UNIVERSITY OF TWENTE.

Medisch Spectrum Twente

BALANCING THE PATIENT FLOW BETWEEN THE ORTHOPAEDIC OUTPATIENT CLINIC AND THE OPERATING ROOM

Public version

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Management Summary

Background

Within MST, the Admission Unit experiences problems filling the OR-time allocated to the Orthopaedic department. This research is initiated because the number of patients waiting for a surgery decreased. This number of patients is too small to fill the OR-time completely resulting in partly filled operating rooms and the necessity to give OR-time to other specialisms while there are increasing waiting lists in the outpatient clinic. This research discusses the causes of this planning problems and presents a scheduling method for preventing these problems in the future. The research question answered in this research is:

> ***How can the allocation of OR-time to specialists be adapted to be able to deal with fluctuations in the patient mix in order to obtain a smooth patient flow and a balanced workload for both consults and surgeries?***

Approach

First, we identified the causes of the planning problem using a problem bundle. We found that the decrease in patients waiting for a surgery is the result is multiple causes. An important cause is the unwillingness to give up OR-time (even during periods with fewer available specialists) resulting in longer waiting lists and corresponding access times for appointments in the outpatient department and a lower inflow of patients needing a surgery onto the waiting list for a surgery. Therefore, we focused the research on the allocation of specialists over activities, i.e. the relationship between consultation and operating time per specialist and access times. We used literature to identify techniques for solving resource allocation problems. We conclude that we deal with a tactical resource allocation problem. Based on the literature study we conclude that it is very hard to explicitly determine the optimal allocation of resources. Furthermore, we observe that little research is done on tactical planning considering multiple departments or resources in health care. We based this thesis on findings by Hulshof et al. (2013). Hulshof et al. propose an allocation method coping with multiple resources, multiple time periods and multiple patient groups with various uncertain treatment paths through the hospital, whereby decisions are made for a chain of hospital resources.

At the moment, OR-time allocated to the Orthopaedic department is allocated between the specialists based on a fixed roster. We introduce two alternatives to this method, allocation of OR-time based on either a flexible and a hybrid roster. In the flexible roster, all OR-time is allocated to specialists based on surgery workloads. In the hybrid roster, specialists have one fixed OR-day per week while the remaining OR-time is allocated based on surgery workloads. Because of the fact that the specialist schedule has to be determined six weeks in advance, we come up with formulas for calculating expected surgery workloads on which the allocation can be based.

In order to determine the most suitable method for allocating specialists to activities, the introduced allocation methods are compared using a simulation model. Using simulation we are able to analyse and compare different allocation methods in terms of access times and throughput. The scope of this model is the Orthopaedic department. We model the appointments in the Orthopaedic outpatient clinic, the Orthopaedic outpatient department clinic and the OR-days allocated to the Orthopaedic department. We experiment with the following three experimental factors:

- Roster on which the allocation is based (fixed, flexible or hybrid)
- Usage of expected surgery workloads
- Reservation of spots for new patients during consultation sessions.

Conclusions

Using the simulation model we generated the following results:

- The current method for allocating specialists to activities based on a fixed roster is not able to achieve a smooth patient flow and balanced workload for both consults and surgeries. Anticipation to fluctuating circumstances is not possible.
- The most important experimental factor is the fact whether expected surgery workloads or current surgery workloads are used.
- The norms for access times according to Treeknormen can only be achieved by using expected surgery workloads.
- If, nevertheless, it is chosen to use current surgery workloads for allocating OR-time, the allocation can better be based on a hybrid roster. The allocation using current surgery workloads based on a hybrid roster achieves 25% lower access times for new patients and 35% lower access times for surgeries compared to the allocation based on a flexible roster.
- Using expected surgery workloads, no statistically significant difference is found between an allocation of OR-time to specialists based on a flexible roster and an allocation based on a hybrid roster. Both methods result in comparable access times for both new patients and surgeries using expected surgery workloads.
- The use of expected surgery workloads (independent on the roster it is based on) results in 50% lower access times compared to the allocation of OR-time using current workloads based on a flexible roster.
- The use of expected surgery workloads (independent on the roster it is based on) results in 35% lower access times compared to the allocation of OR-time using current workloads based on a hybrid roster.

- The importance of reserving spots for new patients depends on the level of access times. With higher access times for new patients the reservation of spots helps continuing an inflow onto the waiting list for surgeries. In the current situation with a fixed roster, the reservation of spots results in higher utilization rates.

Recommendations

We recommend the Orthopaedic department to adopt an allocation method using expected workloads based on a hybrid roster. Although no significant difference was found between the usage of expected workloads based on either a flexible or a hybrid roster, the hybrid roster is recommended because it is more convenient for the specialists because they still have one fixed OR-day every week. In order to implement this method, the specialists have to be convinced of the necessity of changing the current fixed method for allocating OR-time.

In order to use expected workloads, the Orthopaedic department has to collect additional data. Information on waiting lists for new patient consults, recurring consults, treatments and surgeries has to be collected for each of the specialists. For calculating expected workloads it is necessary to divide this waiting lists into waiting lists for the most common diagnoses. At the moment, it is possible already to collect this data out of the data-warehouse.

Furthermore, we only recommend the department to reserve spots for new patients during consultation sessions in situations with high access times for new patients. In that case, the reservation of spots for new patients secures an inflow onto the waiting list for surgeries for recovering balance in the system.

The simulation model we use is built according to the specific procedures and patient mix of the Orthopaedic department within MST. The results, however, can be generalized to other departments and hospitals dealing with resource allocation problems. The introduction of flexibility in the use of resources lead to higher utilization rates and lower access times. Since the basic elements of planning in health care are similar to the basic elements of planning in business environments, the results can also be generalized to business environments.

Management Samenvatting (Dutch)

Achtergrond

Bureau Opname ervaart problemen om de aan afdeling Orthopedie toegewezen OK-tijd te vullen met operaties. Dit onderzoek is gestart omdat het aantal patiënten op de wachtlijst voor een operatie niet langer toereikend is om de toegewezen OK-tijd volledig te vullen. Dit resulteert in gedeeltelijk gevulde OK's en de noodzaak om OK-tijd aan andere specialismen te geven terwijl de wachtlijsten voor afspraken in de polikliniek groeien. Dit onderzoek beschrijft de oorzaken van dit planningsprobleem en onderzoekt verschillende methodes om dit probleem in de toekomst te voorkomen. De onderzoeksvraag die in dit onderzoek wordt beantwoord is:

> ***Hoe kan de toewijzing van OK-tijd aan specialisten worden aangepast om in te kunnen spelen op veranderingen in het patiëntenbestand om een gelijkmatige patiëntenstroom en een gebalanceerde werkbezetting voor de specialisten te realiseren?***

Aanpak

Allereerst hebben we de oorzaken van het planningsprobleem in kaart gebracht door middel van een probleemkluwen. We ontdekten dat de daling van het aantal patiënten op de wachtlijst voor een operatie het resultaat is van meerdere oorzaken. Een belangrijke oorzaak is de onwil om OK-tijd aan andere specialismen te geven ongeacht het aantal beschikbare specialisten. Dit resulteert in langere wachtlijsten en hogere toegangstijden voor afspraken in de polikliniek en een lagere instroom van patiënten op de wachtlijst voor operaties. Daarom hebben we dit onderzoek gericht op de toewijzing van specialisten aan de verschillende zorgactiviteiten (spreekuren, behandelingen, operaties en het bezoeken van geopereerde patiënten op de verpleegafdeling). We hebben ons gericht op de relatie tussen het aantal spreekuren, het aantal OK-sessies en de toegangstijden van een specialist. We hebben de literatuur gebruikt om oplossingstechnieken voor problemen met betrekking tot de toewijzing van capaciteiten te ontdekken. We concluderen dat we te maken hebben met een tactisch planningsprobleem. Gebaseerd op de literatuurstudie concluderen we dat er weinig onderzoek is gedaan naar het tactisch plannen van meerdere afdelingen of zorgactiviteiten. We hebben een aanpak gebruikt gebaseerd op resultaten van Hulshof et al. (2013). Hulshof et al. hebben een methode voor tactisch plannen bedacht waarin rekening wordt gehouden met meerdere zorgactiviteiten, tijdsperiodes en patiëntgroepen met verschillende onzekere behandeltrajecten.

Op dit moment wordt de aan de afdeling Orthopedie toegewezen OK-tijd verdeeld tussen de specialisten volgens een vast rooster. We introduceren twee alternatieven, het verdelen van

OK-tijd gebruikmakend van een flexibel rooster of gebruikmakend van een hybride rooster. Gebruikmakend van een flexibel rooster wordt OK-tijd toegewezen aan specialisten gebaseerd op hun wachtlijst voor operaties. In het hybride rooster hebben de specialisten een vaste OK-dag per week terwijl de resterende OK-tijd wordt toegewezen op basis van hun wachtlijsten voor operaties. Doordat het rooster zes weken van tevoren moet worden opgesteld hebben we formules bedacht om de verwachte wachtlijst voor operaties op dat moment te berekenen. Het toewijzen van OK-tijd kan vervolgens worden gebaseerd op deze verwachte wachtlijsten.

Om de meest geschikte methode voor het toewijzen van OK-tijd aan specialisten te bepalen vergelijken we de verschillende methodes door middel van een simulatiemodel. Door het gebruiken van een simulatiemodel kunnen we de verschillende methodes analyseren en vergelijken op basis van toegangstijden en aantal behandelde patiënten. Het simulatiemodel is gericht op de afdeling Orthopedie. We modelleren de planning van spreekuren, behandelsessies en toegewezen OK-sessies. Met het simulatiemodel experimenteren we met de volgende drie factoren:

- Rooster waar de toewijzing van OK-tijd op wordt gebaseerd (vast, flexibel of hybride)
- Gebruik van verwachte wachtlijsten voor operaties
- Reserveren van plekken voor nieuwe patiënten tijdens spreekuren

Conclusies

Door middel van het simulatiemodel kunnen we de volgende conclusies trekken:

- Met de huidige methode voor het toewijzen van OK-tijd aan specialisten volgens een vast rooster kan geen gelijkmatige patiëntenstroom en gebalanceerde werkbezetting worden gerealiseerd. Het is niet mogelijk om op veranderingen in het patiëntenbestand in te spelen.
- De belangrijkste factor is het al dan niet gebruik maken van verwachte wachtlijsten voor operaties.
- De normen voor toegangstijden zoals vastgesteld in de Treeknorm kunnen alleen worden gehaald door het gebruiken van verwachte wachtlijsten voor het toewijzen van OK-tijd aan specialisten.
- Als men besluit om desondanks gebruik te maken van de huidige wachtlijsten voor het toewijzen van OK-tijd aan specialisten, kan men de toewijzing beter baseren op een hybride rooster dan op een flexibel rooster. De toewijzing gebaseerd op een hybride rooster resulteert dan in 25% lagere toegangstijden voor nieuwe patiënten en 30% lagere toegangstijden voor operaties vergeleken met de toewijzing op basis van een flexibel rooster.
- Gebruikmakend van verwachte wachtlijsten voor operaties kan er geen statistisch significant verschil worden aangetoond tussen toewijzing op basis van een flexibel rooster en toewijzing op basis van een hybride rooster. Beide methodes leiden tot vergelijkbare resultaten.

- De toewijzing van OK-tijd gebruikmakend van verwachte wachtlijsten (onafhankelijk van het basisrooster) leidt tot 50% lagere toegangstijden vergeleken met de toewijzing van OK-tijd gebruikmakend van huidige wachtlijsten op basis van een flexibel rooster.
- De toewijzing van OK-tijd gebruikmakend van verwachte wachtlijsten (onafhankelijk van het basisrooster) leidt tot 35% lagere toegangstijden vergeleken met de toewijzing van OK-tijd gebruikmakend van huidige wachtlijsten op basis van een hybride rooster.
- Het belang van het reserveren van plekken voor nieuwe patiënten tijdens spreekuren hangt af van de hoogte van de toegangstijden. Bij hoge toegangstijden voor nieuwe patiënten helpt het reserveren van plekken voor nieuwe patiënten bij het continueren van een zekere instroom op wachtlijsten voor operaties. In de huidige situatie resulteert reserveren van plekken voor nieuwe patiënten in hogere bezettingsgraden.

Aanbevelingen

Op basis van dit onderzoek adviseren we de afdeling Orthopedie om OK-tijd te gaan toewijzen gebruikmakend van verwachte wachtlijsten voor operaties gebaseerd op een hybride rooster. Hoewel er geen statistisch significant verschil wordt aangetoond tussen het gebruik van verwachte wachtlijsten voor operaties gebaseerd op een flexibel en hybride rooster, adviseren we het gebruik van een hybride rooster als basis. Het hybride rooster is prettiger voor de specialisten omdat ze een vaste OK-dag per week behouden. Om deze methode voor het toewijzen van OK-tijd te implementeren zullen de betrokken specialisten moeten worden overtuigd van de noodzaak om veranderingen aan te brengen in het toewijzingsproces van OK-tijd.

Om gebruik te kunnen maken van verwachte wachtlijsten voor operaties moet de afdeling Orthopedie extra gegevens bij gaan houden. Per specialist zijn er gegevens nodig over de hoogte van wachtlijsten voor nieuwe patiënten, herhaalpatiënten, behandelingen en operatie. Verder is het van belang om hierbij de hoogtes van de wachtlijsten onder te verdelen in groepen voor de meest voorkomende diagnoses. Het is op dit moment al mogelijk om deze gegevens op te vragen uit het datasysteem.

Verder adviseren we de afdeling Orthopedie om plekken voor nieuwe patiënten te reserveren tijdens spreekuren als er sprake is van hoge toegangstijden voor nieuwe patiënten. In dat geval zal het reserveren van plekken voor nieuwe patiënten zorgen voor een zekere instroom op de wachtlijst voor operaties zodat de werkbelasting kan worden gebalanceerd.

Het simulatiemodel is gemaakt volgens de specifieke procedures en patiëntenbestanden van de afdeling Orthopedie binnen het MST. De resultaten kunnen echter worden gegeneraliseerd naar andere afdelingen of ziekenhuizen die te maken hebben met vergelijkbare planningsproblemen. Het implementeren van flexibiliteit in het planningsproces leidt tot hogere bezettingsgraden en lagere toegangstijden. Omdat de basisprincipes voor planning in de gezondheidszorg overeenkomen met de basisprincipes voor planning in het bedrijfsleven kunnen de algemene resultaten ook worden gegeneraliseerd naar een commerciële omgeving.

Preface

Six years ago I started my study Industrial Engineering and Management because I was seriously interested in supply chains and distribution channels and liked mathematics in secondary school. During these years I gained a lot of insights, tricks and techniques to quantify business problems mathematically. In the bachelor phase of the study I never expected to end up doing my master thesis in a hospital. However, after getting acquainted with health care topics during a master course I realised that from a logistic perspective a hospital environment is very comparable to a business environment. Although there are many differences, the basic principles are the same. When searching for a master thesis I eventually was offered an assignment at the Orthopaedic department within Medisch Spectrum Twente. I took this offer and I did not regret it at all.

I want to use this opportunity to thank some people for their help and support during this research. First of all, I want to thank Ilona Grooters-Oosterholt and Irma de Vries-Blanken for the opportunity to do this assignment within MST. Next to that, I thank Ilona for all the support during this assignment and the introduction in the hospital environment. I also want to thank all specialists and employees working for the Orthopaedic department of MST involved during this research. I am glad that everyone was always prepared to answer my questions, provide me with data and help me on.

Furthermore, I thank my supervisors from the UT, Ingrid Vliegen and Erwin Hans for all the help during this thesis. During conversations you have provided helpful insights and have led me in the right direction. Thank you both for that.

I hope you will enjoy reading this thesis.

Enter, February 2014

Rick Ooms

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1. Introduction

The Orthopaedic department within MST deals with a decreased number of patients on the waiting list for a surgery. Due to this decrease the planning department experiences problems filling the operating rooms allocated to Orthopaedics. Resulting in returning OR-time, lower production numbers and a lower turnover for Orthopaedics, which leads to lower fees for the surgeons.

This chapter describes the situation in which this planning problem occurs. Furthermore, it describes the context of the problem. In Paragraph 1.1, we describe Medisch Spectrum Twente. Next, we present the functioning of the Orthopaedic department within MST in Paragraph 1.2. Finally, we describe the problem and the structure of this thesis in Paragraph 1.3.

1.1 Medisch Spectrum Twente

Medisch Spectrum Twente (MST) is a large hospital that integrates basic and top-clinical healthcare services. It has approximately 3.700 employees (including 235 medical specialists). Approximately 1.070 beds are available to serve the 65.000 inpatients, including 32.000 day-care treatments, and 490.000 outpatients visiting the hospital each year (Medisch Spectrum Twente, 2012).

MST has three hospital locations; two of them are located in Enschede while the other one is located in Oldenzaal. Next to the hospital locations there are outpatient clinic centres in Haaksbergen and Losser. Because of these multiple locations MST can offer specialist care close to the patients.

The catchment area of MST is the region Twente. To the primary area belong the municipalities Dinkelland, Enschede, Haaksbergen, Losser and Oldenzaal with a total population of 264.000 people. Besides, the hospital treats many patients from elsewhere due to the top-clinical facilities the hospital has.

MST is organised in profit centres (in Dutch: Resultaat Verantwoordelijke Eenheden). An organizational chart of the hospital is given in Appendix A. Due to this profit centre structure the Orthopaedic department is responsible for its own managerial choices. The resulting (financial) consequences of these choices are incentives to manage the own department as good as possible. Thus, the managerial power is decentralized within MST and the planning problem is to a large extent an ‘Orthopaedic problem’.

1.2 Orthopaedic department.

Within MST the Orthopaedic surgeons do not work directly for the hospital, they are unified in an association (in Dutch: maatschap). The association consists of six Orthopaedic surgeons. Next to these Orthopaedic surgeons there is a surgeon working for the association as a chef de Clinique.

The MST is the only non-academic hospital in the Netherlands with a full training to Orthopaedic surgeon (Medisch Spectrum Twente, 2011). Currently, there are four students following the Specialty Registrar training (in Dutch: AIOS of arts in opleiding tot specialist). Furthermore, there is a nurse practitioner working for the Orthopaedic department. From now on, the Orthopaedic surgeon is referred to as **specialist**.

The specialists consult patients at the different locations of the hospital. Most of the outpatient consults are performed at the main hospital in Enschede. Furthermore, outpatient consults are performed at the hospital in Oldenzaal and the outpatient clinic centres. Finally, special consultations are performed at the Geessinkbrink (consultations in combination with a physiotherapist) and Universiteit Twente. In general, each specialist performs consultations at the main hospital and one of the other locations, and performs special consultation sessions.

