during even weeks), the impact of additional Pediatric outpatient clinic OCT requirements results in a lower service level. Table 5.23 confirms this aspect. If we do not take these shifts into consideration, we find that the balance among the morning and afternoon shifts regarding service level is actually present. However, Tuesday morning (even/odd) shows a lower performance compared to the other morning shifts. Table 5.22 shows that this is the result of a higher number of patients compared to the other shifts. We find that we do not use the most optimal spread of specialists' consulting hours. We designed this schedule based on the impact in terms of the number of patients per specialist. Further optimization might be achieved by using the impact in terms of patient minutes.

We conclude that the spread of specialists' consulting hours is beneficial when the OCT capacity is adjusted accordingly and no unscheduled OCT unavailability takes place.

5.4.2 INTERVENTION 3: COMBINATION OF THE SUB-INTERVENTIONS

This section combines the sub-interventions of intervention 3 to find the best case situation for the cast room. Several of the sub-interventions did not result in an improvement of performance individually. However, the previous sections proved that a combination of interventions could result in remarkable improvements. Therefore, we propose to include the best performing sub-interventions in each combination. Furthermore, we combine the remaining sub-interventions to find the actual best case situation.

We find that the following sub-intervention result in an improvement of the performance:

- Elimination of OCT unavailability (6)
- Eliminate disturbances during patient treatment (7)
- Reduce specialists' waiting time (8)
- Limited use of a DA in the cast room (9a)
- Extensive use of a DA in the cast room (9b)

The other sub-interventions do not result in a significant improvement of capacity. Therefore, we propose to first evaluate each combination of these sub-interventions to determine the best combination. Subsequent, we combine the best three combinations with the sub-interventions listed above. Hereby, we make a distinction based on our expectations regarding the implementation. We expect that it is very hard to achieve the implementation of sub-interventions 6, 9(a/b), and 10 individually on short notice. The combination is even much more difficult. Therefore, we define the following combinations:

- Best three initial combinations + sub-intervention 6 & 7
- Best three initial combinations + sub-intervention 6 & 7 + 6
- Best three initial combinations + sub-intervention 6 & 7 + 9a
- Best three initial combinations + sub-intervention 6 & 7 + 9b
- Best three initial combinations + sub-intervention 6 & 7 + 10
- Best three initial combinations + sub-intervention 6 & 7 + 6 + 9b
- Best three initial combinations + sub-intervention 6 & 7 + 6 + 9b + 10

Hereby, we expect that each set of combinations increases the performance regarding service level compared to the previous combination(s). Before we consider the overall performance, we outline the three best performing combinations (a,b,c):

- *Initial combination a:* Introduce the B10 agenda slot and LVBEG-rule (1a), no-show adjust (5), and no planned slack.
- *Initial combination b:* LVBEG-rule (intervention 2), and limited planned slack.
- *Initial combination c:* Optimize fit between scheduled and actual treatment duration and cast removals at the beginning (2b), improve communications with the inpatient clinic (4), and limited planned slack.

Please note that we did not find successful combinations with the sub-intervention to improve the communication regarding walk-in patients. As stated before, we combine these combinations with sub-interventions 6,7,9a,9b and 10. Table 5.22 shows the results of these combinations. Per set of combinations a,b,c, we highlight the best performing combinations with a green shade.

Intervention 3: More invasive improvement actions	***Service level (Mean)***	***Service level (St. Dev)***	***Stat. signif. (95%)***	***PWT Mean (min.)***	***PWT St.Dev (min.)***	***A.M. overtime (min.)***	***P.M. overtime (min.)***	***Earliest date (%)***
Intervention 2	81.3%	0.7%	n.a.	11.4	0.6	+13.7	-0.6	98.2%
Combination 1 (a + 7,8)	83.9%	0.4%	Yes	9.6	0.3	+11.3	-8.6	99.0%
Combination 2 (b + 7,8)	83.3%	0.5%	Yes	10.0	0.2	+11.9	-5.3	98.1%
Combination 3 (c + 7,8)	82.0%	0.6%	Yes	10.7	0.5	+3.5	-38.0	96.2%
Combination 4 (a + 7,8,9a)	88.9%	0.5%	Yes	6.3	0.3	+9.6	-14.5	99.1%
Combination 5 (b + 7,8,9a)	88.4%	0.5%	Yes	6.5	0.2	+9.3	-10.9	98.0%
Combination 6 (c + 7,8,9a)	87.9%	0.3%	Yes	6.8	0.3	-0.4	-44.9	96.3%
Combination 7 (a + 7,8,9b)	91.3%	0.3%	Yes	4.9	0.2	+6.6	-18.0	99.0%
Combination 8 (b + 7,8,9b)	90.6%	0.3%	Yes	5.2	0.2	+7.0	-14.2	98.2%
Combination 9 (c + 7,8,9b)	90.5%	0.3%	Yes	5.3	0.1	-3.2	-48.5	96.3
Combination 10 (a + 7,8,10)	84.2%	0.4%	Yes	8.8	0.2	+12.1	-6.9	100%
Combination 11 (b + 7,8,10)	83.7%	0.5%	Yes	9.0	0.3	+12.5	-3.6	100%
Combination 12 (c + 7,8,10)	83.4%	0.5%	Yes	9.2	0.3	+0.6	-34.8	98.6%
Combination 13 (a + 6,7,8)	87.9%	0.3%	Yes	7.1	0.2	+11.1	-13.3	99.0%
Combination 14 (b + 6,7,8)	87.6%	0.4%	Yes	7.1	0.3	+11.0	-9.9	98.0%
Combination 15 (c + 6,7,8)	87.4%	0.3%	Yes	7.2	0.1	+2.5	-44.7	96.4%
Combination 16 (a + 6,7,8,9b)	93.9%	0.2%	Yes	3.5	0.1	+6.1	-19.1	99.0%
Combination 17 (b + 6,7,8,9b)	93.7%	0.2%	Yes	3.5	0.1	+6.4	-16.0	98.1%
Combination 18 (c + 6,7,8,9b)	94.2%	0.4%	Yes	3.3	0.2	-4.9	-51.5	96.2%
Combination 19 (a + 6,7,8,9b,10)	94.2%	0.2%	Yes	3.3	0.1	+5.7	-16.5	100%
Combination 20 (b + 6,7,8,9b,10)	94.0%	0.3%	Yes	3.4	0.1	+6.7	-13.9	99.9%
Combination 21 (c + 6,7,8,9b,10)	95.0%	0.1%	Yes	2.9	0.1	-6.7	-46.3	98.6%

Table 5.24: Results of intervention 3: five best combinations of sub-interventions

Interestingly, Table 5.24 shows that the best combination out of the initial combinations a, b or c is not the same for each subsequent combination.