Under normal circumstances patients with complaints are seen by general practitioners first. The general practitioners can decide to refer these patients to the Orthopaedic department. These references are done by writing a letter either manually or electronically using e-mail or fax. Then, the patient gets an appointment with one of the specialists. During this appointment the specialist discusses with the patient about the appropriate way forward. This depends on the complaints, fitness, age and preferences of the patient. Next to referrals by general practitioners, patients can enter the Orthopaedic care chain via the emergency department of MST. After being treated by a surgeon with trauma service in the emergency department, the patient can be referred to the Orthopaedic department for consults or treatments.

A patient with an appointment signs up at the desk by one of the secretaries. Then, the secretary marks the patient as present in the system, so the specialist can see which patients are available in the waiting room. After signing up, the patient waits in the waiting room next to the office of the specialist. In some cases the patient has to go to the radiology department first, in order to make an X-ray photo. The specialist picks up patients from the waiting room and takes them to his office or treatment room. After completion of the consult, the specialist marks the patient as ready in the system. If the patient needs a new appointment or a referral to another specialist/physiotherapist, the patient signs up at the desk again.

During the consult the specialist decides together with the patient about the appropriate way to continue the treatment of the patient. The following ways of continuing the treatment are most common:

- Stop treatment
- Recurring consult in the outpatient clinic

  There are a few different options for a recurring consult, namely:

  - Regular session; recurring consult at one of the regular consultation sessions in one of the outpatient clinics.
  - Special session; recurring consult at a special session in one of the outpatient clinics, for example a consult at a shoulder session (consultation session in combination with a physiotherapist) or a consult at a scoliosis session.
  - Treatment session; recurring consult in the outpatient treatment clinic in the main hospital in Enschede, for example to give the patient an injection.
- Further investigation

  In case the specialist needs information about the state of the injury inside the body, the following options are available:

  - X-ray photo; there is no appointment needed for an X-ray photo, the patient is sent towards the radiology department for making a photo immediately. Normally, this X-ray photo is made before the first appointment.
  - Medical ultrasonography; the secretary makes an appointment for the patient immediately by calling the radiology department. Furthermore, a recurring consult at the outpatient clinic is planned for discussing the results of the ultrasonography.
  - Bone scan; the secretary submits a request for a bone scan to the nuclear medicine department. This department will contact the patient for making an appointment. The patient is told to contact the Orthopaedic department when he knows the date of the bone scan in order to get a recurring consult for discussing the results at the outpatient clinic.
  - MRI-scan; the secretary submits a request for an MRI-scan to the radiology department. The patient will be contacted by this department for making an appointment. As with a bone scan, the patient should contact Orthopaedics for making a recurring consult to discuss the results.
  - CT-scan; same as MRI-scan.
- Surgery

In case the specialist concludes that a surgery is necessary and the patient agrees and wants to be operated, the patient is put on the OR admission list. Then, the patient is sent to the anaesthesia department to undergo a preoperative screening (POS) by an anaesthetist. During this screening an estimation is made about the general health condition of the patient and the expected risk of operating that patient. In an ideal situation the patient undergoes the screening the same day the patient is put on the OR admission list. The surgery cannot be planned before this screening is completed.

- Authorisation for physiotherapy.
- Authorisation for orthopaedic footwear.
- Referral to another specialist (either a specialist from another hospital or a specialist from another specialism).

A flowchart of an outpatient visit is given in Appendix B.

The specialists have to divide their time over the various steps in the care chain. They consult patients in the outpatient clinic, treat patients (for example with injections) in the outpatient treatment clinic, operate patients in the operating room and pay visits to operated patients in the ward. These activities are scheduled by the specialists taking into account capacity restrictions and specialist preferences. Once this schedule is finished, consults and treatments can be planned during the consultation sessions. The consults are planned by the secretaries of the Orthopaedic department. Furthermore, surgeries can be planned during the operating sessions of the specialists. The planning of surgeries is done by the Admission Unit.

1.3 Problem definition

As mentioned in the introduction of this chapter, the Orthopaedic department has experienced a decreased number of patients on the OR admission list. Due to fluctuations in new patient arrivals it is logical that the number of patients on the OR admission list fluctuates too. However, for many years there were between 400 and 500 patients on this list, peaking end 2011-early 2012 with over 500 patients, waiting for a surgery. Since then, the number of patients on this list has decreased. At the start of this research there were less than 250 patients on the OR admission list. In Figure 1 a graph is presented showing the progress of the waiting list over the last three years. In this graph the total number of patients on the OR admission list is equal to the number of patients already planned plus the number of patients not planned. A patient on the admission list is not automatically a patient that can be planned; therefore the number of patients who successfully passed the POS is added to the graph. The Admission Unit can only plan these patients. As can be seen in Figure 1 the number of patients that can be planned (the difference between the number of patients who completed their POS and the number of patients already planned)

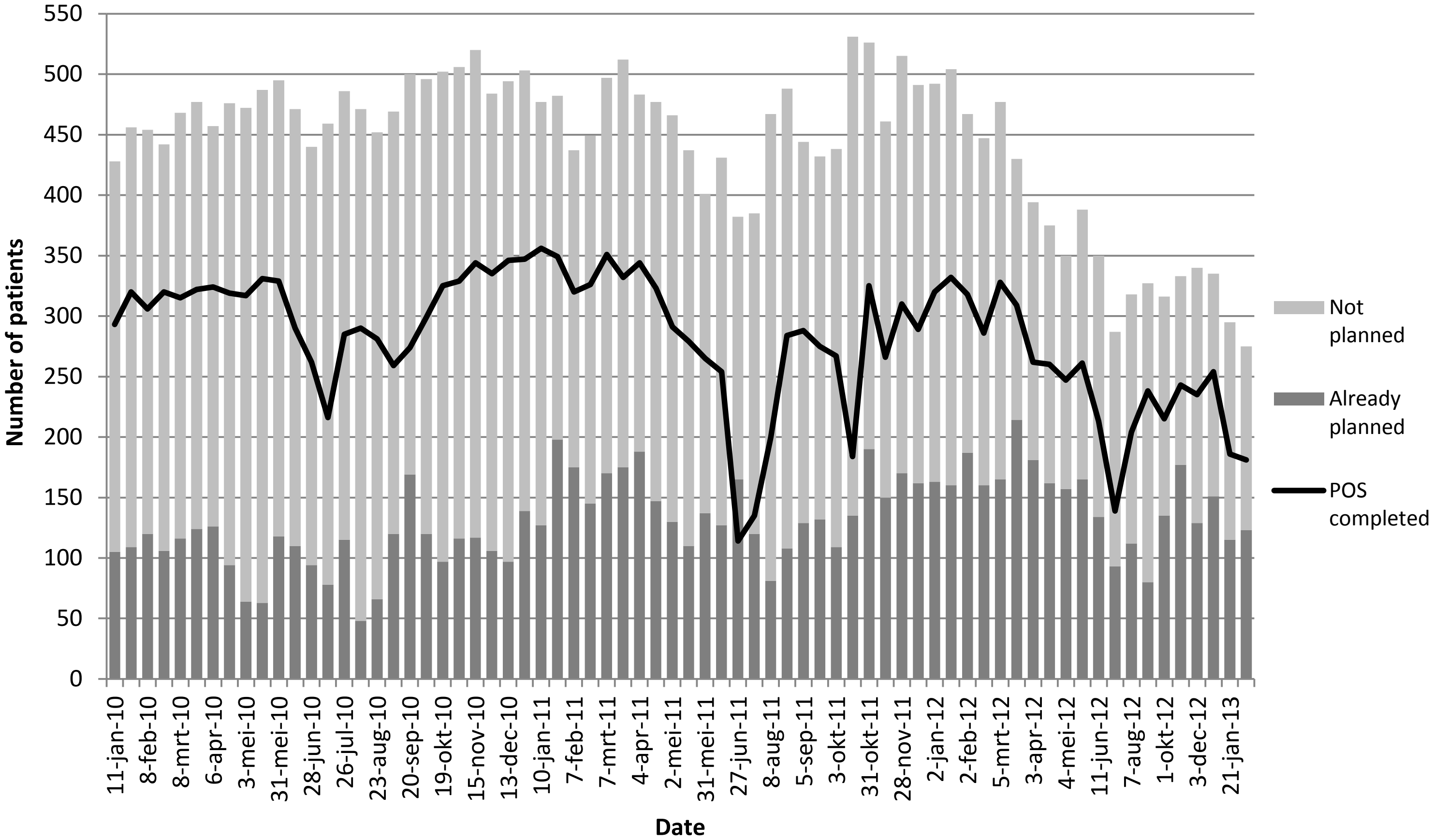

Figure 1: Number of patients on the OR admission list (n=70, T=2010-2013, source=MST)

decreased significantly. It should be noted that the number of patients on the OR admission list does not only fluctuate over time but per specialist too. Since most patients are operated by their own specialist (for simpler surgeries there are some exceptions) the workload with surgeries differs per specialist. However, the Admission Unit experiences a decrease for all specialists.

There is a relation between the number of patients on the OR admission list and the number of patients waiting for a consult in the outpatient clinic or a treatment in the outpatient treatment clinic. Patients waiting for a consult or treatment possibly end up on the OR admission list and vice versa. There should be a balance for all specialists between the different activities in order to ensure a smooth patient flow. A specialist who spends a lot of time operating automatically can spend less time consulting patients. This results in congestion of patients waiting for consultation and a decreasing number of patients waiting for a surgery (assuming that there is an equilibrium between the total number of patients and the capacity of the specialist). On the contrary, when a specialist spends too much time consulting patients the waiting list for surgeries will explode. Opposite to the decreased number of patients on the OR admission list, some specialists have high access times for consults.

From different conversations with people involved it became clear that the OR admission list was actually too high in the past, meaning the time between the date that a patient was added to the OR admission list and the date that a patient was operated was too long (according to the norms). Now however, the OR admission list is halved and the number of unplanned patients who already completed the POS has become too small. These problems result in incomplete filled ORs which forced the Orthopaedic department to return some of their OR-days to other specialisms. This is definitely not something the department likes and is the reason this research is started.

The four key points discussed in this thesis are:

1. *Allocation of specialists*

   The allocation of specialists over the various activities (consulting, treating, operating and visiting patients) is quite fixed at the moment. This allocation does not depend on the waiting lists of the specialists. This research focuses on a more flexible allocation in order to cope with variability in patient arrivals and patient care paths.

2. *Fluctuations in patient mix*

   The arrival pattern of new patients fluctuates both in total number and in composition. In the winter period, for example, the number of patients with hip injuries is higher than in the summer. This research tries to find a way to incorporate these fluctuations in the planning process.

3. *Smooth patient flow*

   The mission of MST is to improve the general healthcare in the region (Medisch Spectrum Twente, 2012). The access time for patients before the first consultation and the access time for a surgery are two indicators for the quality of care (www.treeknorm.nl).

4. *Balanced workload*

   It is important to obtain a balanced workload for the specialists. As mentioned earlier the different tasks of the specialist should be balanced in order to create a smooth patient flow. Furthermore, the specialists require varied OR programs and an attractive schedule.

Based on the problem definition and the key points described, the following research question is formulated:

> **How can the allocation of OR-time to specialists be adapted to be able to deal with fluctuations in the patient mix in order to obtain a smooth patient flow and a balanced workload for both consults and surgeries?**

In order to answer the research question a number of sub-questions have been formulated which are answered throughout this thesis.

- **What is the actual problem and what causes can be identified?**

In Chapter 2 the causes of the planning problem are identified using a problem bundle in which the causes and their relationships are mapped out. This problem analysis was the first step in this research and the research question formulated above was formulated after investigating the core problem.

- **What is already known about appointment planning and resource allocation in a hospital environment?**
  In Chapter 3 a theoretical framework is given around appointment planning and the allocation of resources in general and for a hospital environment in particular.

- **How can this problem be formulated mathematically?**
  In order to solve the problem a mathematical representation is presented in Chapter 4. Due to the fact that it is not possible to solve the issue exact in reasonable time, the mathematical representations had to be translated in a simulation model. This simulation model is discussed in Chapter 5.

- **What does the patient and specialist mix of the Orthopaedic department of MST look like?**
  The patient and specialist mix of the Orthopaedic department are investigated in the sixth chapter of this thesis.

- **How should the planning process be changed?**
  After presenting the simulation model in Chapter 5, the results of this simulation are given in Chapter 7. The conclusions and recommendation follow in Chapter 8, answering the most important question: how can the planning process be changed in order to solve the planning problems experienced?

2. Problem analysis

It is not possible to solve a problem without knowing what the reasons for this problem are (TSM Business School, 1998). In this chapter we therefore analyse the problem and present the causes with respect to the planning of the operating rooms.

Before an analysis of the problem is given, we present an analysis of the stakeholder in this problem in Paragraph 2.1. Next, in Paragraph 2.2, we identify the causes of the planning problem using a problem bundle. Then, we indentify the core problem in Paragraph 2.3. In Paragraph 2.4 we discuss the scope of this thesis. Finally, we present the conclusion of this chapter in Paragraph 2.5.

2.1 Stakeholder analysis

The planning problems experienced by the Admission Unit are not just a problem to the Admission Unit solely. Since multiple parties are involved and affected by the problem we map out the different parties and their interests in this paragraph.

The most important stakeholders and their involvement in the problem are summed up in detail below:

- *Association of Orthopaedic surgeons*
  The association plays obviously the most important role in this problem. The specialists are responsible for the inflow and outflow of patients on the OR admission list. The returning of OR-days to other specialisms directly harms the interests of the specialists. Since the specialists are not employed by the hospital they earn their money mainly based on the number of surgeries. So, for the association an OR admission list with enough patients to fill their OR-days is very important.
- *Team leader Orthopaedic department*
  The team leader of the Orthopaedic department is responsible for the functioning of both the outpatient clinic and the outpatient treatment clinic. This leader has no direct say in the functioning of the specialists but certainly has a problem if they cannot perform their activities in an efficient way.
- *Ward*
  In MST each specialism has its own dedicated wards. The workload of the ward connected with the Orthopaedic department (with an own team leader) depends on the outflow of operated Orthopaedic patients. Fewer Orthopaedic surgeries result in a lower bed occupancy for the ward.
- *Admission Unit*

The Admission Unit is responsible for the planning of the Orthopaedic surgeries. Consequently, they are directly involved with the planning problem because they experience difficulties making an appropriate OR-planning.

- *Secretaries*
  The Orthopaedic secretaries are responsible for the appointment planning in the outpatient clinic and outpatient treatment clinic. This planning influences the number of patients that can be added to the OR admission list. Due to this they are involved in the planning problem for surgeries as well.
- *Manager OR*
  The profit centre OR is responsible for using the ORs as efficiently as possible. Less occupied Orthopaedic OR-sessions result in lower utilization rates.
- *Board of Directors MST*
  The Board of Directors is responsible for the functioning of the whole hospital. For them it is important that the care delivered in MST is of high quality. Furthermore, they request the specialisms to reach the targets set with the health insurance companies as cost-efficiently as possible. The ORs are very expensive resources and therefore have to be used efficiently (Tyler, Pasquariello, & Chen, 2003).
- *Health insurance companies*
  Health insurance companies are involved in this problem because they have made agreements about the number of patients with certain complaints that are treated per period. If the Orthopaedic department is not able to achieve these targets the health insurance will pay less. Furthermore, health insurance companies made agreements about access times before surgery but with the current waiting lists this is not a problem.
- *Patients*
  Patients are involved in the problem because they are the ‘customer’ in this process. Most patients want to be operated as soon as possible and therefore require short waiting lists. The patient has to be kept satisfied otherwise he can leave to another hospital or clinic. Since the access time is low at the moment, patients do not experience long waiting times for a surgery at the moment. However, for certain patients (for example children with foot injuries) the waiting lists in the outpatient clinic are very high.

Comparing the interests of the multiple stakeholders, it can be concluded that short waiting lists are positive to a certain extent. However, the ORs should be used as efficient as possible and with the current waiting lists this is not possible.

2.2 Problem bundle

In order to analyse the problem and give insights in the causes of the problem we have formulated a problem bundle. In Paragraph 2.3 the core problem is identified out of this bundle. The problem bundle is presented in appendix C, the main problem is placed on top of the bundle. Next, we discuss the three direct causes influencing the problems filling the Orthopaedic OR-sessions. These causes are:

- The postponing of surgeries by patients (2.2.1)
- The number of patients who are not ready to undergo surgery (2.2.2)
- The decreased number of patients added to the OR admission (2.2.3)

Furthermore, special attention is given to the planning of consults during consultation sessions in Subparagraph 2.2.4.

2.2.1 Postponing of surgeries by patients

Even though there are patients on the OR admission list, it is hard for the Admission Unit to plan surgeries. In a lot of cases the date of surgery does not appeal to the patient while he has already passed the POS successfully. Since Orthopaedic surgeries are elective surgeries (the injuries of the patients are not life-threatening), the patient decides whether he will be operated on a certain date. The patient is called by the Admission Unit with a possible date of surgery but then the patient decides whether he will be operated that date. According to the planners the patients are more outspoken than some years ago. The most common reasons for postponement of surgeries by patients are the economic crisis (patients postpone their elective surgery because of money issues (own contribution to surgery to high) and uncertain job security issues), holidays (few patients want to be operated in the weeks before and during periods of holidays and vacations) and personal circumstances (patient has to undergo other surgeries first or is physically or mentally not ready for the surgery). Furthermore, patients have more and more preferences regarding the day of surgery due to personal reasons as shopping, babysitting etc.

Of course, this problem does not hold solely for the waiting list for surgeries. This problem is experienced with the number of referrals from general practitioners as well. According to the Orthopaedic specialists it is a national issue that departments/specialisms performing elective surgeries have to cope with a decreasing number of patients.

2.2.2 Patients not ready for surgery

Patients who are added to the OR admission list by the specialist have to undergo a pre-operative screening at the anaesthesia department before their surgery can be planned. Normally, patients are sent to the POS by the secretary directly after the specialist added the patient to the OR admission list. For quality of care and patient satisfaction issues the patient should be screened the same day (especially when the patient has to travel long distances, otherwise the patient has to visit the hospital more often). However, this is certainly not happening for every patient. It is possible that a certain anaesthetist is not available or that the waiting time before the screening is simply too high, such that patients prefer to return another day.

There is an internal agreement that says that 90 percent of the patients have to undergo the screening within a week (preferably the same day). In order to investigate whether this target is met, the Orthopaedic department collected statistics of the patients added to the OR admission list for five weeks. In appendix D is the number of days between the date the patient is added to the OR admission list and the date the patient undergoes a pre-operative screening is analysed. It turns out that the norm of 90 percent within a week is not met at the moment and that only 50 percent of the most healthy people undergo a screening on the same day the specialist adds the patient to the OR admission list.

In the past, the delay before a screening was never a problem to the Orthopaedic department because there was a long waiting list and patients had to wait a couple of weeks before surgery anyhow. Currently however, surgeries can be planned on very short term and the delay before the patient undergoes the screening results in planning problems for the Admission Unit.

Next to this delay there is another factor that influences the number of patients on the OR admission list that can be planned, namely the (temporary) disapproval of the patient. Especially for the patients with a bad general health condition and high risk of surgery it occurs that patients do not pass the screening and additional examinations have to be performed first. Of course, these patients cannot be planned.

2.2.3 Decreased number of patients on OR admission list

The in Paragraphs 2.2.1 and 2.2.2 introduced causes result in planning problems for the Admission Unit but the main cause is the decreased number of patients on the OR admission list. As mentioned in Paragraph 1.3 the list has been decreased significantly during last year. The number of patients on the OR admission list is a balance between the number of patients added to the list by specialists during consultation sessions and the number of patients operated during OR sessions (Figure 2). There are three factors identified that negatively influenced the number of patients on the OR admission list: an increase in number of OR sessions, an increased time between appointments and a decreased number of new orthopaedic patients.

Analysing the number of OR-sessions per week for the orthopaedic department it appears

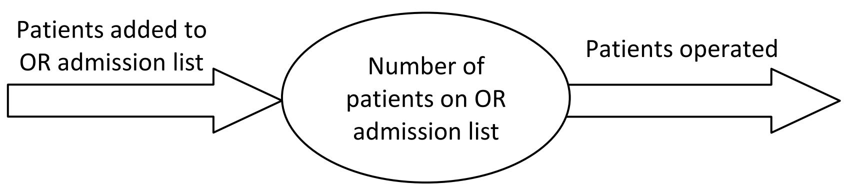

Figure 2: Balance of the number of patients on the OR admission list

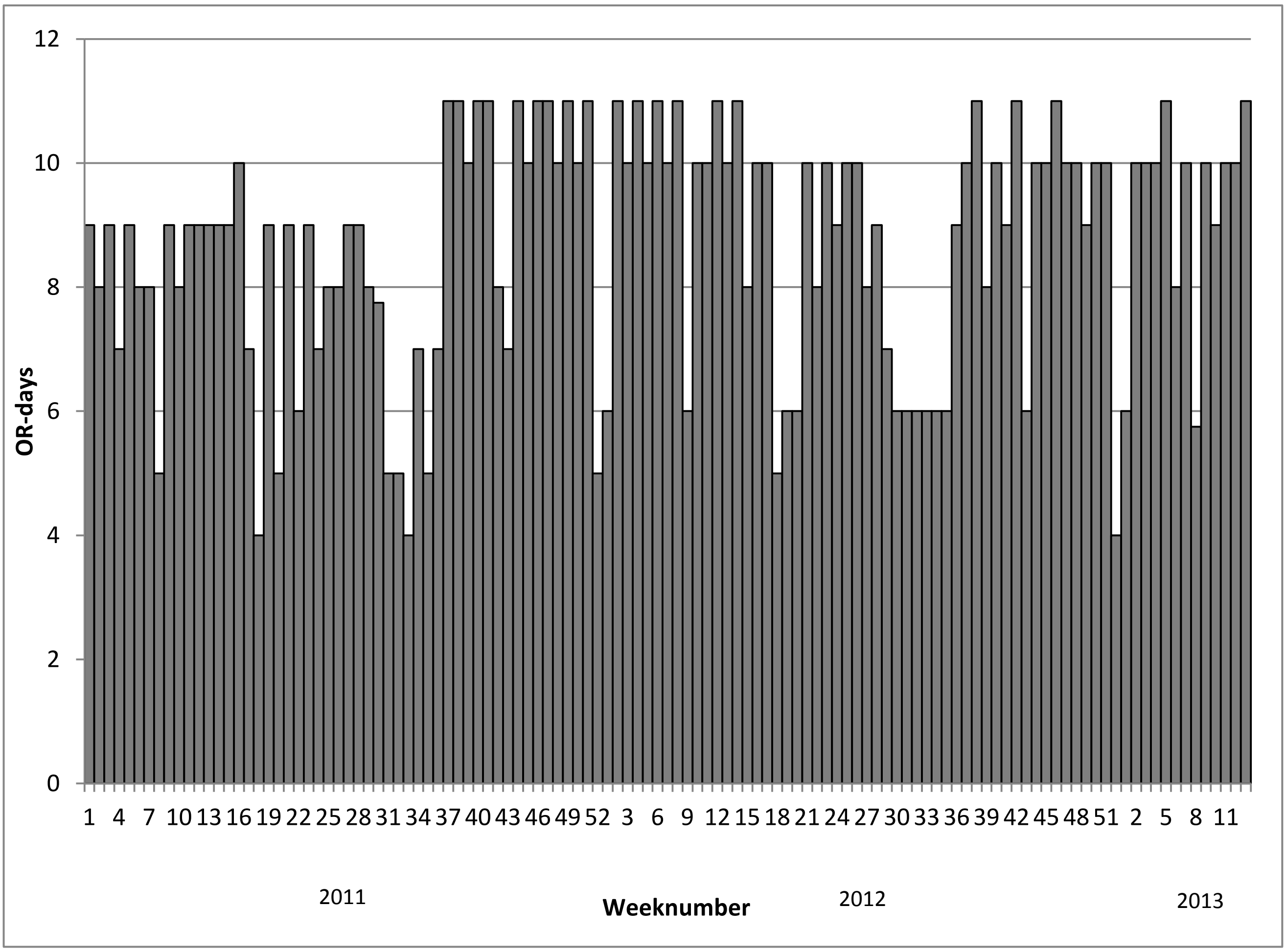

Figure 3: Number of orthopaedic OR-days per week (n=117, T=2011-2013, source=MST)

that this number has been increased since fall 2011. In Figure 3 we see an increase in number of OR-sessions since week 37, 2011. Thereafter, the number of OR sessions per week has not really been decreased except for periods of reduction (periods of holidays and vacations). This increase can be explained by extra allocated OR-days to Orthopaedics due to a seventh specialist. This specialist started working for the association early 2011 but resigned after only one year. From September 2012 to February 2013 a chef de Clinique was working for the association, replaced by another chef de Clinique during March 2013.

Next to the changes in staff, there was serious leave of absence by the specialists. One specialist is recovering from a burn-out since the summer of 2012 and still does not work full-time. Furthermore, another specialist has been operated early 2013 and could not work for some time too. Since the association of Orthopaedic surgeons did not want to give up OR-sessions the other specialists had to take-over the OR-sessions of the absent specialists resulting in less consultation sessions.

A decreasing number of consultation sessions automatically results in less consults because it is not possible to plan more consults per session. Due to this decrease the time before a new patient is seen and the time between recurring consults increased. The access times depend on the specialist; some specialists can see new patients in reasonable time while another specialist sees no new patients at the moment. Both, increased access time and increased time between recurring consults, result in a decreased number of patients added to the OR admission list.

Increased access times do not automatically result in higher numbers of patients waiting for a first appointment in the outpatient clinic. Higher access times will weaken the competitive position of the Orthopaedic department of MST. Patients are more likely to look for possibilities in other hospitals or private clinics when confronted with high access times (Yeung, Leung, McGhee, & Johnston, 2004). Furthermore, general practitioners will possibly refer patients to other hospitals in case of long waiting times in MST. There is disagreement whether this is a serious problem at the moment. On the one hand some people think that the long waiting times have stimulated patients to look for care elsewhere, on the other hand some people think that this is not a big issue since there are still patients added to the waiting lists of the busiest specialists. Since there is no data available about the number of patients looking for Orthopaedic care elsewhere the exact size of this problem is not known.

2.2.4 Planning consult sessions

The increased number of OR-sessions combined with the take-over of OR-sessions from absent specialists has resulted in a decreased number of consultation sessions. However, this is not the only point of concern involving consultation sessions, the use of these sessions plays a role as well. Since there was a decrease in the number of consultation sessions the planning of these sessions was even more important. Inefficient use of these sessions resulted in less patients added to the OR admission list and longer waiting times before appointments. Three factors for spoiling valuable session time are identified, specialists waiting for patients during sessions, administrative tasks during sessions and seeing the ‘wrong’ patient during sessions.

Specialist waiting time during a consultation session is caused by planned patients who are not available when the specialist is ready to see them. Patients can be unavailable for multiple reasons. First, some patients do simply not show up. Either they cancel their appointment on such short notice that is not possible to plan another patient instead or they simply do not show up. Second, some patients do not arrive in time. However, according to the specialists this is not really a problem because most of the time there are other patients available in the waiting room. Third, some patients have to go to the radiology department for an X-ray photo first. It occurs that the patient is not back in time due to waiting time there. Finally, sometimes there is no patient available simply because there is no patient planned. Sometimes spots are scheduled for emergency consults during consultation sessions. The secretaries are supposed to fill these spots with regular consults when these spots are not filled 48 hours before the session. Sometimes however, they do not succeed to make an appointment in that spot.

Combining all these possible sources of waiting time for the specialists during the consultation sessions one should expect that it happens regularly that specialists have to wait during the session. According to the specialists however this is not the case. They state that they rarely have to wait for patients and if so it mostly is quite convenient for the specialist. Mostly there are multiple patients waiting and patients who do not show up help the specialist to finish the session in time.

The specialists complain about the administrative tasks they have to execute during a consult (dictating letters to general practitioners, medication, managing patient records etc). According to the specialists these administrative tasks cannot be decreased because these tasks have to be executed during the consult. In the near future the administration during the session even increases due to the introduction of digital prescribing of medicines and the start of using digital patient records only. The specialists are afraid of these introductions and the probable longer consultation times.

The third factor of spoiling valuable consultation time is the planning of 'wrong' patients during sessions. In order to add knee surgeries to the OR admission list it might be necessary to see some new knee patients during the consultation session instead of patients with shoulder complaints. Furthermore, the chance that a new patient needs a surgery varies on the diagnosis. It is more likely that a new knee patient needs a surgery than a new shoulder patients. Prioritising of the consults at the outpatient clinic influences both the waiting lists of the outpatient clinic and the waiting lists of surgeries.

2.3 Core problem

In the previous paragraph we identified the causes of the planning problem using a problem bundle. In order to solve the problem it is important to choose the core problem (one of the bottom causes in the problem bundle) out of those multiple causes. The core problem should be that cause that can be influenced and is most relevant to the problem situation as a whole (TSM Business School, 1998).

Out of the problem bundle twelve possible core problems can be indentified (the numbers correspond to the numbers in the problem bundle presented in Appendix C):

1. Economic crisis
2. Holidays
3. Personal circumstances
4. Leave of absence by specialists
5. Increased number of OR-sessions
6. Patient cancellations
7. Patients not showing up

8. Patients too late
9. Variable waiting time radiology department
10. Unscheduled spots
11. Administrative tasks
12. Wrong prioritising of consults

The causes 1, 2, 4 and 11 cannot be influenced by the Orthopaedic department and can be struck out immediately. According to the specialists the causes 6 to 10 are not very relevant to the problem situation as a whole. The postponing of surgeries by patients due to personal circumstances (cause 3) could be a very interesting research topic. However, solving this problem will not automatically solve the planning problem since there will be temporarily more patients to operate but with unbalance between the in- and outflow of the OR admission list the number of available patients to plan will decrease again. That leaves the causes 5 and 12, the increased number of OR-sessions (cause 5) is something happened in the past and cannot be influenced anymore but the number of OR-sessions per week in the future (and consequently the balance between consultation sessions and OR-sessions) can be influenced, especially on specialist level (on specialism level this is harder). The prioritising of consults (cause 12) can be influenced for sure. Together these two causes are very relevant for the problem situation as a whole, therefore these causes are chosen as research topic in this thesis.

Both core problems can be seen as resource allocation problems. For the problem with respect to the balance between OR-time and consultation time, the specialist has to divide his time between outpatient clinic, outpatient treatment clinic, operating room and ward. The prioritising of the consults goes one step further, namely the division of time in the outpatient clinic to the different types of patients. In Figure 4 a graphical representation of this problem is given.

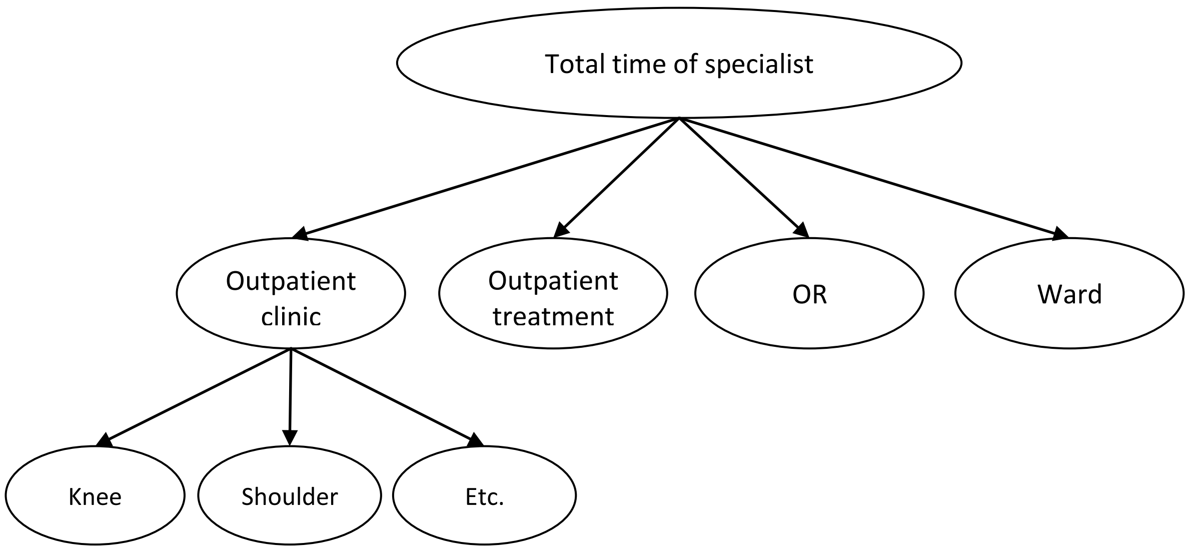

Figure 4: Graphical representation of allocation specialist time

2.4 Scope

The allocation of OR-time to specialists is limited by the total allocated number of OR-days to the Orthopaedic department. It would be optimal to base the allocation of OR-days on actual needs. Considering variability in the number of surgeries, the actual needs of the specialisms fluctuate over time. A more flexible allocation of OR-time, based on actual needs, has the advantage of risk pooling. Risk pooling is a phenomenon very popular in the insurance business. The payout of single insurances is highly variable, pooling multiple insurances (assuming uncorrelated insurances) will make the payout much less variable. The same effects can be used in the allocation of OR-days to specialisms. A single specialism can experience fluctuating needs for OR-days while the need for OR-days by multiple specialisms is much less variable (again assuming that the number of surgeries by one specialism is independent from the number of surgeries by the other specialisms). By introducing more flexibility in the OR-allocation supply and demand can be matched. However, this research is done solely commissioned by the Orthopaedic department. More flexible OR-allocation would require a widely based objective within MST, which is not the case during this project. Therefore this research focuses on the Orthopaedic department, and the allocation of OR-days to Orthopaedics is treated as a fixed capacity.

2.5 Conclusion

In this chapter we analysed the planning problem using a problem bundle. Out of this problem bundle we identified the core problems, namely the balance between OR-time and consultation time and the division of time in the outpatient clinic to different types of patients. The remainder of this thesis focuses on these core problems.

3. Theoretical framework

In this chapter, we present an overview of the relevant literature concerning the planning of patients and scheduling of specialists. First, we present a framework for planning in healthcare proposed by Hans, van Houdenhoven and Hulshof in Paragraph 3.1. This framework helps us to classify the planning functions used within the Orthopaedic department. Next, we searched for literature on surgery planning on a tactical level. Using this literature we want to check whether the current way of planning surgeries using a Master Surgery Schedule is concerned as a promising technique to use the ORs as efficient as possible. This research is presented in Paragraph 3.2. The Orthopaedic department does not have an advanced technique for planning appointments during consultation sessions. Appointments are planned by secretaries with little knowledge of planning and scheduling techniques for optimizing the utilization rate of the specialist's time and minimizing the waiting time for patients during the session. In Paragraph 3.3 we show some simple rules for improving both. Since we want to research how the allocation of specialists can be adapted to be able to deal with fluctuations in the patient mix, we searched for techniques to solve resource allocation problems. We present several techniques for such problems in Paragraph 3.4. Finally, in Paragraph 3.5, we summarize the theoretical framework.

3.1 Framework for planning in healthcare

Classically, planning functions are decomposed hierarchical into three categories (Anthony, 1965). Planning functions can be strategic, tactic or operational of nature. The operational level can be subdivided into offline operational and online operational to reflect the difference between 'in advance' and 'reactive' decision making (Hans, van Houdenhoven, & Hulshof, 2012).

Hans et al. (2012) proposed a generic framework for healthcare planning and control. This framework spans the above mentioned hierarchical levels of planning along with four managerial areas. These managerial areas include medical planning, resource capacity planning, materials planning and financial planning. The framework is shown in Figure 5.

The planning problems experienced by the Orthopaedic department belong to the resource capacity planning category since all problems are related to appointment planning and staff scheduling. The planning of surgeries by the Admission Unit as well as the planning of consults by the secretaries can be categorized as an offline operational resource capacity planning problem. The scheduling of the specialists into consulting, treating, operating and visiting activities can be categorized as a tactical resource capacity planning problem. The focus of this thesis is marked with a red rectangle in Figure 5.