The best case situations (combinations 16-21) show the best combinations with the initial combination *"c"*. However, we find that the initial combination *"a"* shows the best performance for the combinations of intervention 3 that are more easy accessible in our opinion.

The best case situation increases the service level exactly to our target service level of 95% (see Chapter 2). We stated that the best case situation is very hard to achieve, because of the various related stakeholders as well as additional financial requirements to increase capacity (9a/b). However, the results do emphasize the importance of improving unscheduled OCT unavailability, disturbances and delays during treatments, as well as the variance in actual treatment duration compared to the scheduled duration. We state that an improvement in coordination of these occurrences is able to improve the current performance as well, so that additional financial resources are not directly required.

In the remainder of this section, we discuss the best combination in more detail.

SERVICE LEVEL

Table 5.18 shows the service level for both scheduled patients for intervention 3.

Intervention 3: More invasive improvement actions	***Service level (Mean)***	***Service level (St. Dev)***	***Service level (scheduled) (Mean)***	***Service level (walk-in) (Mean)***
Intervention 2	81.2%	0.7%	83.6%	77.0%
Combination 1 (2b,4,6,9b,10)	95.0% ✓	0.1%	96.3% ✓	92.6% ✓

Table 5.25: Service level for scheduled patients and walk-in patients in intervention 1 compared to intervention 2

We find that our interventions have the best result for scheduled patients. We clarify this difference as the focus of our interventions is for the scheduled patients with rules of thumb regarding appointment scheduling and the elimination of punctuality.

Table 5.26 shows the service levels per shift for the best case situation compared to intervention 2.

Shift service levels		***Even week***					***Odd week***				
		Mo	*Tu*	*We*	*Th*	*Fr*	*Mo*	*Tu*	*We*	*Th*	*Fr*
Intervention 2	*a.m.*	91%	76%	91%	86%	92%	79%	78%	93%	87%	91%
	p.m.	70%	45%	81%	81%	88%	81%	59%	86%	83%	69%
Intervention 3	*a.m.*	95%	95%	96%	97%	94%	96%	94%	97%	95%	95%
	p.m.	96%	96%	93%	96%	94%	97%	94%	95%	96%	93%

Table 5.26: Shift service levels (intervention 2 vs. intervention 3)

Table 5.26 shows that the performance in service level per shift improves proportionate to the overall shift level increase. This confirms our expectations. We provide insight in the waiting time during the same with Figure 5.3.

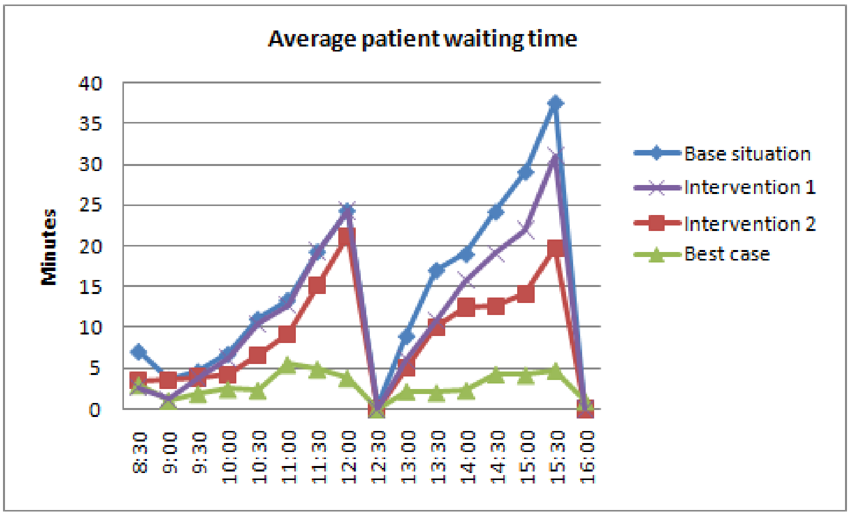

Figure 5.4: Average patient waiting time (Base situation, intervention 2, and best case situation)

Figure 5.3 confirms that we balance the average patient waiting time during the day. We conclude that the best case situation results in a balance of workload and eliminates the key deteriorating factors of the current cast room performance.

OCT OVERTIME

Table 5.19 shows the OCT performance for intervention 3 compared to intervention 2.

Intervention 3: More invasive improvement actions	***Average AM overtime***	***% AM overtime of total AM shifts***	***Average PM overtime***	***% PM overtime of total PM shifts***
Intervention 2	+12.4 min.	74.3%	-2.2 min.	46.1%
Combination 1 (2b,4,6,9b,10)	-6.7 min. ✓	41.6% ✓	-46.3 min. ✓	30.0% ✓

Table 5.27: OCT overtime for intervention 2 compared to intervention 1

We find that intervention 3 decreases the occurrence of OCT overtime as well as the average OCT overtime. The huge decrease in OCT afternoon overtime is a result of the sub-intervention improvements in communication between the inpatient clinic and the cast room. Hereby, we reduce the number of same-day inpatients that receive an appointment on the same day. However, we still reserve capacity for same-day patients at the end of the day, which results in fewer patients present at the end of the day, and thus a decrease in average OCT overtime.

Furthermore, the sub-intervention optimize fit between scheduled and actual treatment duration contributes to the decrease in overtime as well. It is possible that a patient receives a treatment until the end of a shift. However, if the actual treatment duration is longer than the scheduled treatment, this causes overtime. In addition, patients with a long treatment duration have a higher variability in actual treatment duration than patients with a shorter treatment duration. The rules of thumb to schedule long treatments at the end of the day or shift could result in additional overtime as a result of this variability. The optimization of the fit between scheduled and actual treatment duration denies this occurrence, which decreases the overtime. In any case, the decrease in treatment setup time, OCT unavailability, and internal waiting time result in an increase in available treatment time during a shift, which further contributes to the decrease in OCT overtime.

To conclude, our (sub)-interventions result in additional OCT capacity at the end of the day to treat more patients. Hereby, we are able to counter a potential increase in the number of cast room patients.

APPOINTMENT SCHEDULING

Table 5.20 shows the performance of appointment scheduling regarding percentages of patients that receive their appointment close to the earliest possible date.

Intervention 3: More invasive improvement actions	***% scheduled on earliest possible date***	***% scheduled within five days of earliest possible date***
Intervention 2	99.9%	100.0%
Combination 1 (2b,4,6,9b,10)	98.6% ⊗	99.5% ⊗

Table 5.28: Appointment scheduling performance for intervention 1 compared to the base situation (21,482)

We find that the percentage of patients scheduled on the earliest possible date decreases to 98.6%. However, this is still higher than the 90% of the base situation. The rules of thumb regarding appointment scheduling improved the percentage to nearly 100%. However, the sub-intervention optimize fit between scheduled and actual treatment duration results in the decrease to 96.5%. This sub-intervention results in varying slot lengths. Treatments with a treatment duration longer than 45 minutes block much of the agenda space. Hereby for these occurrences, the probability increases that patients cannot be scheduled during the earliest possible date. Furthermore, the percentage of patients scheduled within five days of the earliest possible date is equal for intervention 3 compared to intervention 2.

CHAPTER 6 - ORGANIZATIONAL IMPLEMENTATION

This chapter describes the implementation of our (sub-)interventions and extensions. Per intervention, we describe our recommendations to actually implement the (sub-)interventions and the improvements in the current cast room situation. We discuss the implementation per (sub)-intervention. Hereby, we use the same structure and sequence as in Section 4.5 and Chapter 5.

6.1 INTERVENTION 1: LESS INVASIVE IMPROVEMENT ACTIONS

We outline our recommendations to implement the sub-interventions one by one. Hereby, we discuss each sub-intervention as presented in Section 4.5 and Chapter 5. As our sub-interventions result in an improvement of the current cast room performance, we strongly recommend to implement all of them.

OCT PUNCTUALITY

The sub-intervention OCT punctuality does not require any changes in resources, but only changes in the OCT behavior. On first view, the sub-intervention OCT punctuality is easy to implement by starting with patient treatments on time, thus at 8.30 AM. We understand that the OCTs prefer to come together before the day actually starts. However, Chapter 5 shows the improvement of performance as a result of this punctuality. Furthermore, it allows the OCTs to be finished on time as well, which results in time to spend the end of the day together as well. Also, the OCTs can arrive earlier so that they do not have to start immediately. We conclude, that these benefits should result in the implementation of this sub-intervention. However, we expect that this happens correctly for a few weeks, after which the OCTs tend to return to their old behavior. Therefore, one of the OCTs or someone from Workplace Management (WPM) should monitor and control this sub-intervention continuously to maintain the improvement in performance.

INDIVIDUAL LUNCH BREAKS

Like OCT punctuality, individual lunch breaks do not require any changes in resources, but only changes in the OCT behavior. We think that the individual lunch breaks are easy to implement, but they will collide with personal motivation of the OCTs. However in our opinion, the OCTs should be aware of the overall increase in performance as a result of this sub-intervention. Furthermore, it results in an increase of undertime, which can be spend together at the end of the day as a compensation. As with the sub-intervention OCT punctuality, we expect that the individual lunch breaks will happen correctly for a few weeks after implementation. However, it is possible that the OCTs return to their old behavior after some time. Therefore, one of the OCTs or someone from Workplace Management (WPM) should monitor and control this sub-intervention continuously to maintain the improvement in performance.

CANCELLATIONS

The goal of the sub-intervention cancellations is to remove cancellations from the agenda system to create a more representative view of the shift workload. Furthermore, cancellations result in free appointment slots for same-day patients.

In the current situation, usually DAs are aware of cancellations. We recommend that DAs remove cancellations before the actual day of treatment from the agenda system. If a cancellations occurs during the day, the DAs should notify the OCTs of the cancellation and make sure that the cancellations is marked as a cancellation on the printed version of the treatment schedule. This would require a DA to enter the cast room. However, as they do not disturb a treatment, we do not regard this as a problem.

However, we strongly recommend a different approach to counteract the problem of cancellations as our recommendation regarding cancellations is twofold. On one hand, we desire insight in peak and non-peak moments during a day to schedule same-day appointments at non peak moments. On the other hand, the higher goal is to establish a real-time insight of the workload of a shift on any moment. In the current situation, the cast room works with hardcopy versions of the treatment schedule, which are printed before the consulting hours start.

We recommend the use of a digital system in which the OCTs directly see what patients are scheduled during a shift. In combination with the appointment characteristics, like treatment duration and appointment time, the actual workload is more obvious. Furthermore, we recommend a system in which it is also clear which patients are already present in the waiting area. This also could improve the patient prioritization, but more important it creates insight of the actual workload at a given time.

OPERATING ROOM CAPACITY BLOCKING

Chapter 5 provides insight in the impact on performance as a result of temporary OCT unavailability like external treatments at the operating room. In this case, the OCT has to leave the cast room, unable to perform treatments for regular patients during some time. Treatments at the operating room are known at least one week in advance. Therefore, we recommend that it is not possible to schedule additional patients during the interval that an OCT performs a treatment at the operating room. Hereby, we propose to block slots in the agenda during the scheduled operating treatment. Whenever the operating room treatment is known, an OCT should directly notify a DA to block the agenda slots. We are not aware if the current agenda system allows for this kind of capacity blocking. Therefore, we recommend the outpatient clinic management to ask the IT-department to create specific 'block'-slots.

IMPROVE PATIENT PRIORITIZATION

Sometimes, differences in patient punctuality result in undesirable levels of waiting time. Therefore, we recommend to treat patients according to a patient prioritization rule. We propose to see scheduled patients with priority, only if their appointment time has passed. In any other case, we recommend to first treat walk-in patients. Furthermore, if patients arrive at the same time, we recommend to give priority to inpatients and second consults. If these patient characteristics are the same, we suggest to see patients on a first come first serve basis.

The current situation makes it difficult to perform this prioritization rule. Section 2.2 describes that there is a box at the entrance of the cast room, in which patient appointment cards are put. These patient appointment cards belong to the patients waiting for treatment. As the hard-copy schedule of patient treatments is not near this box, OCTs do not have insight if a patient has an appointment or not. Furthermore, we observed that different people (DAs, OCTs, and specialists) put the cards in the box using different ways. This results in a sequence of patients that is less fair than when they use the same way. Therefore, we recommend to put two boxes at the entrance of the cast room, one for patients with an appointment, one for patients without an appointment. In addition, we recommend that the DAs make sure that the cards are in the correct box and sequence, so that the OCTs can pick up the patient with priority.

However as we explained at cancellations, we strongly recommend the use of a digital system, which requires additional resources. This system should directly notify the OCTs which patients with what characteristics are present in the waiting area. Furthermore, the system can automatically determine the sequence of the patients.

6.2 INTERVENTION 2: REDESIGN OF THE AGENDA SYSTEM AND APPOINTMENT SCHEDULING

This section describes our recommendations regarding the implementation of intervention 2. We do not discuss the implementation of our rules of thumb regarding appointment scheduling individually. We recommend that the outpatient clinic implements theses rules as a part of the process appointment scheduling. This also applies for the redesign of the agenda system.