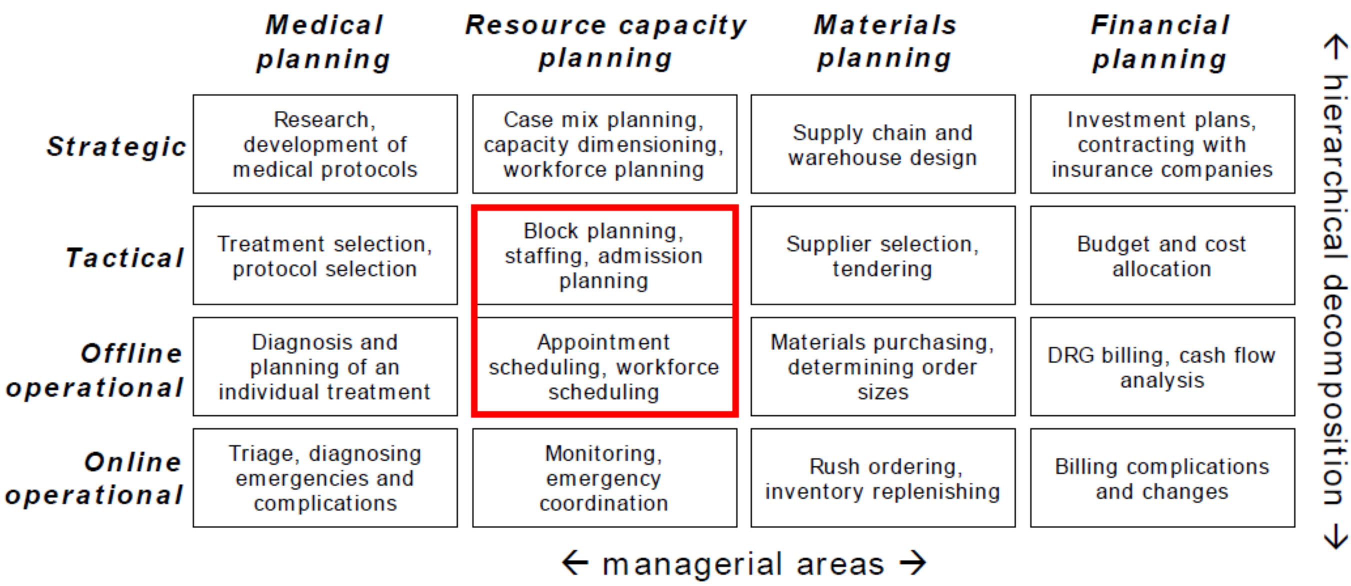

Figure 5: Framework for healthcare planning and control (Hans et al., 2012)

3.2 Surgery planning

Since the operating theatre is a significant cost driver of hospitals (Macario, Vitez, Dunn, & McDonald, 1995), it is important to use the operating rooms as efficient as possible. A better OR planning can improve the efficiency of the resources, level staff workload, reduce waiting time, reduce cancellations and improve overall performance of the hospital (Cardoen, Demeulemeester, & Beliën, 2009). Therefore, we searched for literature on surgery planning on a tactical level to check whether the current way of planning surgeries is concerned as a promising technique.

The current way of planning the ORs in MST can be divided into three stages. First, a certain number of OR-days are allocated to the Orthopaedic department. Then, the allocated OR-days are divided between the specialists. When OR-days are connected with specialists, surgeries can be planned in these ORs. The first two stages can be classified as tactical resource capacity planning, while the last stage is offline operational (Hans, van Houdenhoven, & Hulshof, 2012).

Once every three months, the total amount of OR-days is allocated to the different specialisms by the OR-committee. In this allocation all available OR-days (normally all ORs are available but during holidays some ORs are closed) are assigned to specialisms based on use of ORs in the past. The ORs are allocated in blocks of complete working days. In general the allocation is very rigid. When the OR-days are allocated to the specialisms, the specialists subdivide the OR-days allocated to the Orthopaedic department between the specialists. In a biweekly meeting the association connects the OR-days with specialists. Usually, one specialist is connected to one OR. However, occasionally two specialists operate together and are connected both to an OR-day.

The operational planning of surgeries is done by the Admission Unit. The vast majority of Orthopaedic surgeries involves elective surgeries, i.e. surgeries that can be planned in advance. The Admission Unit plans patients from the OR admission list who have successfully passed the Pre-Operative Screening into the available OR-days. Early 2012, a Master Surgical Schedule (MMS) system is introduced for this planning. Normally, a MSS is a cyclic timetable for the operating rooms where the operating room opening hours are divided into predefined blocks and allocated to the various specialties (Blake, Dexter, & Donald, 2002). In MST the MSS is not used to allocate OR time to specialties but the Orthopaedic department uses it for allocating the Orthopaedic OR time to the various types of Orthopaedic surgeries. The incentive for researching the planning method was a fluctuated patient flow from ORs to the ward resulting in fluctuating needs for beds and personnel in the ward. By introducing this MMS the inflow of patients in the ward could be balanced. Another reason for the introduction of this MMS was the possibility of giving the patient the date of surgery right after completing the POS. The research and development of the MSS was very comparable to several studies in the literature, for example the studies by Beliën & Demeulemeester (2007) and Vanberkel et al. (2011).

In order to find out whether we need to do new research to surgery planning we searched in the literature for results of using an MMS in healthcare planning. In the literature we found that the use of an MMS is considered as a promising technique for planning elective surgeries (see e.g. van Oostrum et al. (2008) and Adan et al. (2009)). Next to that, the amount of surgeries is not adequate to fill all allocated OR-time at the moment. Therefore the remainder of this research does not focus on techniques for planning surgeries.

3.3 Consult planning

The planning of appointments in the outpatient clinic of the Orthopaedic department can be divided into two parts. The first part relates to the appointment time at which a patient should be planned while the second part relates to which patient should be planned during a session. This latter question is comparable to the allocation of specialists to activities which will be discussed in Paragraph 3.4. For the planning of appointments, the total specialist time should be translated to total session time while the allocation of total time to certain activities should be translated to the allocation of session time to certain patient groups.

In the literature, pure block appointment planning, individual appointment planning and mixed block-individual appointment planning are the most suggested techniques for planning outpatient appointments in healthcare (Cayirli & Veral, 2003). In a pure block appointment system all patients in a consultation session are given the same appointment time and are seen by the specialist according to a first come-first served principle. The advantage of this system is a high utilization rate for the specialist's time since the chance that the specialist has to wait before a new patient arrives is small (with multiple patients scheduled at the same time, the chance is very small that they all arrive too late). However, the system has a major disadvantage since the patient waiting time is very large for the last patient being served. A modification of this system is a system in which the session is subdivided in multiple sub-sessions with patients arriving at the start of each sub-session.

An individual appointment system assigns a unique appointment time to each of the patients in a session. Due to variability in lateness of patients and variability in consultation time the utilization rate of the specialist's time and the patient waiting time are more variable compared to the pure block appointment system. The average utilization of the specialist's time is lower (higher average lateness) while the patient waiting time is lower too (the last patient being served does not arrive simultaneously with the first patient as is the case in the pure block appointment system). Ho and Lau (1992) proposed a variable-interval appointment scheduling rule to correct the problem of long waiting times of patients at the end of the consultation sessions.

In a mixed block-individual appointment system a group of patients is scheduled at the start of the consultation session to provide some buffer for the specialist. The other patients are scheduled according to the individual appointment system described above. This system combines the advantages of both systems, a relatively high utilization rate of the specialist's time and relatively low waiting times for the patients. Most of the other appointment systems are a modification or combination of one or more of the above described systems.

The Orthopaedic department in MST uses a pure individual appointment system for planning appointments in the outpatient clinic. In the outpatient treatment clinic a modified block appointment system is used. Up to five patients can be treated simultaneously using parallel treatment rooms. For these five parallel rooms usually one specialist is available (accompanied by assistants). In theory the utilization rate of the specialist's time is higher in the outpatient treatment clinic than in the outpatient clinic.

3.4 Resource allocation

In this paragraph we present several techniques for solving resource allocation problems in order to research how the allocation of specialists can be improved. We searched for techniques that are able to deal with fluctuating circumstances.

As discussed in Paragraph 3.1, the scheduling of the specialists can be categorized as a tactical resource allocation process. The main objectives of this allocation process are to achieve equitable access times for patients, to meet production targets and to use resources efficiently (Hulshof, Boucherie, Hans, & Hurink, 2013). According to Hulshof et al., tactical resource and admission planning approaches in health care are often myopic, meaning that they consider one department or resource solely. They state also that the benefits of an integrated planning approach are often recognized (for example by Hall (2006)), but that relatively few articles are written about this integrated planning approach for decision making in a care chain. Hulshof et al. (2013) propose a method to develop a tactical resource allocation and elective patient admission plan. The method allocates available resources to various care processes and determines the selection of patients to be served that are at a particular stage of their care process. Their method copes with multiple resources, multiple time periods and multiple patient groups with various uncertain treatment paths through the hospital, whereby decisions are made for a chain of hospital resources. They state that their method leads to a more equitable distribution of resources and provides control of patient access times, the number of patients served and the fraction of allocated resource capacity. Furthermore, they state that their method is applicable to various settings of tactical hospital management.

Another way to incorporate multiple resources and patient flows is to model the system as a Markovian Decision Process (MDP) (Kapadia, Vineberg, & Rossi, 1985). MDPs can be used for making decisions in situations with different states and probabilities of going for one state to another (e.g. a patient is now in the outpatient clinic and has *x %* chance of needing an operation and *1-x %* chance of needing a treatment in the outpatient treatment clinic). However, Nunes et al. (2009) argued that the MDP approach is not suitable for realistically sized problems.

Another often used technique for the efficient allocation of resources is mathematical programming. For example, for allocating operating time to various departments equitably, Black and Donald (2002) formulate the problem as an integer programming problem. However, due to the variability in arrival rate, the variability in patient characteristics and the variability in resource availability it is very hard to compute the exact solution to this problem in reasonable time.

Another method to solve this problem found in the literature is to analyse the resource allocation problem as a polling system. According to Al Hanbali et al. (2012), a polling system is equivalent to a set of queues with arrivals all requiring service from a single server. The server serves each queue to a specific service discipline and after serving a queue he will move to a next queue (Al Hanbali, de Haan, Boucherie, & van Ommeren, 2012). The resource allocation problem in the Orthopaedic department in MST can be seen as a server (specialist) that treats patients from one queue (performs a certain activity) and moves to the next queue (performing another activity) as a specific service discipline is reached (waiting list under a certain pre-defined level). However, seeing this problem as a polling system oversimplifies the situation, for example it is not realistic to serve queues until a certain pre-defined level is reached because of the need to fill allocated OR-time and the need to see patients out of other queues on short notice.

Reducing the complexity of a problem to make analytical models suitable is not ideal and literature recommends simulation models over analytical models (Lowery, 1998). Simulation models can be used to study systems that do not exist, to predict consequences of actions and decisions, or do experiments that are too costly to perform in reality (Lagergren, 1998).

3.5 Literature summary

In this chapter we presented relevant literature concerning the planning of patients in a healthcare environment. First, we showed a framework for healthcare planning and control. We found out that we the Orthopaedic department deals with a tactical resource capacity problem. Literature concerning integrated planning is scarce. However, from the literature it can be concluded that it is very hard (if not impossible) to explicitly calculate the optimal allocation. Hulshof et al. (2013) propose a method to develop a tactical resource allocation and elective patient admission plan. They state that their method leads to a more equitable distribution of resources and provides control of patient access times, the number of patients served and the fraction of allocated resource capacity. With the amount of data and detail in this research and the fluctuating circumstances an exact calculation is not realistic. A simulation model is the only realistic way for determining what allocation technique is most suitable. In a simulation model we can model the system as a Markov Decision Process

Planning of surgeries using a Master Surgical Schedule is concerned as a promising technique, so no further investigation is needed related to the planning of surgeries in MST. In order to decrease the waiting time during consultation sessions the Orthopaedic department could use a variable-interval appointment scheduling rule as proposed by Ho and Lau (1992).

4. Mathematical model

The resource allocation problem of allocating the specialist time over the various activities for a single specialist is presented in Figure 6 along with the patient flow. The specialist can perform only a single activity at a time. When operating patients in the OR, the waiting list in front of the OR decreases while the waiting list in front of the outpatient clinic increases (due to both the inflow of patients referred by general practitioners and the emergency department as well as the inflow of operated patients needing a control consult). Opposed to that, when consulting patients in the outpatient clinic the waiting list of patients waiting for a consult decreases while the waiting lists of patients waiting for surgery and patients waiting for treatment in the outpatient treatment clinic increase.

Next to the fact that a specialist cannot be in more than one place at a time, there is a maximum number of specialists that can perform the same activity at the same time. Within MST the number of allocated ORs to the Orthopaedic department at a particular day determines the number Orthopaedic specialists that should operate that day. This OR-allocation is therefore a restriction to the division of activities over the specialists. However,

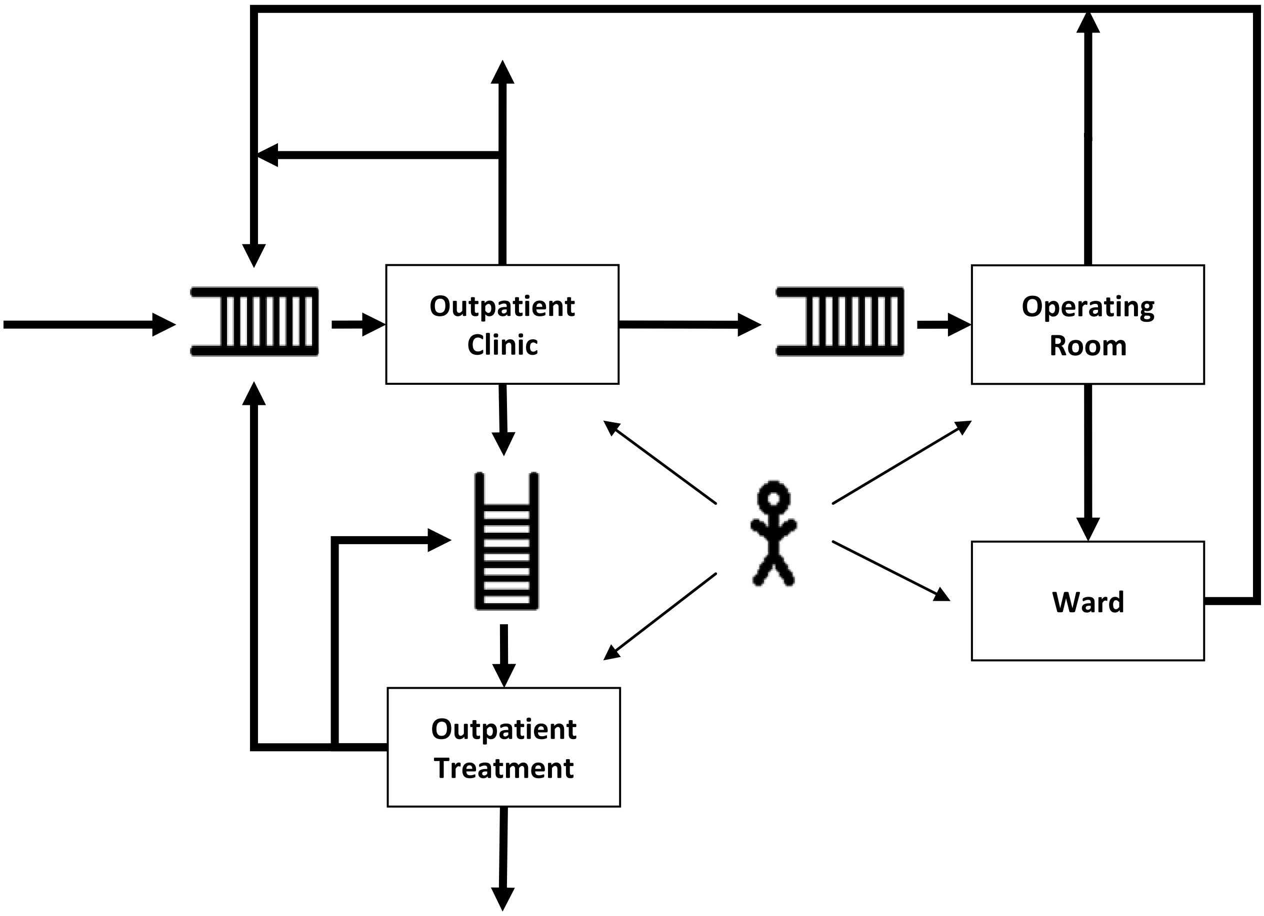

Figure 6: Graphical representation of the specialist allocation and patient flow

this OR-allocation is fixed for three months and also rigid in the long time (the allocation does not change significantly from quarter to quarter).

Since each specialist has its own patients, each specialist has its own waiting lists for consults and surgeries. This results in different workloads for the specialists. Treatments in the outpatient clinic can be performed by other specialists, however the patient still belongs to the original specialist who performed the consults and/or surgery. Apart from these treatments, the patient flow for a single specialist as represented in Figure 6 depends only on other specialists due to the sharing of resources. The outpatient clinic has sufficient capacity to accommodate all specialists simultaneously and therefore the allocation of OR-time to specialists is the only connection between the individual workloads. For example, when specialist X uses the single allocated OR, specialist Y cannot operate regardless the waiting list with surgeries (so the activities of specialist X influences the waiting lists of specialist Y). The number of new patients referred varies both in total number and in diagnosis. This results in variable waiting lists for the specialists. By using fixed schedules specialists cannot respond to changes in these waiting lists. A more flexible schedule to allocate specialists based on their waiting lists can help solving the planning problems experienced by the Admission Unit.

In Paragraph 4.1, we discuss the current specialist allocation method and alternative methods. Next, we present a method for calculating expected surgery workloads in Paragraph 4.2. In Paragraph 4.3 we will discuss the prioritising of consults. Finally, we summarize the findings in Paragraph 4.4.

4.1 Specialist allocation

The Orthopaedic department uses fixed rosters for scheduling the activities of the specialists at the moment. Based on the number of allocated OR-days to the Orthopaedic department and specialist preferences two rosters are made, one for the odd weeks and one for the even weeks. These rosters contain information about the activities performed per specialist during the week and at what time these activities are scheduled. However, due to changes in specialist availability (e.g. holidays) and the exact number of allocated OR-days (in holiday weeks the number of allocated OR-days is lower, see Figure 3 in Paragraph 2.2) the roster needs some adjustments each week. These adjustments are needed to match the number of operating sessions in the roster with the number of allocated OR-days. When the number of operation sessions in the fixed roster exceeds the number of allocated OR-days in a week, one or more specialists have to do more consultation sessions instead of an operating session that week. On the contrary, when the number of allocated OR-days exceeds the number of operation sessions in the fixed roster in a week, one or more specialists have to do more operating sessions instead of a consultation session that week. At the moment, these adjustments are made based on the surgery workload (number of patients waiting for surgery multiplied by their expected surgery duration). According to internal procedures, the final roster of the specialists should be determined six weeks in advance. Mathematically, in week *t* the specialist schedule for week *t+6* has to be determined. The secretaries and the Admission Unit need this time to plan consults and surgeries.

The current method for allocating specialists has some advantages and disadvantages. It is a great advantage that the specialists know the situation far in advance and does not change heavily, except for some adjustments. A great disadvantage of this allocation method is the impossibility to deal with fluctuating circumstances. Due to variability in number of patients, patient mix, and patient care paths the waiting lists fluctuate over time. An allocation of OR-time based on a fixed roster instead of surgery workloads (except for the adjustments) cannot respond to these fluctuations, resulting in lower utilization rates (specialists having operation sessions that they cannot fill completely) and higher access times.

As alternative to the current allocation method, we expect that a more flexible method will result in higher utilization rates and lower access times. Flexibility can be achieved by basing the allocation of OR-time on surgery workloads instead of a fixed roster. Total flexibility can be achieved by dividing allocated OR-days between specialists based on surgery workloads. A disadvantage of this method is that the roster changes from week to week. In order to combine the advantages of both methods, a hybrid allocated method can be used in which some of the OR-time is allocated based on a fixed roster and the remaining OR-time is allocated based on surgery workloads.

In this thesis we analyse and compare the effects of using these different allocating methods using a computer simulation. In the remainder of this thesis, the current allocation method is called **fixed**. The allocation of OR-time based completely on workloads is called **flexible**, while the allocation partly based on a fixed roster and partly on workloads is referred to as **hybrid**.

4.2 Calculation of workloads

As discussed in the previous paragraph, the fixed allocation of OR-time needs some adjustments due to changes in specialist availability and exact number of allocated OR-days. These adjustments are made based on the surgery workloads of the specialists. These workloads are calculated per specialist by simply multiplying the number of patients waiting for a surgery by their expected surgery duration. However, this workload is the current workload instead of the workload in six weeks when the roster is used. In this paragraph we present a method for calculating the expected surgery workload per specialist.

In order to calculate the expected surgery workload per specialist six weeks in advance, it is important to take into account the workloads for the outpatient clinic, the outpatient treatment clinic and the operating room during this six week. This has to be taken into account because the expected surgery workload six weeks from now depends on current workloads, the specialist allocation in these six weeks and new patient arrivals. Besides, the workload cannot be calculated explicitly due to variability in the number of patient referrals and patient trajectories. Nevertheless, the workload of a specialist can be estimated by taking into account expected number of patient referrals and expected patient trajectories.

We use *t* as the index for days, where *t*=1 represents now and *T* represents the day for which the expected workloads are calculated. For calculating the expected workloads, the following notation is used:

$\mathrm{WC_t}$ = Number of patients waiting for a consult on day t
$\mathrm{WO_t}$ = Number of patients waiting for a surgery on day t
$\mathrm{WT_t}$ = Number of patients waiting for a treatment on day t
$\mathrm{C_t}$ = Number of patients consulted on day t
$\mathrm{O_t}$ = Number of patients operated on day t
$\mathrm{T_t}$ = Number of patients treated on day t
$\mathrm{N_t}$ = Number of expected new referrals on day t

pcs = Probability that a consulted patient needs a surgery
$\mathrm{pct_i}$ = Probability that a consulted patient needs a treatment i days later
$\mathrm{pcc_i}$ = Probability that a consulted patient needs a consult in the outpatient clinic i days later
$\mathrm{pst_i}$ = Probability that an operated patient needs a treatment i days later
$\mathrm{psc_i}$ = Probability that an operated patient needs a consult in the outpatient clinic i days later
pts = Probability that a treated patient needs a surgery
$\mathrm{ptt_i}$ = Probability that a treated patient needs a treatment i days later
$\mathrm{ptc_i}$ = Probability that a treated patient needs a consult in the outpatient clinic i days later

The number of patients waiting for an appointment with specialist X in the outpatient clinic on day *t* is equal to the number of patients waiting for an appointment with specialist X in the outpatient clinic at the start of day *t-1* minus the number of consulted patients on day *t-1* plus the number of patients added to the waiting list on day *t*. The number of consulted patients is the number of patients having an appointment with specialist X on day t. The number of patients added to the waiting list on day *t* consists out of two parts, (1) new referrals and (2) recurring patients needing an appointment on day *t.* This number of recurring patients does not include patients who were already waiting for an appointment at the start of day *t* (only patients needing a recurring consult from day *t* onwards, e.g. patients being operated on day *t-28* needing a control consult four weeks later). As a result, the number of recurring patients added to the waiting list on a certain day depends on the number of consultations and surgeries in the weeks before.

Mathematically, the expected number of patients waiting for a consult in the outpatient clinic *T* days from now can be calculated using the following formula:

$$WC_T = WC_{T-1} - C_{T-1} + N_T + \sum_{i=1}^{T-1}[C_{T-i} * pcc_i + O_{T-i} * psc_i + T_{T-i} * ptc_i]$$

Using the same logic, the number of patients waiting for a surgery by specialist X on day *t* is equal to the number of patients waiting for a surgery on day *t-1* minus the number of patients being operated on day *t-1* plus patients being added to the waiting list by the specialist on day *t-1*.

Mathematically, the expected number of patients waiting for a surgery *T* days from now can be calculated using the following formula:

$$WO_T = WO_{T-1} - O_{T-1} + C_{T-1} * pcs + T_{T-i} * pts$$

The number of patients on the waiting list for a treatment can be calculated in the same way as the number of patients on the waiting list for a consult. Mathematically, the expected number of patients waiting for a consult in the outpatient clinic *T* days from now can be calculated using the following formula:

$$WT_T = WT_{T-1} - T_{T-1} + \sum_{i=1}^{T-1}[C_{T-i} * pct_i + O_{T-i} * pst_i + T_{T-i} * ptt_i]$$

In the presented formulas the number of patients consulted, treated or operated on day *t* cannot exceed the number of patients waiting for a consult, treatment or surgery that day. Mathematically,

$$C_t \leq WC_t$$
$$O_t \leq WO_t$$
$$T_t \leq WT_t$$

In these formulas patients are strictly consulted, treated and operated by the same specialist. The formulas can be extended with probabilities of patients going from one specialist to another. Furthermore, they can be extended by subdividing the waiting lists into smaller waiting lists per group of patients or diagnose.

The above procedure for calculating waiting lists can be modelled as a Markov Decision Process (see Paragraph 3.4) since the number of patients on the waiting list depends on both the decisions made and some randomness.

In order to calculate the number of patients on the waiting list on day *T*, the numbers of patients on the waiting list on day *T*-1, *T-2*, *T-3*, etcetera until the number of patients on the waiting list tomorrow, have to be calculated first (the number of patients on the waiting list today should be known). Furthermore, the numbers of patients consulted, treated and operated from day *t=1 to T-1* have to be determined based on available sessions of the specialist (note that the number of patients consulted/treated/operated on a certain day cannot exceed the number of patients waiting for a consult/treatment/surgery on that day).

Finally, for calculating the expected workload of the specialists in the outpatient clinic, outpatient treatment clinic and operating room the number of patients have to be multiplied by the time needed per appointment or surgery.

In this thesis we analyse and compare the effects of using this method for calculating expected workloads instead of using current workloads. In the remainder of this thesis, we refer to this calculation as an allocation based on **expected workloads**. The case without calculating expected workloads is referred to as an allocation based on **current workloads**.

4.3 Prioritising of consults

As soon as the activities of the specialists are scheduled, the specialist schedule is sent to the secretaries and the Admission Unit. Then, consults can be planned during consultation sessions and surgeries during operating sessions. During consultation sessions time has to be divided between new patients and recurring patients. In most cases recurring patients need an appointment in a certain week, e.g. a control appointment six weeks after surgery or a consult for discussing MRI-results as soon as the results are known. In contrary, new patients normally do not need an appointment in a certain week. However, this does not mean that specialists can solely schedule recurring patients during consultation sessions. On the one hand, the access time before a first consult should meet the norms as determined by Treeknormen (www.treeknorm.nl). According to these norms, eighty percent of the patients should get a first consult within three weeks and hundred percent within four weeks. On the other hand, specialists need new patients in order to assure a certain number of surgeries in future weeks.

Next to the division of patients in new patients and recurring patients, patients can be divided into patient groups, e.g. knee patients, shoulder patients, arthrosis patients etc. In order to use the MSS for scheduling surgeries in the OR a similar inflow of patients to the waiting list for surgeries is required. Some time ago the specialists made an agreement to reserve spots in each session for new knee- and arthrosis patients. In reality, however, this agreement is not met by all specialists. In this thesis we will analyse the effects of reserving spots for certain patients .

4.4 Conclusion

In this chapter we discussed the concepts used by the Orthopaedic department for scheduling activities and planning appointments. We discussed the current method for allocating specialists over the different activities based on a fixed roster. Using this method it is not possible to respond to changing circumstances. Therefore, we came up with a flexible and a hybrid method. These methods achieve flexibility by basing the allocation of OR-time on surgery workloads instead of a fixed roster.

The optimal moment to allocate the specialists to the different activities would be at the start of each day. In that case the exact workloads of the specialists are known and the operating rooms can be assigned to the specialists with the largest workloads for surgeries. However, due to practical issues the allocation of specialists has to be done six weeks in advance. Using the formulas presented in this chapter, the expected workloads for consults, treatments and surgeries for each of the specialist can be calculated six weeks in advanced. Based on these expected workloads specialists can be allocated to activities.

In the next chapter, we will present the simulation study used for analysing and comparing the fixed, flexible and hybrid allocation method. Furthermore, we analyse the effects of using an allocation based on expected workloads instead of current workloads. Finally, the we study the effects of reserving spots for certain patients.

5. Simulation study

In this and the following chapters we present the steps taken in the simulation study for analysing and comparing the effects of different scheduling methods. As guideline, we have followed the ten steps out of which a typical simulations study is composed (Law, 2007):

1. *Formulate the problem and plan the study*

   In this step we determine the objectives of the simulation study, the level of detail of the model, the performance measures, the scope of the model, the system configurations we model, and the software we will use (see Paragraph 5.1).

2. *Collect data and define a model*

   During this step, we collect information on the system procedures and data to specify the model parameters and input distributions (the system procedures have already been discussed in Chapter 4 while the data collection is presented in Paragraph 5.2).

3. *Check whether the assumptions are valid*

   In this step we validate the assumptions made so far (see Paragraph 5.3).

4. *Construct a computer program and verify*

   We program the simulation model in this step. Furthermore, we verify that the simulation model represents the system procedures and assumptions correctly (see Chapter 6).

5. *Make pilot runs*

   During the fifth step, we make pilot runs for validation purposes in the next step.

6. *Check the validity of the model*

   In this step we check the validity of the model by reviewing the model results for correctness (see Paragraph 6.7).

7. *Design experiments*

   We specify for each of the system configurations we study the length of the simulation run, the warm-up period, and the number of runs in the seventh step (see Paragraph 7.1).

8. *Make production runs*

   In this step we run the simulation model.

9. *Analyse output data*

   In the ninth step we determine the absolute performance of the system configurations and compare the configurations in a relative sense (see Chapter 7).

10. *Document, present and use results*

    Finally, we document and present the study results and come up with recommendations for future use of the results (see Chapter 8).

5.1 Problem formulation

In this paragraph we present the objectives of the simulation study (5.1.1), the level of detail and scope of the model (5.1.2), the performance measures (5.1.3), the system configurations we model (5.1.4), and the software we will use (5.1.5).

5.1.1 Objectives

This simulation study is designed for analysing and comparing different methods for allocating OR-time to specialists. We want to study the effects of these different methods on waiting lists, access times and utilization rates of the time of specialists. Furthermore, we want to find out what allocation method should be used.

5.1.2 Detail and scope

The level of detail of the simulation model is based on the objectives of the study. In this study we analyse methods for allocating OR-time to specialists and study the effects on waiting lists, access times and utilization rates. Therefore, we need a simulation model that is detailed down to patient level. Furthermore, on patient level we need patient information like diagnoses, patient care paths, and surgery types for dividing patients between specialists. However, it is not realistic to model every patient specifically because of the large number of different diagnoses, number of surgeries, and number of possible care paths per diagnosis. We, therefore, subdivide the patients into patient groups with similar diagnoses, similar surgery types, and similar care paths.

The sequence of consults and surgeries in a session is not important in this research. For calculating waiting lists we only need the dates of the appointments and the time between consecutive appointments. Therefore, we only model the dates of the appointments without modelling the actual appointment times and waiting times during sessions.

The scope of the model is the Orthopaedic department. We only model the appointments in the Orthopaedic outpatient clinic, the Orthopaedic outpatient department clinic and the OR-days allocated to the Orthopaedic department. Furthermore, we model the appointments in the outpatient clinic as if these appointments only take place in the main hospital. It is not necessary to model consultation sessions in the hospital in Oldenzaal and the outpatient clinic centres separately because no separate waiting lists are used for these locations.

5.1.3 Performance indicators

In order to compare the different allocation methods it is important to identify indicators for measuring the results. We have identified the following indicators for measuring the efficacy of the different system configurations:

1. Total throughput (i.e. the number of consults, treatments and surgeries per year).
2. The access time for a new referral before the first consult (i.e. the time between referral by general practitioner and the first consult).

3. The access time before surgery (i.e. the time between referral to surgery and the actual surgery date).
4. The access time for a recurring consult (i.e. the time between the date the patient needs a recurring consult and the actual consult date).

5.1.4 System configurations

In this simulation study we analyse and compare different methods for allocating OR-time to specialists. We study the allocation of OR-time using either current surgery workloads or expected surgery workloads based on a fixed, flexible or hybrid roster. Furthermore, we analyse the effects of reserving spots for certain patients during consultation sessions.

5.1.5 Software

The simulation model we built for comparing the different allocation methods is classified as a discrete-event simulation model. Discrete-event simulation concerns the modelling of a system as it evolves over time by a representation in which the state variables change instantaneously at separate points in time (Law, 2007). These points in time are points at which events occur that change the system. In this simulation model these events are the arrivals of patients, the allocation of specialists to activities, the planning of appointments during consultation sessions, treatment sessions and operating sessions, the actual consults and surgeries, etcetera. Although discrete-event simulation could conceptually be done by hand calculations, the amount of data stored and the number of events for most real-world systems require such an amount of calculations that a computer is necessary (Law, 2007). For building a simulation model for this analysis, the *Plant Simulation* software published by Siemens PLM Software is used. This software is a discrete-event simulation tool that helps creating digital models of logistic systems to explore system characteristics and optimise its performance. This software is used because it is available and suitable for this simulation study.

5.2 Data

In this paragraph we describe how we analysed the data and show what data we use the simulation model. First, we describe in Subparagraph 5.2.1 Diagnosis Treatment Combinations because they contain a lot of logistic relevant information. Next, we group patients based on similar care paths in Subparagraph 5.2.2. In Subparagraph 5.2.3 we present the care paths per diagnosis. Then, we describe the arrival pattern of patients to the Orthopaedic department in Subparagraph 5.2.4. Thereafter, in Subparagraph 5.2.5, we present the different surgery types used for planning by the Admission Unit. Finally, in Subparagraph 5.2.6 we discuss the capacity characteristics.

5.2.1 Diagnosis Treatment Combinations

Due to the gradual introduction of competition in the Dutch care system in 2005, Diagnosis Treatment Combinations (DTCs, in Dutch: DBC's) were introduced. A DTC is a representation of all steps a patient needs in order to diagnose and treat the patient. Starting with the first visit and ending with the last check-up of the patient (DBC-Onderhoud, 2013). Over the years the need for a more uniform declaration system increased. In order to create a more stable, more complete and more transparent declaration system, the DOT-systematic (DTCs towards transparency, in Dutch: DBC's op weg naar transparantie) was introduced in 2012 (NZa, 2011). Within the DOT-systematic the DTC is no longer defined in advance, it is determined afterwards by a grouper (a central web-application). Care providers pass on which care (diagnosis and treatments) is delivered to a patient and the grouper determines to which DTC-product it belongs. The care provider can declare this DTC-product to the health insurance company.

When a patient arrives at the hospital with a new demand for care (an injury the patient is not in treatment for), a new initial DTC is started immediately. In this DTC all the activities needed for diagnosing and treating the injury are registered. These activities can include outpatient consults, imaging activities, outpatient treatments, surgeries, clinical episodes, etc. After completing the treatment process or after at most 365 days after starting the DTC, it is closed and sent to the grouper. If the treatment process is not completed 365 days after the first visit a follow-up DTC can be opened. A closed DTC cannot be reopened and a follow-up DTC can be opened only after closing an initial DTC. In case a DTC is closed and the patient returns to the hospital with complaints a new initial DTC has to be started.

An exception for closing DTCs after completing the treatment or 365 days after starting the DTC are DTCs including clinical episodes. These DTCs are closed 42 days after the patient is discharged from the hospital. A follow-up DTC can be started afterwards.

Since DTCs contain a lot of logistic relevant information, they are a good starting point for analysing the patient flow within the Orthopaedic department. For multiple reasons, only DTCs with a start-date in 2012 are used in this analysis. First, DTCs started in 2012 contain recent data. Second, due to the introduced DOT-systematic, data before 2012 differs from afterwards and are difficult to compare. Third, most DTCs started in 2012 were closed at the moment of analysis.

5.2.2 Patient grouping

The DTC-data of 2012 consists of 205 different diagnoses. As explained in Paragraph 5.1 it is not realistic to model all different diagnoses and care pathways, we therefore group patients based on similar care paths. For representation, it is important to group patients in such way that a limited number of groups cover a large number of surgeries. Using the DTC-products declared by MST to the health insurance companies in 2012, the thirteen diagnoses with the most surgeries are selected. A group representing the patients with another diagnose is added as remaining group. These diagnoses and the total number of patients, outpatient visits, outpatient treatments and surgeries belonging to each of these diagnoses are shown in Appendix J.

Together, the selected diagnoses cover 39% of the total patient population of the Orthopaedic department. These patients use 45% of the appointments in the outpatient clinic, 50% of the appointment in the outpatient treatment clinic and 71% of the surgeries. These numbers are also shown in Appendix J. The remainder of the patients are grouped in a remaining group, resulting in fourteen different patient groups. It is not meaningful to further subdivide this remaining group because of the large number of diagnoses and different care pathways.

5.2.3 Patient care paths

Each patient group has its own care pathway. By connecting data from different information systems using Microsoft Excel a care pathway is created for each of the selected patient groups. An example of such a care pathway is given in Figure 7. This care pathway is based on data extracted from the information systems X-Care and OR-Suite and conversations with the specialists.

In Figure 7 it can be seen that 79% of the patients with diagnosis 1801 (knee arthritis) follow a conservative trajectory. The remaining 21% of the patients end up being operated. Normally an operative trajectory involves a recurring consult in the outpatient clinic approximately six weeks after the first consult. The direct arrow from first consult to surgery is explained by the fact that a significant amount of patients decide to go for surgery more than a year after the first consult (in this case the first consult is actually not the first consult because a part of the trajectory is followed before). After the second consult, some patients try an injection in the outpatient treatment clinic before being operated. The after-surgery trajectory consists out of an appointment in the outpatient treatment clinic for removing stitches (approximately two weeks after surgery), a control visit in the outpatient clinic (approximately 2 months after surgery) and a control visit after a year. However, this last visit falls outside the scope of a DTC and such a control visit is seen as a new conservative trajectory (the operative DTC with clinical episodes has to be closed 42 days after being discharged and the follow-up DTC is conservative because that DTC does not include clinical episodes anymore, see Paragraph 5.1).