First, we outline what rules to implement. Based on the result of Chapter 5, we recommend to implement the following rules of thumb:

- Schedule around peak moments
- Low variance at the beginning / Cast removals at the beginning
- Long expected treatment duration at the end of the day
- Use of limited planned slack

Second, we recommend to implement the redesign of the agendas in combination with these rules of thumb regarding appointment scheduling. This means that we reserve capacity for same-day patients. Also, we propose the use of ‘block’-slots to block an agenda during scheduled OCT unavailability.

The rules of thumb and the redesign of the agendas require adjustments in the XCare agenda system. We recommend the outpatient clinic management to consult the IT department of the possibilities of XCare to cope with our recommendations. We do not expect problems regarding opening an additional agenda in combination with specific ‘block’ slots and non-overbooking allowances. However, the rules of thumb might require specific adjustments in XCare that require additional budget or resources. The benefit of applying these rules in combination with the agenda adjustments should be sufficient motivation to implement the adjustments.

6.3 INTERVENTION 3: MORE INVASIVE IMPROVEMENT ACTIONS

We outline our recommendations to implement the extensions one by one. Some of the extensions require additional resources or budget. Therefore, we recommend the outpatient clinic management to thoroughly consider to what extent and at what cost they want to improve the cast room performance.

6.3.1 ADJUSTMENT OF THE MINIMUM AGENDA SLOT LENGTH

We recommend to adjust the minimum length of agenda slots to 5 minutes. The results of our observation period clearly shows that specific treatment durations result in a misfit with current slot possibilities. We recommend to consult with the IT-department to adjust this minimum slot allowance. Furthermore, we recommend the OCTs to reconsider the current list of treatment types and pre-specified treatment duration to determine what adjustments can be made to fit the new agenda slots.

In addition, we strongly recommend to implement the cast removals at the beginning rule of thumb regarding appointment scheduling. Chapter 5 shows its benefits compared to the LVBEG-rule if the minimum agenda slot length is in place.

Furthermore to improve the scheduling of appointments, we recommended to clearly fill in the yellow paper for appointment scheduling (see Section 2.2). We recommend the OCTs to fill in what duration in minutes they expect for a specific treatment, rather than just filling in the treatment type. Hereby, we reduce potential errors in the scheduled treatment duration.

6.3.2 IMPROVEMENTS IN COMMUNICATION

This section describes our recommendations regarding communication between the cast room personnel and other AMC personnel.

COMMUNICATION BETWEEN INPATIENT CLINIC AND CAST ROOM

In the current situation, the inpatient clinic requests a cast treatment for an inpatient during the day by a telephone call directly to the cast room. However, the cast room stakeholders indicated that most of these cast room treatments are known in advance. Therefore, these inpatients should have a prescheduled appointment. The cast room stakeholders indicate that the inpatient clinic uses specific forms to indicate requirements for any treatment of inpatients during their stay. They mention that the requirements for a cast treatments are not specific on those forms. We follow the advice of the cast room stakeholders to include these requirements on the inpatient clinic forms. We recommend that the outpatient clinic management discusses this matter with the inpatient clinic management and acts accordingly. In addition, this sub-intervention reduces the number of disturbances as the inpatient appointment requests during a shift disturb the treatment of cast room patients.

COMMUNICATION TO REDUCE THE PERCENTAGE OF WALK-IN PATIENTS

Cast room stakeholders indicate that 41% of the walk-in patients in the current situation should have received a scheduled appointment. As lack in communication or lack in clear communication as a result of the use of the yellow appointment card, these error occurs. We mentioned recommendations regarding this card in a previous section of this chapter. Again, we emphasize the importance of clearly filling in these yellow cards. Furthermore, we recommend the DAs to ask the OCTs if there is any unclearness about appointment scheduling.

REDUCE THE PERCENTAGE OF NO-SHOWS AND CANCELLATIONS

The current situation encounters a percentage of nearly 10% no-shows.. We found that for 80%, these no-shows are actually cancellations. Patients, specialist, and DAs make cancellations. We recommend to improve the communication between the outpatient clinic regarding appointment scheduling. At the moment, appointment scheduling uses a yellow paper, which is not very clear. We recommend to make this form more specific, and furthermore to more clearly write down (by the health care professionals) the exact appointment requirements. This should contribute to an increase of correct appointments, and thus fewer no-shows or cancellations.

6.3.3 DOCTOR’S ASSISTANT IN THE CAST ROOM

Chapter 5 shows the large improvements in performance if a DA is present in the cast room, either limited or extensively. We strongly recommend to place a DA in the cast room. However, this results in additional budget requirements. Therefore, we focus this section on the added value of a DA when present in the cast room. In our model, a DA decreases the average patient waiting time as a result of the following tasks:

- Picking up patients, while the OCT cleans the treatment bed.
- Picking up a specialist for advice, while the OCT removes the cast of a patient.
- Providing assistance to an OCT during treatment, while other OCTs continue their work.
- Dealing with disturbances while OCTs continue treatment.

However, we observed several problems in the current situation that do not directly have an impact on the service level of overtime. To conclude, we briefly outline these additional tasks:

- Treatment registration: in the current situation, patient treatments and specific treatment characteristics are not registered directly, because of lack in time for the OCTs.
- Appointment scheduling: this chapter describes the importance of clearly filling in the yellow appointment card. However, the best way to decrease error in appointment scheduling is when a DA is present in the cast room. Hereby, the DA is able to directly communicate with the OCT about the treatment requirements.
- Real-time insight of workload: we recommend adjustments regarding IT to create a real-time insight of the cast room workload. While OCTs are performing treatments, the DA is able to check for present patients by means of the box at the entrance of the cast room. In addition, the DA tracks which patients are served, so that it is clear when same-day patients can be fit in.

CHAPTER 7 - CONCLUSIONS & RECOMMENDATIONS

Section 7.1 concludes our research and describes our conclusions. Section 7.2 describes recommendations that were not evaluated in our simulation study, while Section 7.3 describes areas for further research regarding the cast room situation.

7.1 CONCLUSIONS

This report confirms that the cast room has an unbalance between supply and demand that results in increased patient waiting times and decreases quality of labor and quality of care. Our goal was to identify and evaluate organizational interventions to optimize the performance of the cast room. Furthermore in consultation with the cast room stakeholders, we defined a desired service level in terms of the percentage patients seen in the cast room within a waiting time of 20 minutes. This desired service level is 95%, whereas the observation period indicates that the current service level is 74%.

We used the literature as well as findings from the observation period to design (sub)-interventions to improve the current situation. To evaluate our interventions, we built a simulation model to represent the cast room situation. Based on annual patient numbers and updates in staffing schedules of the outpatient clinic, we determined the base situation of the cast room. Hereby, we mean the current situation of the cast room translated into our model. The service level of the base situation is 72.2% with an average patient waiting time of 17.7 minutes. Hereby, the average OCT overtime for the morning and afternoon equals 4.3 minutes and -7.6 minutes respectively.