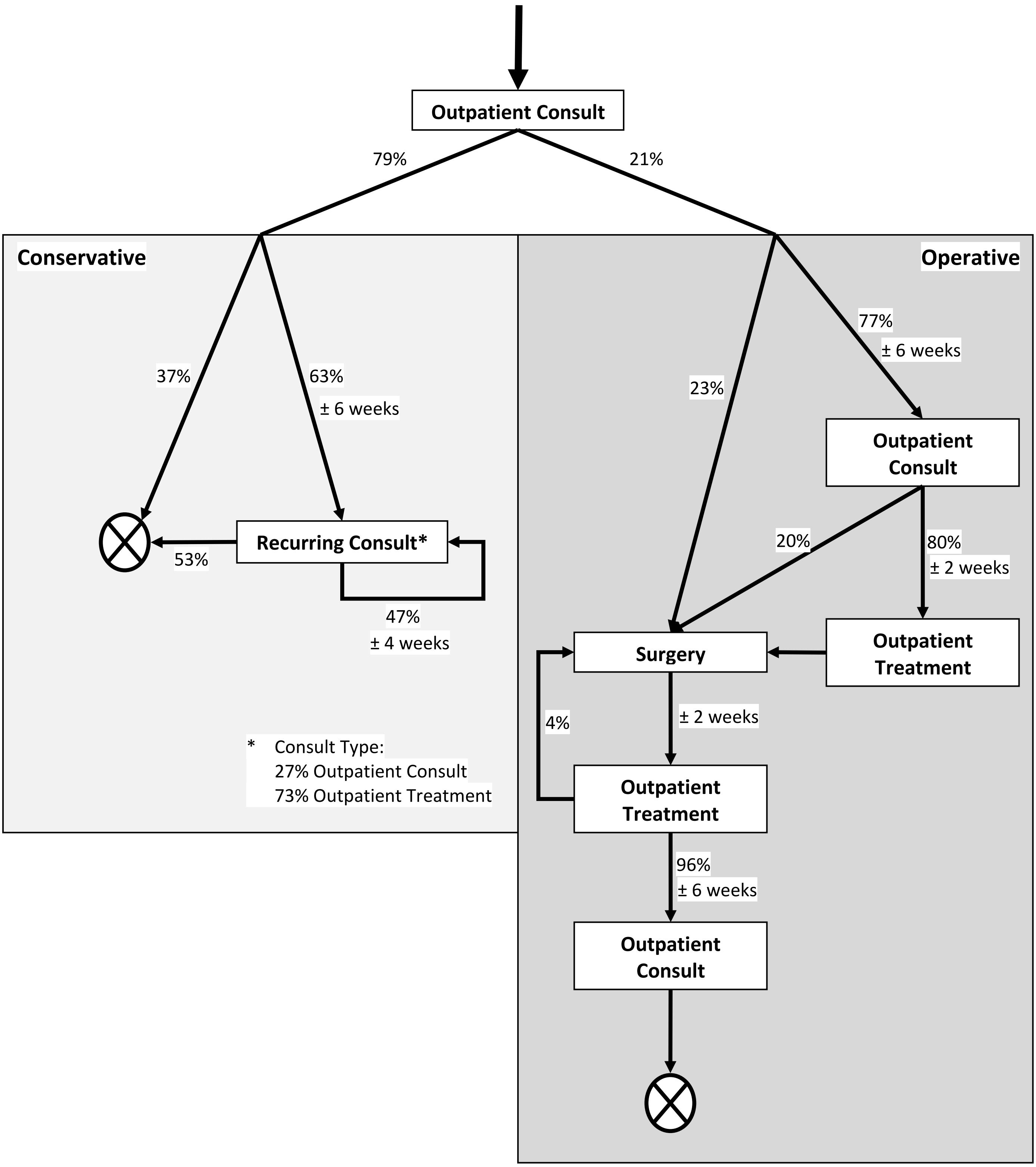

Figure 7: Flowchart of the patient flow of patients with diagnosis 1801 (knee osteoarthritis)

From the 79% of the patients following a conservative trajectory, 37% finish the trajectory after only one consult in the outpatient clinic. The other 63% have a second consult approximately six weeks after the first visit. This consult can be either in the outpatient clinic (27%) or in the outpatient treatment clinic (73%). Since the conservative trajectories are very different from patient to patient, it is chosen to model the number of consults by a growth rate after each consult (growth rate between 0 and 1, resulting in an exponential decrease of the number of patients needing a next consult). With a growth rate of 0,47 the number of consults equals the actual number of consults. Again, these consults can be either in the outpatient clinic (27%) or in the outpatient treatment clinic (73%).

Some patients need a second surgery after being operated. In this case four percent of the patient undergoes a second surgery. This surgery can be either a re-operation or a surgery on the other knee. The care pathways of the other selected diagnoses are shown in Appendix E.

From the remaining group, nine percent undergoes an operative trajectory. After consultation of specialists we chose to model this trajectory with two outpatient consults before surgery and one outpatient treatment combined with two control consults after surgery. For the conservative trajectory, a patient needs a recurrent consult with growth rate 0,40 (divided over outpatient clinic (26%) and outpatient treatment clinic (74%). The flowchart for this remaining group is also shown in Appendix E.

5.2.4 Arrival pattern

The arrival rate of new patients differs over the year. These seasonal fluctuations are caused by holidays, weather, sport season etc. In order to find trends in the monthly number of new patients DTC data of the years 2008-2012 is used. However, since DTCs are started during the first consult the date of referral is not registered in the system. We assume that the time between referral and first consult is short and stable. This is a reasonable assumption according to the specialists. The distribution of arrivals per month per diagnose is given in Appendix F. The expectation with respect to the future is that the annual number of patients will stabilize with numbers equal to 2012. Therefore, the number of patients, consults, treatments and surgeries in 2012 are used in the simulation model.

5.2.5 Surgeries

As mentioned in Paragraph 3.2, the Admission Unit uses a Master Surgery Schedule (MSS) for planning Orthopaedic surgeries. In this MSS, the Orthopaedic surgeries are clustered in nine groups and a remaining group (Apenhorst, 2011). These groups are shown in Appendix J. The surgeries belonging to each of these groups can be found in the internal document *Keten in Balans – MSS Orthopedie* by Gerwen Apenhorst. There is one-to-one relationship between diagnose and type of surgery. In order to find out whether the surgeries belonging to the selected diagnoses in Paragraph 5.2.2 cover the surgery clusters in the MSS, the total number of surgeries per surgery cluster is counted for the selected diagnoses. This coverage of surgeries by patients in selected diagnoses can be found in Appendix J. This appendix also includes the total number of surgeries per surgery cluster. Based on these numbers, we conclude that the selected diagnoses cover the vast majority of the surgery clusters apart from the trauma and miscellaneous group. We therefore conclude that the selected diagnoses are chosen such that all important surgery types are covered.

In Appendix J, we show the connection between diagnoses and surgery types. We conclude that the data we use is correct since it does not include combinations of knee-diagnoses with patients with a diagnoses with knee complaints and a shoulder surgery or comparable odd cases.

Due to differences in specialist characteristics and focus, patients are assigned to specialists. In order to find out which patients are assigned to which specialist, the percentages of surgeries performed by the different specialists per diagnose is determined. As discussed in Paragraph 4.1, there is an agreement between the specialists to include spots for new knee- and arthrosis patients (generally for patients with diagnoses 1701, 1801 or 1805) in order to equalize the number of surgeries per specialist. However, as can be seen in Appendix J the number of surgeries is not evenly spread for these diagnoses and the agreement is not met during 2012.

One should expect that the percentages of consults performed by the different specialists per diagnose is comparable. However, as can be seen in Appendix J, these percentages differ significantly. Two reasons can be identified for this difference. The first reason is that patients with more complex complaints (higher chance of resulting in a surgery) are assigned to the specialists that focus on these complaints while patients with less serious complaints can be assigned to other specialists as well. A second reason is that patients are seen by a certain specialist and in case of a surgery are referred to a specialist that focuses on that type of surgery. In the simulation model the percentages presented in Appendix J are used for assigning operative patients to specialists and for assigning conservative patients to specialists.

5.2.6 Capacity characteristics

In 2012, the Orthopaedic department consisted of six specialists. One specialist was absent during the months June to September while working partially from October to December. Because of this absence, a chef de Clinique was contracted starting in August. Most of the tasks of the absent specialist were taken over by the chef de Clinique. The remaining patients were divided over the other specialists. In consultation, we assume that these remaining patients can be neglected and that the patients consulted/treated/operated by the chef de Clinique can be added to the patients seen by this specialist. Next to the specialists, one nurse practitioner and four assistants (AIOS) work for Orthopaedics. The surgery duration depends on both the type of surgery and the specialist. In Appendix K the average duration is given per surgery cluster and per specialist.

5.3 Assumptions

In order to translate the system in a simulation model we have to make some assumptions. Since a simulation model is a simplification of reality, this is not unusual for simulation model. Most of the assumptions are already handled throughout this thesis, but for convenience they are summarized as follows:

- Patients cannot change from specialist, meaning that patients are consulted and operated by their own specialist. Patients, however, can be treated by other specialists.
- In reality, emergency patients and patients having a consult more than a year later are handled as recurring patients. The exact numbers of these patients are not known, in the DTC-data these patients are registered as new patients. We, therefore, handle these patients as new patients.
- The number of patients entering the system is fixed per month. However, the number of patients per specialist and per diagnose varies.
- Operative trajectories are equal per diagnose, i.e. every patient with meniscus problems needing a surgery follows the same trajectory (number of consults, number of treatments, time between consults, etcetera.).
- When entering the system, it is determined whether the patient follows an operative or a conservative trajectory. However, because the model does not use this information for making consults with new patients this does not influence the results.
- It is assumed that all patients planned show up and are handled during the session. In reality, approximately three percent of the patients cancel their consult or do not show up at all. Since these patients mostly do not need a new consult this is not taken into account in the model.
- We assume that there is no difference between consultation sessions in the outpatient clinics, i.e. no difference between consultation sessions in the main hospital and consultation sessions at other locations.
- Absence of specialists is not taken into account. Nevertheless, non-clinic related activities are taken into account.
- Surgeries are scheduled according to the MSS as much as possible.
- In reality, some patients who undergo a hip- or knee replacement follow an intensive ten-day rehabilitation program at an external ward in Boekelo after five days of recovery at the ward in MST. In Boekelo the Orhopaedic department has four rooms available for these patients. In order to fill these rooms every day the Admission Unit has to integrate the planning of surgeries with the planning of rooms in Boekelo.

However, due to the small amount of patients this is not included in the simulation model.

- Assistants are not included in the allocation of specialists to activities. Surgeries of patients by assistants are performed supervised by a specialist, therefore these surgeries are planned during regular sessions of this specialist. Consults and treatments of these patients do not influence the results and are therefore kept out of the model.

6. Simulation Model

In this chapter we present the construction of the computer simulation program.

6.1 Patient generation

For generating new referrals to the system a patient generator is modelled such that every day a certain (variable) number of new patients arrives to system. This represents the reality in a good way because new referrals (by fax or internet) are handled and distributed over the specialist once a day.

Based on probabilities a diagnosis is assigned to each of the new referrals. Based on this diagnosis and the probability that a patient with a certain diagnosis needs a surgery along his care path, it is determined whether the patient follows an operative or a conservative trajectory. When the patients diagnosis and trajectory are known the patient is assigned to one of the specialists based on the profile of the specialists.

6.2 Patient routing

The waiting list with patients waiting for an appointment in the outpatient clinic is subdivided in two parts, (1) a waiting list for new patients and (2) a list for recurring patients. After being assigned to a specialist the patient is added to the waiting list for new patients of that particular specialist.

As soon as the patient is planned in one of the consultation sessions, the patient is moved from the waiting list to the list with planned patients. During consultation sessions the patients with an appointment during that session are moved to the outpatient clinic where the next step is determined based on consult type and diagnosis. This next step can be a recurring consult in the outpatient clinic, a treatment in the outpatient clinic, a surgery or the trajectory can be ended. After determining the next step the patient is moved, either to one of the waiting lists or removed from the system in case of an ending trajectory.

Patients who need a recurring consult are moved to the waiting list with recurring consults in the outpatient clinic. Patients needing a treatment are moved to the waiting list for an appointment in the outpatient treatment clinic and patients needing a surgery are moved to the OR waiting list.

As with appointments during consultation sessions, patients waiting for a treatment or surgery are moved to the list with planned patients as soon as the appointment is made. As soon as the treatment or surgery is completed, the next step is determined based on diagnosis and treatment/surgery in the same way as is the case with consulted patients.

The time between consults, treatments and surgeries is based on diagnose and trajectory. For example, knee patients needing an MRI-scan have to wait approximately six weeks between consults, while patients needing a treatment for removing stitches after surgery can undergo this treatment approximately two weeks after surgery.

6.3 Specialist scheduling

At the start of week *t*, the specialist schedule for week *t+6* has to be determined. In this paragraph we describe the programming of the allocation methods based on a fixed (current method, 6.3.1), a flexible (6.3.2), and a hybrid roster (6.3.3).

6.3.1 Fixed roster

Every Monday, at the start of each week, the simulation model determines the specialist schedule for the week six weeks later. It starts with creating an empty roster (all specialist-day part combinations are unfilled). In case of an odd week the empty roster is filled with the standard roster for odd weeks. Otherwise, it is filled with the standard roster for even weeks. These standard roster includes consultation sessions, treatment sessions, operating sessions, Trauma services and non-clinic related activities. If the week includes a holiday (New Year's Day, King's Day, Easter, Ascension Day, Pentecost or Christmas) the activities on that day are removed from the roster for all specialists. Furthermore, in case of specialists having days off during that week, the activities on these days are removed from the roster as well. This results in a complete roster for all specialists available that week.

As explained in Chapter 4 this roster has to be adjusted due to the changes in specialist availability and the exact number of allocated ORs. In case the number of operating sessions in the completed roster exceeds the number of allocated OR's that week, the specialist with the most operating sessions loses an OR-session until the number of operating sessions equals the number of allocated OR's. If a specialist loses an OR-session, both day parts (morning and afternoon) are filled with a consultation session. In other cases, where not all allocated OR's are filled, the specialist with the fewest operating sessions gets another OR-session until the number of sessions equals the number of allocated OR's.

Hereafter, the model checks whether there is still a specialist with Trauma service on Wednesday. If this is not the case, Trauma service is assigned to an available specialist. Mostly, this happens during days off only. Furthermore, it is checked whether all treatment sessions are filled with at least one specialist. Unfilled treatment sessions are assigned to available specialists based on the number of treatment sessions in the standard fixed roster.

This procedure of determining the specialist schedule is presented in a diagram in Appendix G.

6.3.2 Flexible roster

For determining the specialist schedule six weeks in advance based on a flexible roster the same starting roster is used as before. However, in this case the starting roster is adjusted by replacing all operating sessions by consultation sessions. This results in complete flexibility because OR-sessions can be assigned to the most suitable specialist. This procedure is given in Appendix G too.

Using this allocation method, the number of operating sessions in the roster starts with zero and is raised to the number of allocated OR-days by adding OR-days instead of consultation sessions to specialists based on either current surgery workloads or expected surgery workloads six weeks later. The first OR-day is allocated to the specialist with the highest surgery workload. Then, the new remaining OR-workload is determined for this specialist before the next OR-day is allocated. This procedure is repeated for all allocated OR-days to the Orthopaedic department. When all OR-days are allocated, the to a specialist assigned OR-sessions replace some of their consultation and treatment sessions that week. As constraint, we set a maximum of three OR-days per specialist per week.

6.3.3 Hybrid roster

The determination of the specialist schedule based on a hybrid roster also starts with the same starting roster as the fixed and flexible roster. Using this method, however, every specialist keeps only one OR-session per week. The other OR-sessions are replaced by consultation sessions. The remaining to Orthopaedics allocated OR-days are allocated to specialists according to the same procedure as described above for the allocation based on a flexible roster. This procedure is also presented in Appendix G.

6.4 Consult planning

At the start of each week, in addition to the allocation of activities to specialists six weeks from now, the consultation sessions one week from now have to be filled with appointments. In reality, it is possible that consults are planned up to six weeks in advance as long as the specialist allocation is released for that week. However, it is reasonable to assume that all patients needing a consult are added to the waiting list and consults are being planned one week in advance. This is reasonable because new patients are already added to the waiting list first and recurring patients can be added to the waiting list with a preferred consult date.

The planning of consults differs based on the number of spots reserved for new patients with a certain diagnose (see Paragraph 4.1). When no spots are reserved for new patients at all, the consultation sessions are filled with recurring patients needing a recurring consult that week. If the consultation sessions are not filled completely, consults of new patients are planned based on a first-come, first-served (FCFS) principle. In case of spots reserved for a certain type of patients, these spots are filled with these patients solely. If the number of patients waiting for a consult is not sufficient to fill all of these spots, these spots remain empty. The remainder of the spots are filled with recurring patients needing a consult that week first, after which new patients are planned FCFS independent of the type of patient.

If a consultation sessions cannot be completely filled (either because of a lack of patients or because of unfilled reserved spots), the simulation model tries to fill the sessions again two days before the session takes place. Shorter before the session is not possible due to the fact that patients have to be informed etcetera. For sessions without reserved spots consults are added to the session as before, first recurring patients and then new patients. For sessions with unfilled reserved spots, the model checks first whether there are now new patients of that particular type on the waiting list. If there still are empty reserved spots after this check, these spots can be filled with recurring patients and other new patients.

6.5 Treatment planning

The planning of treatments in the outpatient treatment clinic differs from the planning of consultation sessions because of the fact that patients can be treated by other specialists as discussed in Paragraph 4.1. Similar to the planning of consults, the planning of treatments is done on a weekly basis. Since it is preferable to plan patients during treatment sessions with their own specialist, all treatment sessions are filled with own patients. If treatment sessions are not filled completely patients from other specialists are planned. Patients are planned based on the preferred date of treatment (this preferred date of treatment differs per diagnose and trajectory).

6.6 Surgery planning

In reality, the planning of surgeries in the operating room is done by the Admission Unit using a Master Surgical Schedule. The planning of the surgeries in the simulation model is somewhat simplified because the order during the day does not matter in the model (only the day of surgery). As with consults and treatments, the simulation model plans surgeries one week in advance.

Every week, the simulation model checks the waiting list with patients waiting for a surgery. Starting with the patient waiting longest, it is checked whether the specialist belonging to this patient has a operating session. Furthermore it is checked whether it is allowed by the MSS to perform this surgery type. In case the specialists has an operating session and the surgery type fits in the MSS, it is checked whether the surgery duration fits in the operating session. If the surgery duration fits, the surgery is planned. Continuing with the next patient, the entire waiting list is checked. If all patients are checked and one or more operating sessions are not filled completely, these sessions are finished by planning surgeries of patients on a FCFS basis (keeping in mind that the surgery duration has to fit but without keeping in mind the MSS).

6.7 Validation

In order to ensure that the outcomes of the simulation model are sufficiently accurate the model is verified and validated. Verification is the process of ensuring that the model design has been transformed into a computer model with sufficient accuracy, i.e. ensuring that the simulation model is built right. Validation, on the other hand, is the process of ensuring that the model is sufficiently accurate for the purpose at hand, i.e. ensuring that the right model is built (Robinson, 1997).

The verification of the model has been a gradual process since the simulation model was very simple and straightforward initially and made more complicated gradually. After each extension of the model with new procedures we made sure that the simulation model represented the conceptual model. This verification is done by checking the model step-by-step using the animated version of the simulation model and debug when necessary.

For validating the model the outcomes of the simulation model using arrival rates out of 2012 are compared with the real numbers (numbers generated out of the data warehouse and numbers tracked by one of the specialists). It turns out that the total number of consults, treatments and surgeries are accurate both in total and per specialist. As discussed in Paragraph 5.3, we have more new patient consults in the model than in reality because of the fact that emergency patients and patients having a consult more than a year after the last consult are handled as new patients. However, since the total number of consults is correct we conclude this part to be valid. Furthermore, using the current procedure for making the specialist schedule, the allocation method based on a fixed roster, the number of consultation sessions, operating sessions and treatments sessions corresponds with the total sessions in 2012. A side-effect of the incorrect division between the number of new patient consults and the number of recurring consults is the difference in access times in the model and the access times in real. As a result the access time outcomes cannot be compared to real data.

Another difficulty in validating the model is the fact that the system ‘explodes’ with the current allocation method based on a fixed roster, i.e. the waiting lists with new patients and corresponding access times keep growing (technically to infinity if the model runs forever). However, this result is realistic since in reality ‘double bookings’ are used multiple times for preventing the waiting lists to explode (‘double bookings’ are extra appointments during consultation sessions when the session is already filled completely resulting in less time per appointment or overtime). This method is not desirable and therefore not taken into account in the model but results in difference between model outcomes and reality. The access times before surgery in the model are similar to the access times in reality.

7. Results

In this chapter we present the outcomes of the simulation model presented in Chapter 6. First, in Paragraph 7.1, we present the configurations we analyze and compare. Along with the configurations we specify the length of the runs, the length of the warm-up periods and the required number of replications. In Paragraph 7.2, we present the outcomes of the experiments. The sensitivity analysis is discussed in Paragraph 7.3.

7.1 Experiment design

In this study, we analyze and compare the effect of different methods for allocating OR-time to specialists. In Chapter 4, we discussed the current method based on a fixed roster and alternative methods based on either a flexible or a hybrid roster. The first factor we experiment with is therefore the type of roster on which the allocation of OR-time is based. Furthermore, we discussed two methods for allocating the remaining OR-time when using a flexible or a hybrid roster. These methods use either current surgery workloads and expected surgery workloads. The second experimental factor is therefore the method for allocating the remaining OR-time.

The third and last experimental factor is the question whether spots are reserved during consultation sessions. As discussed in Paragraph 4.3, the specialists agreed to reserve spots for new knee and new arthrosis patients during consultation sessions. However, this agreement is not met by all specialists. In order to analyze the effects of reserving spots, we experiment with and without reserving spots. Summarizing we have ten different combinations. The design matrix is shown in Table 1.

Combination	Roster	Allocation technique	Reserved spots
1	Fixed	-	No
2	Fixed	-	Yes
3	Flexible	Current workload	No
4	Flexible	Current workload	Yes
5	Flexible	Expected workload	No
6	Flexible	Expected workload	Yes
7	Hybrid	Current workload	No
8	Hybrid	Current workload	Yes
9	Hybrid	Expected workload	No
10	Hybrid	Expected workload	Yes

Table 1: Experiment configuration

As discussed in Paragraph 5.1.3 the outcomes are measured using four indicators; total throughput, access time for a new referral before the first consult, access time before a surgery and access time before a recurring consult. The total throughput can be easily accessed by counting the number of consults, treatments and surgeries per specialist. For calculating the average access time before the first consult, the number of days between the date of the first consult and the date of entering the system is calculated. For calculating the average access time before a surgery, the number of days between the date of the surgery and the date of the referral to surgery is calculated. Finally, in order to calculate the average access time before a recurring consult, the number of days between the required consult date and the real consult date is calculated.

For each of the system configurations described in Table 1, we have to specify the following:

- Length of simulation run (7.1.1)
- Length of warm-up period (7.1.2)
- Number of replications (7.1.3)

7.1.1 Length of simulation run

This simulation is nonterminating of nature since there is no natural event that specifies the length of a run, i.e. the simulation model can be run infinitely. In theory, the performance of a nonterminating simulation is measured by steady-state parameters if these are characteristics of the steady-state distribution of some output stochastic process (Law, 2007). In this simulation the access times for each patient and the throughput are stochastic parameters. However, due to system changes over time (the arrival rate, the number of allocated operating rooms and the specialist availability change over time) there is no steady-state distribution. However, the time axis can be divided into equal-length time intervals (cycles) such that the average access time and throughput per time interval are steady-state cycle parameters. These steady-state cycle parameters do have a steady-state distribution. In this simulation, cycles of one week are used for the output parameters. This means that all output parameters are measured per week in order to calculate the average, in the long run this will result in the same mean with a lower variance.

7.1.2 Length of warm-up period

Since it is not easy to start the simulation with the actual patient distribution over specialists, diagnoses and phases in the care chain, the simulation is started empty (zero patients scheduled and zero patients on waiting lists). Therefore the system needs a 'warm-up'-period before it reaches the steady state. The consequence of this convergence to the steady-state mean is that the output parameters belonging to this warm-up period should be ignored. The technique most used to deal with this problem is initial-data deletion where observations from the beginning of a run are deleted while the remaining observations are used to estimate the steady-state mean (Law, 2007). Law (2007) suggests that Welch's graphical procedure is the simplest and most general technique for determining the length of the warm-up period. Using Welch's procedure we determined that the first 150 output parameters have to be deleted. The calculation is shown in Appendix H.

7.1.3 Number of replications

In order to get statistical significant results, experiments have to be repeated multiple times. For obtaining a point estimate and confidence interval for the mean of each outcome parameter we used the replication/deletion approach for means (Law, 2007). Using this approach one can determine the number of replications required for estimating the mean of the outcome parameters with a specified precision. We chose to calculate point estimates with 95-percent confidence intervals. It is important to use the experiment requiring the most replications for obtaining statistical significant outcomes as a base for all experiments such that the results are comparable. In Appendix I the calculations for determining the required number of replications are presented. For these experiments we need 20 replications per experiment with a length of 650 weeks (with deleting the first 150 outcome parameters per replication).

7.2 Outcomes

After determining the length of the warm-up period and the required number of replications we simulated the different experiments (10 experiments x 20 replications x 650 weeks (including 150 weeks warm-up time)). As discussed before, the results should not be interpreted as exact outcomes in case such scenario is implemented in reality (due to division new patients/recurring patients). However, the differences between the experiments can be interpreted as differences between the outcomes if such scenarios are implemented in reality. As explained in Paragraph 6.7, the access times before the first consult and before surgery do not stabilize for the experiments with a fixed roster. The access times before the first consult (in days) resulting from the other experiments are presented in Table 2.

Experiment	Roster / Allocation technique / Reserved spots	Point estimate	95-percent confidence interval
1	*Fixed / - / No*	infinite	-
2	*Fixed / - / Yes*	infinite	-
3	*Flexible / Current workload / No*	30.66	(30.26 , 31.07)
4	*Flexible / Current workload / Yes*	31.09	(30.59 , 31.60)
5	*Flexible / Expected workload / No*	14.10	(13.97 , 14.22)
6	*Flexible / Expected workload / Yes*	14.73	(14.62 , 14.84)
7	*Hybrid / Current workload / No*	22.48	(22.20 , 22.76)
8	*Hybrid / Current workload / Yes*	23.25	(22.91 , 23.58)
9	*Hybrid / Expected workload / No*	14.63	(14.44 , 14.82)
10	*Hybrid / Expected workload / Yes*	15.44	(15.21 , 15.67)

Table 2: Average access times before first consult in days

The results show that the allocation method using current workloads based on a flexible roster achieves the highest average access times before a first consult. An allocation method using current workloads on a hybrid roster has approximately 25% lower average access times. Both allocation methods using expected workloads to allocate OR-time to specialists perform significantly better than the ones using current workloads. The norms according to Treeknormen (eighty percent within three weeks with a maximum of four weeks) can only be met by using an allocation method using expected workloads. We conclude that in terms of access time for new patients, it is better to use expected workloads for allocating OR-time to specialists. Furthermore, we can conclude that using current workloads it is better to base the allocation on a hybrid roster. Using expected workloads there is a statistically significant difference between the flexible and hybrid roster in favour of the flexible roster. However, the difference is very small.

The experimental factor with respect to the reservation of spots does not influence the average access times as much as the type of roster and the allocation technique. However, for all combinations of roster and allocation technique the experiment with reserved spots lead to slightly higher access times. On first sight, this seems strange because there are spots reserved for new patients at all times. In hindsight however, we can explain this by the planning procedure. At the start of week *t*, appointments during consultation sessions in week *t+1* are planned, resulting in spots for new patients in week *t+1* filled when new patients are available while it is possible that there are regular spots available sooner.

The access times before a recurring consult show less significant differences. However, as with the access times before a first consult the access times for a recurring result are higher using the current workloads as allocation technique than using the expected workloads as allocation technique. Furthermore, the allocation based on a hybrid roster always outperforms the allocation based on a flexible roster in terms of access time before a recurring consult. As expected, the reservation of spots during consultation sessions leads to higher access times before a recurring consult than consultation sessions without reserved spots for new patients. The access times before a recurring consults are shown in Table 3.

Opposed to the access times before a recurring consult, the access times before a surgery show clearly different results. The pattern in these results is quite similar to the pattern in the results of the access times before a first consult. First, allocating specialists using current workloads based on a flexible roster results in the highest access times for surgeries. The allocation of specialists using current workloads based on a hybrid roster result in approximately 30% lower average access times. Furthermore, allocation using expected workloads outperforms allocation using current workloads regardless the roster it is based on. The reservation of spots for new patients result in lower access times. However, these differences are not statistically significant. Although the experiments with the current fixed

Experiment	Roster / Allocation technique / Reserved spots	Point estimate	95-percent confidence interval
1	*Fixed / - / No*	2.57	(2.55 , 2.59)
2	*Fixed / - / Yes*	2.97	(2.95 , 3.00)
3	*Flexible / Current workload / No*	3.81	(3.76 , 3.85)
4	*Flexible / Current workload / Yes*	4.62	(4.55 , 4.68)
5	*Flexible / Expected workload / No*	3.30	(3.28 , 3.32)
6	*Flexible / Expected workload / Yes*	3.78	(3.74 , 3.81)
7	*Hybrid / Current workload / No*	3.19	(3.14 , 3.23)
8	*Hybrid / Current workload / Yes*	3.83	(3.79 , 3.87)
9	*Hybrid / Expected workload / No*	2.92	(2.90 , 2.94)
10	*Hybrid / Expected workload / Yes*	3.42	(3.39 , 3.46)

Table 3: Average access times before recurring consult in days

roster do not converge to a steady-state, we see that the reservation of spots for new patients leads to lower access times for surgeries. This can be explained by the fact that the inflow of patients needing a surgery is more levelled using reserved spots during consultation sessions. Out of this we can conclude that the reservation of spots during consultation sessions only pays off in case the access times for new patients are high. The access times for a surgery are presented in Table 4.

The average number of first consults, recurring consults and surgeries is quite similar for all experiments excluding the experiments with a fixed roster. As expected (because of the increasing number of new patients in the system) the results of these experiments show slightly less consults and surgeries. For validating reasons it is a good signal that the results

Experiment	Roster / Allocation technique / Reserved spots	Point estimate	95-percent confidence interval
1	*Fixed / - / No*	infinite	-
2	*Fixed / - / Yes*	infinite	-
3	*Flexible / Current workload / No*	53.71	(52.85 , 54.56)
4	*Flexible / Current workload / Yes*	51.94	(51.07 , 52.85)
5	*Flexible / Expected workload / No*	24.10	(23.70 , 24.49)
6	*Flexible / Expected workload / Yes*	23.71	(23.29 , 24.14)
7	*Hybrid / Current workload / No*	35.52	(34.69 , 36.35)
8	*Hybrid / Current workload / Yes*	34.34	(33.83 , 34.85)
9	*Hybrid / Expected workload / No*	23.19	(22.64 , 23.73)
10	*Hybrid / Expected workload / Yes*	23.24	(22.73 , 23.85)

Table 4: Average access time before surgery in days

Experiment	First consults (average per week)		Recurring consults (average per week)		Surgeries (minutes per OR-session)	
1	194.7	(194.6 , 194.8)	135.6	(135.4 , 135,7)	370.2	(369.4 , 371.1)
2	195.1	(195.0 , 195.2)	135.8	(135.6 , 136.0)	370.5	(369.9 , 371.1)
3	195.6	(195.4 , 195.7)	136.3	(136.1 , 136.5)	370.5	(369.5 , 371.5)
4	195.6	(195.5 , 195.7)	136.4	(136.2 , 136.6)	371.4	(370.4 , 372.5)
5	195.5	(195.4 , 195.6)	136.5	(136,3 , 136.7)	371.1	(370.2 , 372.1)
6	195.4	(195.3 , 195.6)	136.6	(136.3 , 136,8)	371.4	(370.6 , 372.3)
7	195.8	(195.7 , 195.9)	136.6	(136.1 , 136.6)	371.4	(370.6 , 372.2)
8	195.8	(195.7 , 195.9)	136.5	(136.2 , 136.7)	372.1	(371.3 , 373.0)
9	195.6	(195.5 , 195.7)	136.5	(136.3 , 136.7)	372.2	(371.4 , 372.9)
10	195.5	(195.3 , 195.7)	136.4	(136.1 , 136.7)	371.5	(370.5 , 372.6)

Table 5: Average number of first consults, recurring consults and surgeries

of the other experiments do not differ significantly because it shows that the total number of patients served are comparable. These results are shown in Table 5.

7.3 Sensitivity analysis

The simulation model built in this thesis is a representation of the actual situation. In order to check whether the results are robust in the presence of uncertainty a sensitivity analysis is conducted. A sensitivity analysis is conducted for verifying whether the results of the model are comparable with somewhat changed input parameters. This analysis is based on 'what-if'-questions; i.e. what if the number of patients increase or decrease with twenty percent, what if the division of patients over the various diagnoses changes and what if the number of ORs is decreased.

By performing a sensitivity analysis we found that the results of this thesis are robust. This is not strange since it is important to allocate your resources in an optimal way under all circumstances. It turned out that the higher the utilization rates are (thus an increased number of patients or decreased amount of capacity), the more important a good allocation of specialists over activities is. In case of an increase of twenty percent new patients per month, only allocation methods using expected workloads converge to steady-state output parameters. In that case, allocation methods using current workloads are not able to handle all new patients. In extreme situations with a very high number of patients the system will congest anyway but even then it is important to serve as many patients as possible. In case of a decrease of twenty percent new patients per month, the allocation method is not important anymore since all patients can be handled easily within norms according to Treeknormen.

8. Conclusions and recommendation

This chapter finalises this thesis by presenting the conclusions. In Paragraph 8.1, we discuss the conclusions. The recommendations are discussed in Paragraph 8.2.

8.1 Conclusion

In this thesis we analysed the planning problems experienced by the Admission Unit. The Admission Unit experiences problems filling the OR-time allocated to the Orthopaedic department. This research is initiated because the number of patients waiting for a surgery decreased. This number of patients is too small to fill the OR-time completely resulting in partly filled operating rooms and the necessity to give OR-time to other specialisms while there are increasing waiting lists in the outpatient clinic.

The decrease in patients waiting for a surgery is the result of multiple causes. An important cause is the unwillingness to give up OR-time (even during periods with less available specialists) resulting in longer waiting lists in the outpatient department and a lower inflow of patients needing a surgery onto the waiting list with patients waiting for a surgery. In the literature there is consensus about the fact that a good allocation of specialists over activities is very important for obtaining a smooth patient flow and balanced workload for both consults and surgeries.

In order to determine the most suitable method for allocating specialists to activities, multiple methods are compared using a simulation model. With this simulation model experiments are performed for comparing allocation methods based on fixed, flexible and hybrid rosters using either current or expected workloads. Furthermore, experiments are performed for analyzing the effects of the reservation of spots during consultation sessions.

Using the simulation model, we conclude that the current method for allocating specialists to activities based on a fixed roster is not able to handle all patients without ‘double bookings’. In reality, ‘double bookings’ are added to the consultations sessions when the sessions are already filled completely resulting in less time per appointment or overtime. This procedure is not taken into account in the simulation model because the use of ‘double bookings’ is not desirable.

The usage of expected workloads for allocating OR-time to specialists results in statistically significant better outcomes than the usage of current workloads. Both, the access times for new patients and for surgeries, are statistically significant lower by using expected workloads instead of current workloads. Based on this result, we conclude that current workloads are bad estimators for the workloads six weeks later. By calculating expected workloads, specialists can be allocated to activities such that a more smooth patient flow and balanced workload is achieved. Only by using expected workloads for allocating OR-time the norms according to Treeknormen can be achieved.

In case the current workloads are used for allocating OR-time to specialists, it is better to base this allocation on a hybrid roster than on a flexible roster. The allocation based on a hybrid roster results in approximately 25% lower access times for new patients and 30% lower access times for surgeries. Based on this result, we conclude that an allocation based on a flexible roster using current workloads results in a roster six weeks from now with activities that do not match the workloads at that moment.

In case the expected workloads are used for allocating OR-time to specialists, there is no clear difference between an allocation based on a flexible roster and an allocation based on a hybrid roster. The access times for new patients with an allocation based on a hybrid roster are statistically significant lower. However, the difference is small. For the access times for surgeries there is no statistically significant difference between an allocation based on a flexible or an allocation based on a hybrid roster.