We design three interventions including several sub-interventions to improve the current situation (we evaluate the performance of the (sub)-interventions with a 95% confidence interval compared to the base situation):

Intervention 1: Less invasive improvement actions

Intervention 1 combines recommendations regarding improvements in communication and behavior of both the OCTs as the DAs. Hereby, the main goal is to decrease or remove delay in the cast room process. Hereby, we mean delay as a result of lack in communication between the OCTs and DAs, as well as timeliness of the OCTs. We deem these recommendations to be easy accessible in the current situation. Our simulation model shows that intervention 1 increases the service level to 77.7% with an average patient waiting time of 13.9 minutes. Hereby, we show that with low invasive improvement tasks, we are able to improve the current average waiting time with 21%. Furthermore, the OCT undertime decreases to 4.3 minutes overtime in the morning, and increases to -11.1 minutes overtime in the afternoon. We state that intervention 1 is a essential precondition for further experimentation.

Intervention 2: Redesign of the agenda system and of the appointment scheduling

The goal of intervention 2 is to balance the workload for OCTs throughout the shift. Hereby, we redesign the agenda system in combination with several rules of thumb regarding appointment scheduling to actually balance the workload for OCTs. Our simulation model shows that the best combination of intervention 2 increases the service level to 81.3% with an average patient waiting time of 11.4 minutes. The OCT overtime decreases to 13.7 minutes in the morning, and -0.6 minutes overtime in the afternoon.

Intervention 3: More invasive improvement actions

To further improve the current situation, we design improvement actions that require changes that are more invasive and furthermore might require additional financial budget. These improvement actions include further alterations in the agenda system regarding the slot duration, improvement in communication regarding the lack in appointment scheduling of walk-in patients and same-day patients, reducing the percentage of no-shows and cancellations, and adjustments in the outpatient clinic capacity to further improve the performance of our interventions in the cast room. The combination of extensions without presence of a DA in the cast room increases the service level to 87.9% with an average patient waiting time of 7.1 minutes. The OCT overtime decreases to 11.1 minutes overtime in the morning, and decreases to -13.3 minutes overtime in the afternoon. However, the presence of a DA in the cast room in combination with the other extensions results in an increase of the service level to 95.0% with an average patient waiting time of 2.9 minutes. The OCT overtime decreases to -6.7 minutes overtime in the morning, and to -46.3 minutes overtime in the afternoon. We conclude that the best case results in additional capacity at the end of the day to treat a higher number of patients.

We conclude that we are able to improve the current cast room performance to the desired service level of 95% and the average patient waiting time to 2.9 minutes. However, the best case situation is hard to implement, certainly on a short notice. Intervention 1 shows that we can improve the current situation with low invasive improvement actions with a reduction of 21% of the average patient waiting time. Furthermore, the adjustments regarding appointment scheduling contribute to the spread of workload for OCTs. We recommend to implement intervention 1 and 2 as soon as possible, as they do not require additional (financial) resources. Intervention 3 indicates the importance of controlling cast room capacity as well as reducing disturbances and variance during treatments. Hereby, we adjust capacity to deal with these occurrences (see Section 4.5.3). Those adjustments require additional financial resources. Therefore, we also recommend that the OCTs collaborate with the outpatient clinic stakeholders to adjust the current capacity levels so that no additional financial resources are required. Furthermore, the increase in coordination of external tasks around peak moments contributes to the desired performance as well.

7.2 RECOMMENDATIONS

This section provides recommendations that could not be evaluated during the simulation study. Therefore, we did not outline these recommendations in Chapter 6.

During this study, we encountered a lack in detailed process data. The hospital information systems XCare and the DBC-database lack in providing clear and representative data about the process and its patients. As a result, we had to perform an observation period to determine essential characteristics and figures of the cast room process. We propose to store information about every cast room treatment. Hereby, we mean patient type, type of appointment/arrival, treatment durations, et cetera. More detailed information contributes to an increase of the understanding of the process as well as improved solutions for its bottlenecks.

The increase in detailed information requires improvements in IT systems in and around the cast room. The current IT resources in the cast room also limit the current cast room process in terms of delays during the treatment of patients. Hereby, we refer to IT resources in terms of hardware as well as user accounts. Hereby, we noticed that certain OCTs do not have user accounts to enter specific IT systems, while the OCTs do require these systems to perform their work. This results in disturbances and additional delays of the cast room treatments.

7.3 FURTHER RESEARCH

In this section, we present areas for future research, which might result in further improvements of the cast room.

Some studies explore possible benefits of allowing patients to walk-in rather than schedule appointments. Most cast room patients require a combination appointment. However, it might be beneficial to allow patients to walk-in who do not require a combination appointment. It might also be interesting to evaluate the requirements of a specific specialist for patients. Sometimes, the advice of a specialist is required to determine the further treatment procedure. We observed that this decision is made very fast by specialists, while the waiting time for specialists can be quite long. Therefore, we propose to evaluate if OCTs can make this decision on their own. This could result in the elimination of internal waiting time.

During our research, we did not take the specialists' agendas into account. In addition to the cast room agenda system, each specialist has its own agenda filled with appointments. We propose to research the agenda system for the entire outpatient clinic and the relations between them as a result of combination appointments.

Chapter 2 describes the treatments in the Pediatric outpatient clinic and its effect on the cast room. In our research, we defined and evaluated recommendations to improve the performance of the cast room in the outpatient clinic Orthopedics, Traumatology, and Plastic Surgery. This recommendations have an effect on the performance regarding cast treatment at the Pediatric outpatient clinic. We propose to research the effect on the Pediatric outpatient clinic and possibly implement some of the recommendations of the cast room.

In Chapter 5, we evaluate the OCT capacity levels per shift based on workload. Hereby, we set fixed capacity levels for an entire shift. Green et al. (2006) discuss the potential of flexible staffing levels during the day. We propose to investigate the prospect of flexible capacity during shifts to further improve the cast room performance. Hereby, a fixed workload during the shift is not required.

In Chapter 4 and 5, we evaluate the scheduling of appointment requests without combination appointment requirements during non peak moments. We find that these non peak moments are limited in the current situation. Therefore, we recommend to consider the cast room opening hours during further research. Hereby, we recommend to consider the start time and end time of the day, as well as the possibility of scheduling appointments during the lunch break.

Chapter 5 evaluates the presence of a DA in the cast room. The benefits are clear. However, an additional DA requires additional budget for the cast room. Therefore, we recommend to evaluate flexible presence of a DA in the cast room. Hereby, we mean that a DA is present during the peak moments at the cast room to improve the service level.

This report does not include the evaluation of OCT capacity levels per shift. However, we described the importance to have sufficient capacity per shift in various Chapters. The document and excel-sheet 'Capaciteitsbepaling gipskamer' (2010) describe two methods to determine the required number of OCTs per shift to achieve a given utilization rate and service level. The first method uses a workload calculation to determine the required number of OCTs per shift. The second method uses a simulation-based optimization method to determine the OCT capacity per shift. Both methods determine the core capacity. This means the required capacity to deal with patients in the cast room, discarding the presence of external tasks or treatments.

Finally, this document compares the performance of both methods. Hereby, we propose adjustments in the workload calculation to better match the required OCT capacity.
This tool support the Workplace Management (WPM) to determine the actual required number of OCTs to meet a desired service level. Furthermore, the tool enables WPM to determine the required OCT FTE per year.

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APPENDIX A: DESCRIPTION OF THE PATIENT GROUPS

This section describes the patient groups, as presented in table 2.1, in detail:

INPATIENTS

- *Post operative:* After the operation of an post operative inpatient, the patient requires cast replacement during his stay in the hospital.

- *Not post operative:* A post operative inpatient may require cast (re)-placement to prevent or support treatment in the operating room.

- *Discharge:* An inpatient doctor decides when the inpatient is allowed to leave the hospital. Before the patient can go home, the inpatient requires cast replacement.

OUTPATIENTS

- *Combination appointment:* outpatients that combine an appointment to the cast room with an appointment to their specialist. This combination appointment is known and scheduled in advance e.

- *Combination – ad hoc:* the outpatient only has a scheduled appointment at a specialist. During this appointment, the specialist decides the requirements of a combination appointment, and refers the patient to the cast room on that day.

- *Cast problems:* An outpatient visits the cast room with cast problems.

- *Cast replacement:* The replacement of a patient's plaster cast without the requirements of a combination appointment.

- *Cast removal:* The removal of a patient's plaster cast.

- *Emergency – Subsequent appointment:* A patient visits the cast room with a temporary plaster cast to receive a definite plaster caster. The temporary cast was received at the emergency room the other day.

- *Emergency – ad hoc:* A patient is directly referred to the cast room by the emergency room.

- *2nd consults:* After treatment, it is possible that an outpatient has to visit the cast room for a second time that day. This depends on either the advice of specialist or the results of a X-ray.

APPENDIX B: SPECIALIST CONSULTING HOURS SCHEDULE

The following figure presents the schedule of the specialist consulting hours during the observation period (25 May – 19 June 2009). This schedule was applicable during October 2008 – September 2009.

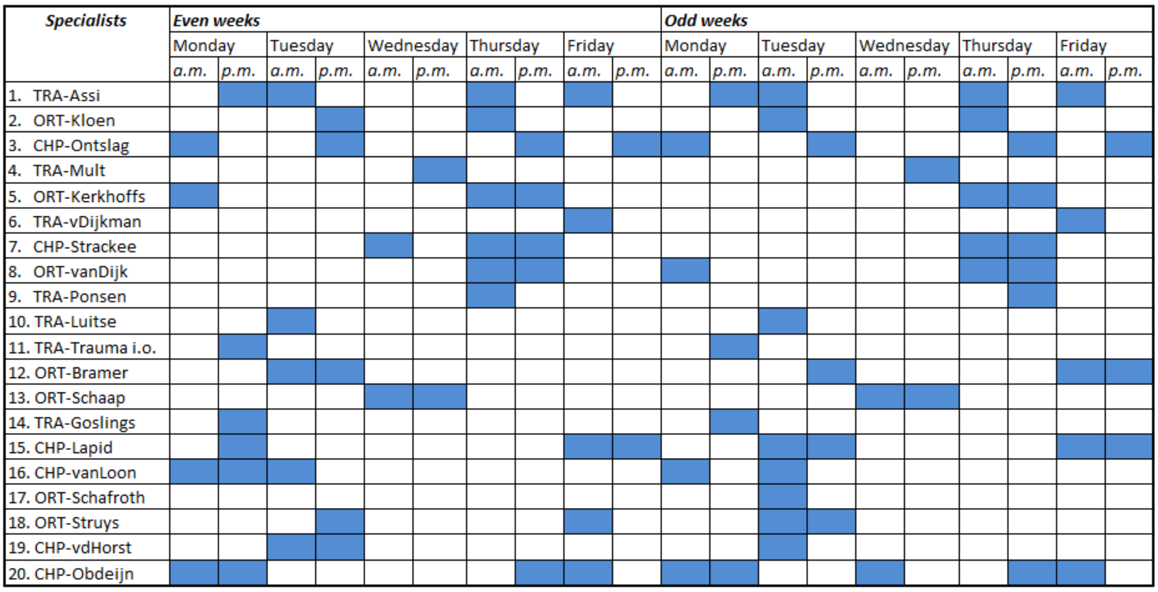

Figure B1: Specialist consulting hours schedule (Outpatient clinic Orthopedics, Traumatology & Plastic Surgery: 1 October 2008 – 30 September 2009)

APPENDIX C: SPECIFICATION OF THE TREATMENT TYPES

The following table presents the different cast room treatment types. The table includes the scheduled duration, as determined by the OCTs, the realized number of treatments during the observation period, and the average duration and standard deviation per treatment during the observation period.

The letters in the table have the following meaning:

- A: cast placement
- B: cast removal and placement
- n.a. = not applicable

Treatment Name / ID		Scheduled duration (hh:mm)	Number	Average realized duration (hh:mm)	Standard deviation (hh:mm)
Cast removal	1	0:15	108	0:07	0:05
Mallet	2A	0:15	1	0:21	n.a.
	2B	0:15	3	0:10	0:05
Finger brace	3A	0:15	4	0:17	0:08
	3B	0:30	2	0:45	0:37
Forearm	4A	0:15	23	0:16	0:12
	4B	0:30	21	0:25	0:12
Upper arm	5A	0:15	5	0:14	0:08
	5B	0:30	3	0:26	0:13
Detachable forearm brace	6A	0:30	3	0:19	0:06
	6B	0:30	1	1:25	n.a.
Forearm brace	7A	0:30	9	0:29	0:13
	7B	0:30	4	0:22	0:12
Upper arm brace	8A	0:45	1	0:31	n.a.
	8B	0:45	1	0:49	n.a.
Upper arm	9A	1:00	0	n.a.	n.a.
hinge-cast	9B	1:00	1	0:23	n.a.
Dynamic brace	10A	0:45	1	0:37	n.a.
	10B	1:00	2	0:48	0:19
Dynamic brace	11A	1:00	2	1:23	0:21
(more fingers)	11B	1:15	0	n.a.	n.a.
Spastic hand	12A	1:30	3	0:56	0:37
/fingers	12B	1:30	1	0:35	n.a.
Ankle wrap	13A	0:15	13	0:17	0:08
/soft cast	13B	0:15	18	0:17	0:09
Cast shoe	14A	0:15	3	0:09	0:06
	14B	0:30	3	0:28	0:11
Foreleg	15A	0:15	37	0:24	0:13
	15B	0:30	24	0:28	0:15
Foreleg brace	16A	0:30	14	0:34	0:17
	16B	0:45	5	0:39	0:21
Detachable foreleg	17A	1:00	18	0:33	0:14
cast for walking	17B	1:15	7	0:27	0:10
Knee tube	18A	0:30	1	0:14	n.a.
	18B	0:30	2	0:20	0:06
Detachable tube	19A	0:45	4	0:34	0:20
/upper leg cast	19B	0:45	1	1:01	n.a.
Knee hinge-cast	20A	1:00	0	n.a.	n.a.
	20B	1:00	0	n.a.	n.a.
Upper leg	21A	0:30	0	n.a.	n.a.
	21B	0:30	0	n.a.	n.a.
Clubfoot	22A	1:00	0	n.a.	n.a.
	22B	1:00	1	0:42	n.a.
Cast pants	23A	1:30	0	n.a.	n.a.
	23B	1:30	0	n.a.	n.a.
Cast corset	24A	1:30	1	1:18	n.a.
	24B	1:30	0	n.a.	n.a.

Table C1: Overview of the cast room treatments (Observation period 25 May – 19 June 2009, N=556 patients)

APPENDIX D: GLOSSARY FOR FORMAL PROBLEM DESCRIPTION

Section 3.2 includes the formal problem description. The following tables present a glossary to explain the terms in Table 3.1.

Strategic problem description

Term	*Explanation*
Size of demand	Annually demand
OCTs	Orthopedic Cast Technicians: doctors that treat cast patients
Specialists	Give advice about further cast treatment
Beds	Cast treatments are performed while the patients lies on the bed
Capacity	Combination of OCTs and beds

Table D1: Glossary for strategic problem description

Tactical problem description

Term	*Explanation*
Additional tasks	OCTs perform other tasks in addition to cast treatments (e.g. (administration, material supply)
Specialist impact	Number of cast room patients (combination or ad hoc) related to specialist consulting hours
Specialist schedule	Schedule of specialist consulting hours per shift during the week
OCT schedule	Schedule of OCT presence per shift during the week
Shift duration	The duration/length per shift during the week
Agenda schedule	Number of agendas and agenda times for scheduling cast patients during the week
Capacity reserving	Reserving agenda slots, OCTs, or beds for certain patients types during the week
Specialist shift restrictions	Restrictions whether specialist consulting hours can be scheduled during certain shifts
OCT contractual agreements	Number of shifts/hours per week for each OCT

Table D2: Glossary for tactical problem description

Operational offline problem description

Term	*Explanation*
Appointment request	Request for appointment of scheduled patients
Treatment duration	Duration of treatment
Specialist	Requirements for combination appointment by a specialist
Treatment period	In how many weeks does the appointment has to be scheduled
Agendas	See agenda schedule
Appointment time	Scheduled appointment time for appointment request
Appointment duration	Scheduled appointment duration for appointment request

Table D3: Glossary for operational offline problem description

Operational online problem description

Term	*Explanation*
Same-day request	Request for appointment of same-day patients
Walk-in patients	Patient who arrive at the outpatient clinic without appointment
Scheduled patients	Patients with scheduled appointment (either scheduled or walk-in)
Disturbance prob/dur.	Probability that treatment is disturbed with certain duration
Specialist advice prob/dur.	Probability that specialist advice is required with certain duration
Punctuality	Distribution for the arrival time of scheduled patients
No-show	Probability that scheduled patients do not show up
Arrival time	Arrival time of patients in the waiting area of the outpatient clinic
Capacity type	The amount by which capacity is decreased while treating the patient
OCT unavailability prob/dur.	Probability and duration of a decrease in OCT capacity due to external treatments or meetings
D.A. presence	Presence of a D.A. to perform certain cast room tasks
Capacity type restrictions	Inpatients can only be treated in cast room 2.

Table D4: Glossary for operational online problem description

APPENDIX E: SHIFT SPECIFICATIONS FOR VALIDATION

This section provides specific characteristics per shift as displayed in Figure 4.9 in Section 4.4. The values are an average of 20 replications.

2 OCTS

2 OCTs	*Monday a.m. (Even)*	*Wednesday a.m. (Even)*	*Tuesday p.m. (Odd)*	*Wednesday a.m. (Odd)*
Service level	45%	76%	57%	96%
Utilization	58%	33%	50%	42%
# OCTs	2	2	2.1	2.4
Avg. treatment duration	18.4 minutes	19.0 minutes	19.7 minutes	19.2 minutes
# patients	12.3	9.1	10.2	7.6
% scheduled	66%	37%	44%	42%
% walk-ins	18%	35%	29%	28%
% inpatients	9%	15%	14%	17%
% 2nd consults	6%	12%	12%	12%

Table E1: Shift characteristics during a capacity level of 2 OCTs (Simulation study, 10 replications of 1000 days)

3 OCTS

3 OCTs	*Monday p.m. (Even)*	*Tuesday p.m. (Even)*	*Wednesday p.m. (Even)*	*Friday a.m. (Even)*	*Friday p.m. (Even)*
Service level	33%	35%	78%	87%	88%
Utilization	50%	58%	46%	44%	24%
# OCTs	3	2.7	2.5	3	3
Avg. treatment duration	18.9 minutes	18.7 minutes	19.3 minutes	18.7 minutes	19.8 minutes
# patients	17.3	21.1	11.4	12.8	8.1
% scheduled	64%	68%	46%	58%	44%
% walk-ins	21%	21%	34%	23%	30%
% inpatients	7%	5%	10%	10%	14%
% 2nd consults	8%	6%	9%	8%	11%

3 OCTs	*Monday a.m. (Odd)*	*Monday p.m. (Odd)*	*Wednesday p.m. (Odd)*	*Friday a.m. (Odd)*	*Friday p.m. (Odd)*
Service level	49%	52%	89%	86%	88%
Utilization	37%	35%	46%	27%	28%
# OCTs	3	3	2,8	3	3
Avg. treatment duration	18.5 minutes	19.0 minutes	19.3 minutes	18.5 minutes	19.5 minutes
# patients	12.9	16.5	10.6	13.6	8.5
% scheduled	62%	66%	47%	57%	41%
% walk-ins	21%	18%	33%	25%	33%
% inpatients	9%	7%	11%	9%	14%
% 2nd consults	7%	8%	7%	8%	11%

Table E2: Shift characteristics during a capacity level of 3 OCTs (Simulation study, 10 replications of 1000 days)

4 OCTS

4 OCTs	*Tuesday a.m. (Even)*	*Thursday a.m. (Even)*	*Thursday p.m. (Even)*
Service level	91%	63%	53%
Utilization	68%	74%	50%
# OCTs	4	4	4
Avg. treatment duration	18.6 minutes	18.0 minutes	19.6 minutes
# patients	14.4	26.2	17.3
% scheduled	49%	61%	46%
% walk-ins	34%	29%	30%
% inpatients	9%	3%	10%
% 2nd consults	7%	7%	13%
4 OCTs	*Tuesday a.m. (Odd)*	*Thursday a.m. (Odd)*	*Thursday p.m. (Odd)*
Service level	84%	77%	59%
Utilization	58%	40%	42%
# OCTs	4	4	3,6
Avg. treatment duration	18.4 minutes	18.5 minutes	19.3 minutes
# patients	20.1	22.1	17.2
% scheduled	56%	61%	42%
% walk-ins	32%	28%	39%
% inpatients	5%	4%	8%
% 2nd consults	6%	6%	10%

Table E3: Shift characteristics during a capacity level of 4 OCTs (Simulation study, 10 replications of 1000 days)

APPENDIX F: SPECIALIST SCHEDULE OPTIMIZATION

Section 4.5 provides a brief description of the integer linear programming (ILP) problem to balance the expected patient impact per shift during a cycle of two week. The expected patient impact is a result of the specialist consulting hours schedule. This section provides the detailed problem formulation of the ILP:

ENTITIES

Entities	***index***
Shifts	*t* (subset t^e=1,..,10 : even week ; subset t^o=11,..,20 : odd week)
Specialists	*s* (1,..,20)

Table F1: Entities of the integer linear programming problem

PARAMETERS

Parameters	***Description***
d_s	Demand generated by specialist *s* during one shift.
c_s	Total required consulting hours of specialist *s.*
$\bar{c}_s^e$	Maximum number of consulting hours of specialist *s* during t^e.
$\bar{c}_s^o$	Maximum number of consulting hours of specialist *s* during t^o.

Table F2: Parameters of the integer linear programming problem

DECISION VARIABLES

Decision variables	***Description***
$X_{st} \in \mathbb{B}$	0 : Specialist *s* is not present during shift *t ;* 1 : Specialist *s* is present during shift *t*
$Y_t \in \mathbb{R}$	Total impact during shift *t*
$Z \in \mathbb{R}$	Maximum impact

Table F3: Decision variables of the integer linear programming problem

CONSTRAINTS

Constraints	***Description***
$\sum_{t \in T} X_{st} = c_s \; (\forall s)$ (1)	The scheduled number of consulting hours for specialist *s* equals the total required number of consulting hours for specialist *s.*
$\sum_{t^e \in T} X_{st} \leq \bar{c}_s^e \; (\forall s)$ (2)	The scheduled number of consulting hours for specialist *s* during an even week is smaller or equal to the maximum number of consulting hours of specialist *s* during an even week.
$\sum_{t^o \in T} X_{st} \leq \bar{c}_s^o \; (\forall s)$ (3)	The scheduled number of consulting hours for specialist *s* during an odd week is smaller or equal to the maximum number of consulting hours of specialist *s* during an odd week.
$Y_t = \sum_s d_s \times X_{st} (\forall t)$ (4)	The total impact during shift *t* is equal to the sum of the presence of specialist *s* times the impact of specialist *s* for all specialists.
$Z \geq Y_t \; (\forall t)$ (5)	The maximum impact is larger or equal to the total impact during shift *t*

Table F4: Constraints of the integer linear programming problem

OBJECTIVE FUNCTION

Objective function	***Description***
Minimize Z	The objective is to balance the maximum impact per shift over all shifts. By minimizing Z, equal to the highest impact for a shift, our problem formulation ensures this balance.

Table F5: Objective function of the integer linear programming problem

SOLUTION

The following figure shows the schedule for specialist's consulting hours as the optimal solution of our ILP problem.

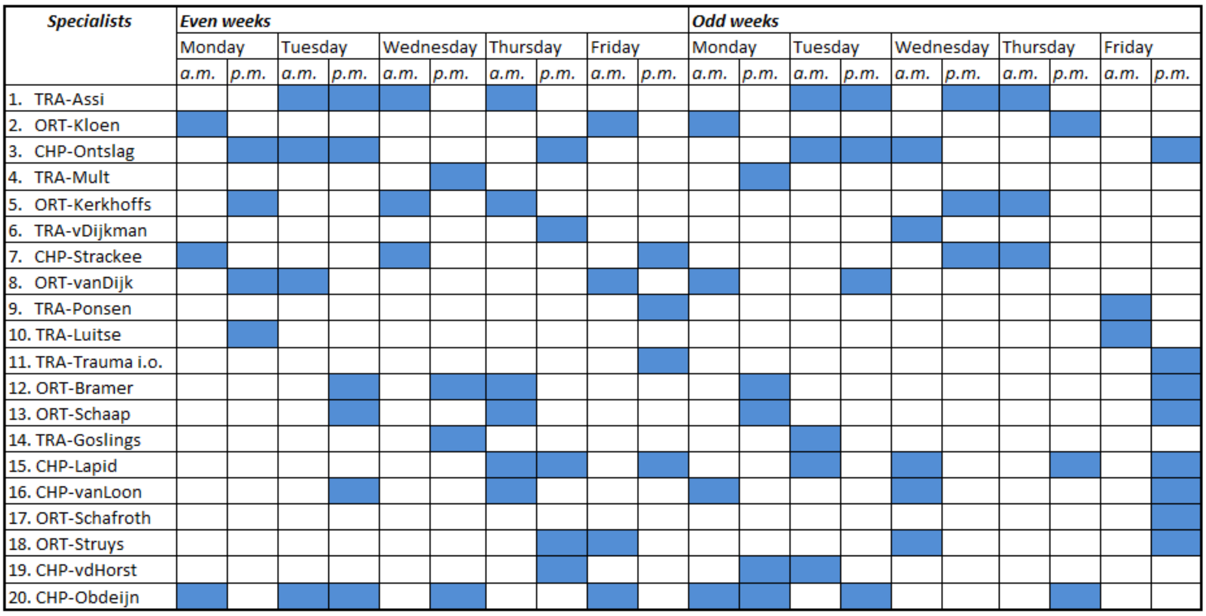

Figure F1: Specialist consulting hours schedule (ILP optimal solution