There is no statistically significant different between the results with respect to the reservation of spots. This is partly caused by the fact that the ratio between new and recurring patients in the simulation model is higher than in reality due to the fact that emergency patients and patients having an appointment more than a year after their last consult are handled as new patients too. There will be greater differences in case of a lower ratio between new and recurring patients. However, the importance of the reservation of spots for new patients depends on the access time levels. With higher access times for new patients the reservation of spots helps continuing an inflow onto the waiting list for surgeries. In the current situation with a fixed roster, the reservation of spots results in higher utilization rates.

The simulation model we use is built according to the specific procedures and patient mix of the Orthopaedic department within MST. The results, however, can be generalized to other departments and hospitals dealing with resource allocation problems. The introduction of flexibility in the use of resources lead to higher utilization rates and lower access times. Since the basic elements of planning in health care are similar to the basic elements of planning in business environments, the results can also be generalized to business environments.

8.2 Recommendations

Based on the conclusions, we recommend the Orthopaedic department to adopt an allocation method using expected workloads based on a hybrid roster. Although no significant difference was found between the usage of expected workloads based on either a flexible or a hybrid roster, the hybrid roster is recommended because it is more convenient for the specialists because they still have one fixed OR-day every week.

For introducing this allocation method, there has to be agreement between the involved specialists. The specialists have to understand the necessity of changing the allocation method. If the specialists can be convinced to adopt an allocation method based on a hybrid method, this can be implemented very easy. The only action needed for this implementation is an agreement between the specialists to choose one fixed OR-day every week. The allocation of the remaining OR-time should be discussed during the bi-weekly meetings of the specialists.

We recommend to allocate the remaining OR-time using the calculation of expected workloads. In order to use expected workloads, the Orthopaedic department has to collect additional data. Information on waiting lists for new patient consults, recurring consults, treatments and surgeries has to be collected for each of the specialists. For calculating expected workloads it is necessary to divide this waiting lists into waiting lists for the most common diagnoses. At the moment, it is possible already to collect this data out of the data-warehouse. If this data is collected, the formulas presented in Chapter 4 can be used to calculate the expected workloads. In these formulas, the transition probabilities as presented in Appendix E have to be used.

In case the above recommended method is not adopted to allocate the OR-time over specialists, we recommend the reservation of spots for new patients in order to maintain a secured inflow onto the waiting lists for surgeries. In case the above recommended method is used, we do not advise to reserve spots for new patients. However, in case of accidentally high access times for new patients the temporarily reservation of spots for new patients help securing a secured inflow to balance the workloads again.

Outside the scope of this thesis, the patients of the Orthopaedic department experience long waiting times during sessions (time between arrival time at desk and actual consultation time) compared to other specialisms within MST according to the team leader of the Orthopaedic department. In order to tackle this long waiting times it can be helpful to adopt an appoint scheduling rule compared to the variable-interval appointment scheduling rule as proposed by Ho and Lau (1992). This rule corrects the problem of long waiting times of patients at the end of the consultation sessions by planning less time per appointment early in the session and more time per appointment later in the session.

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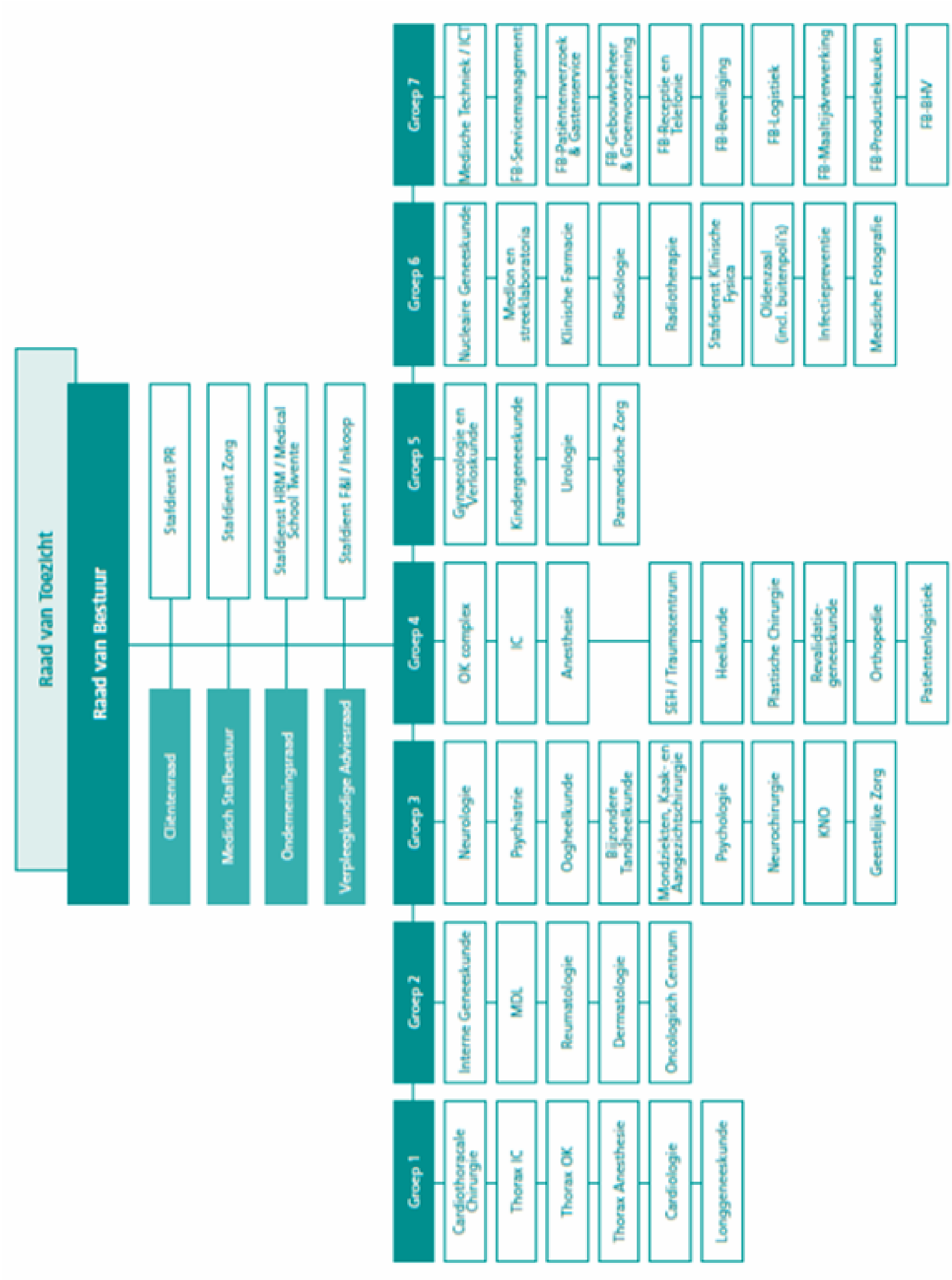
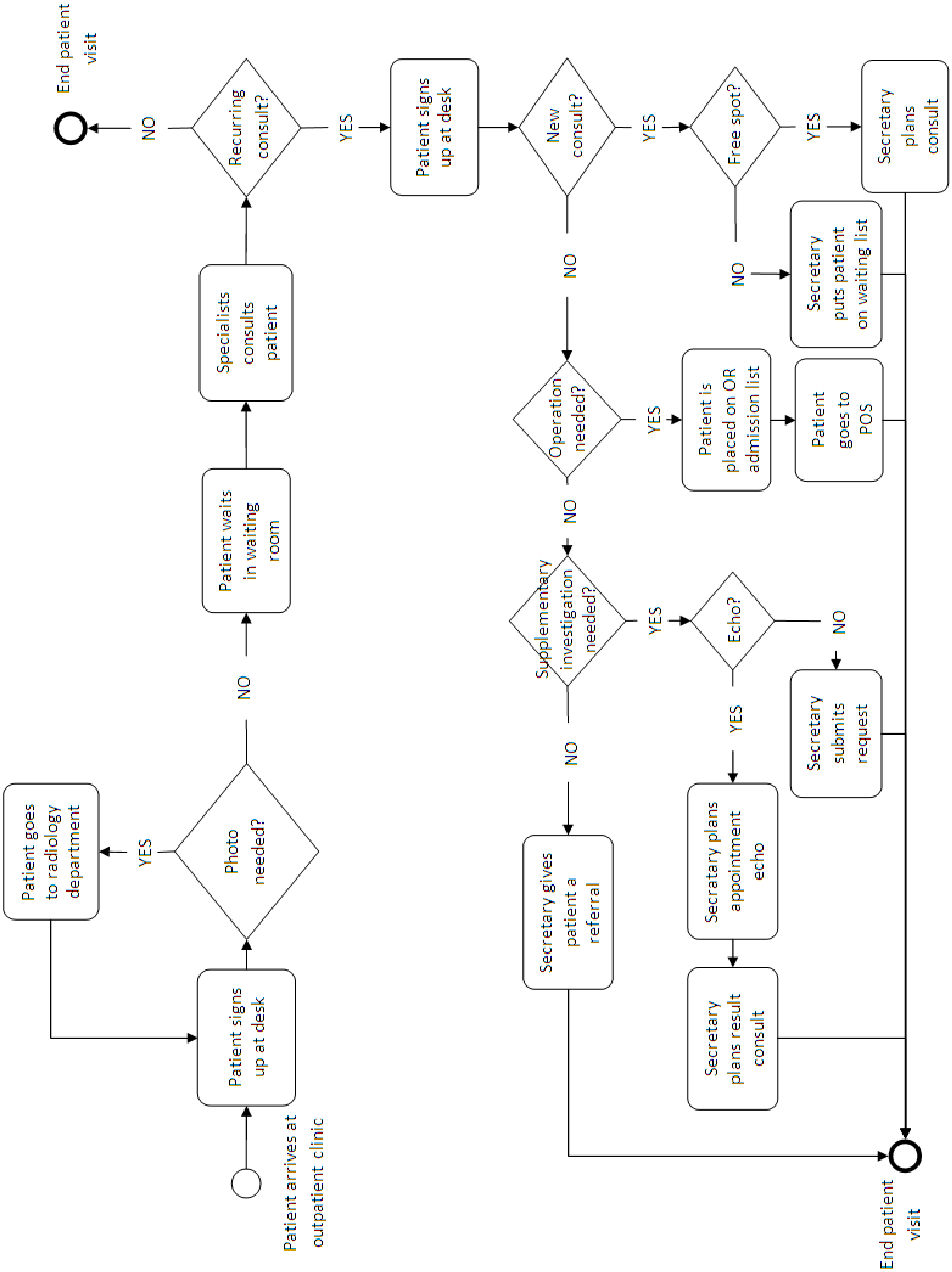
Appendix A Organizational chart

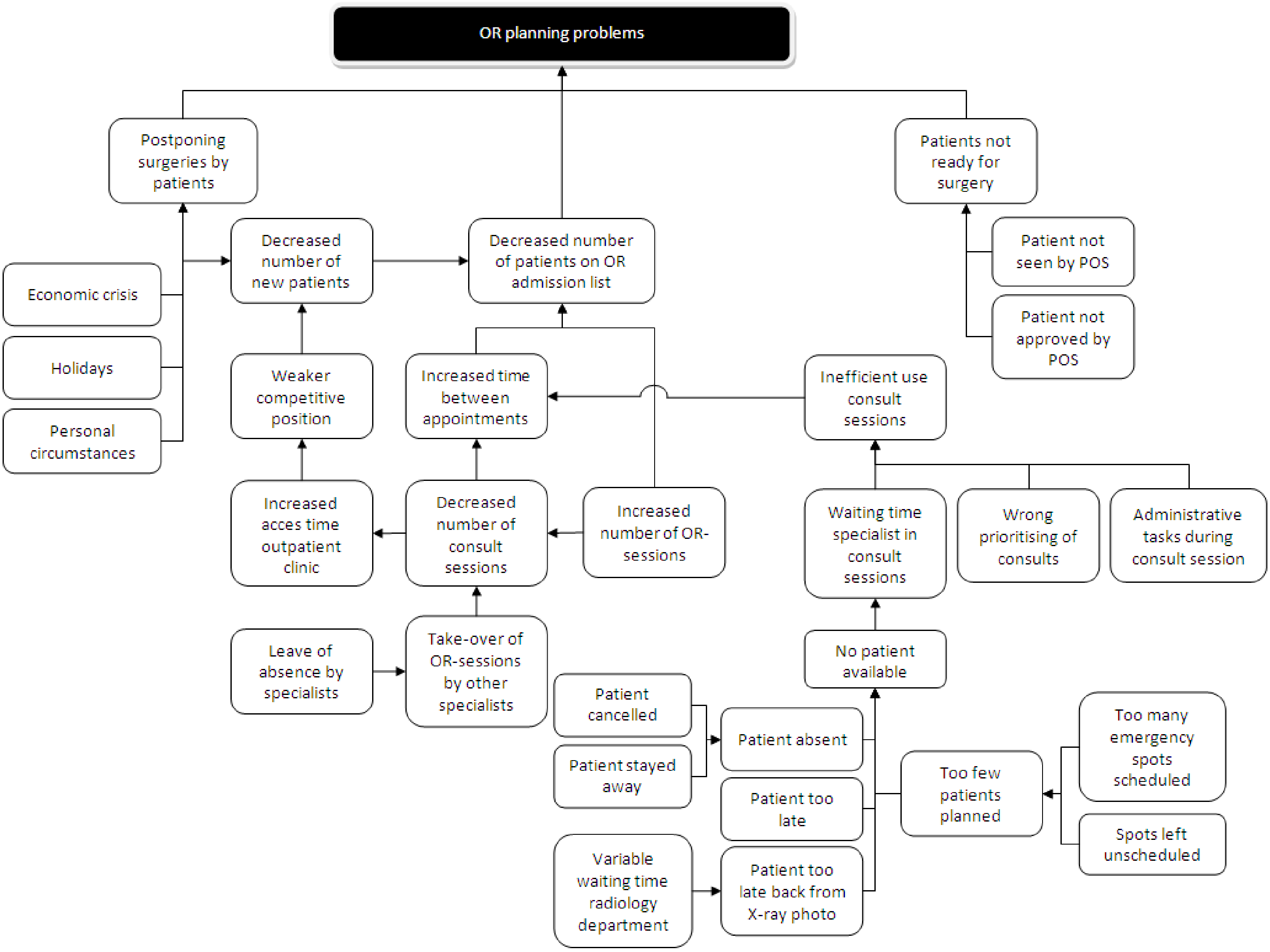


(Medisch Spectrum Twente, 2012)

Appendix B Flowchart outpatient visit



Appendix C Problem bundle



Appendix D Analysis delay before POS appointment (Confidential)

Appendix E Flowcharts patient flow (Confidential)

Appendix F Distribution new arrivals (Confidential)

Appendix G Allocation Techniques

Diagram for allocation technique based on a fixed roster:

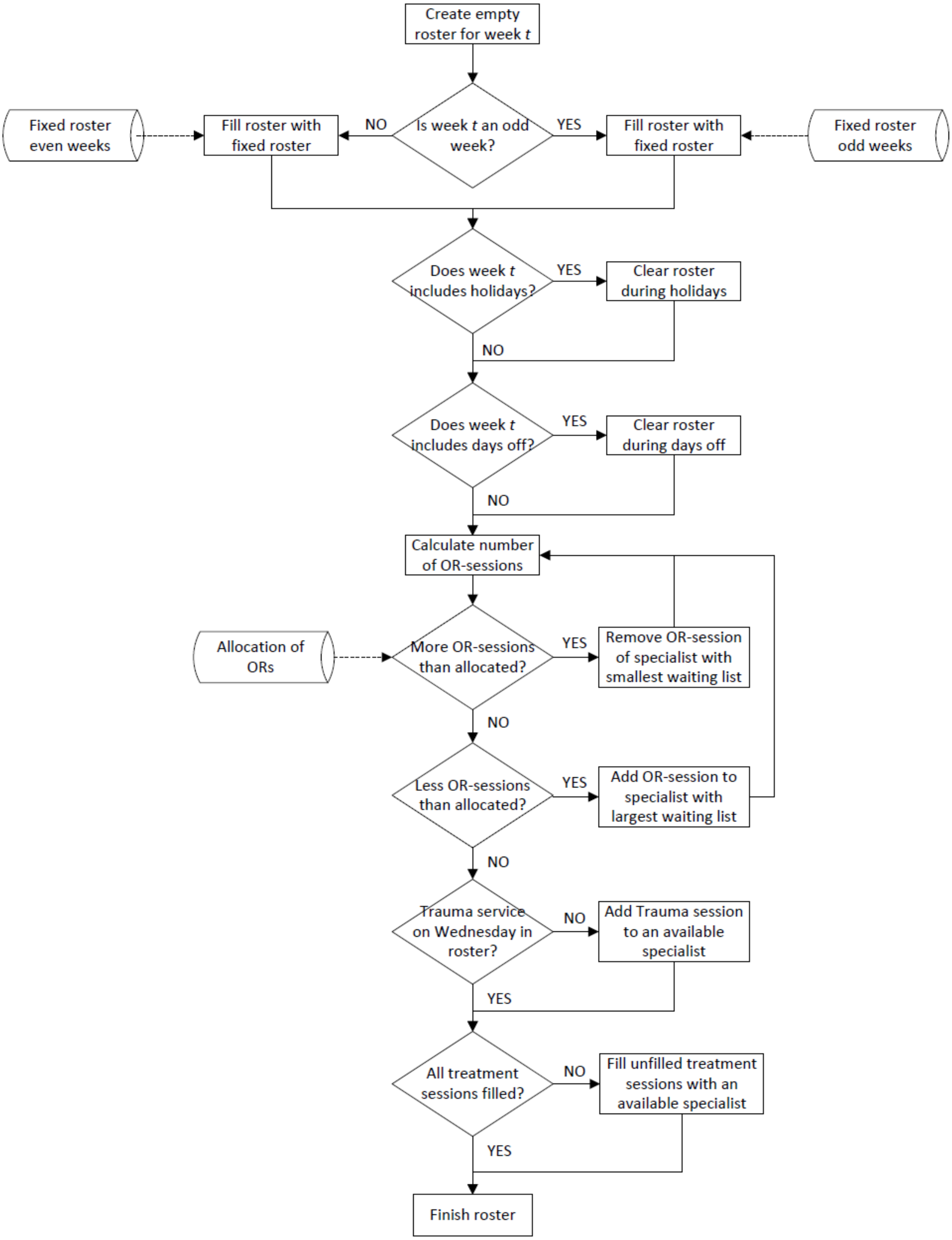


Diagram for allocation technique based on a flexible roster using workloads to allocate OR-sessions to specialists:

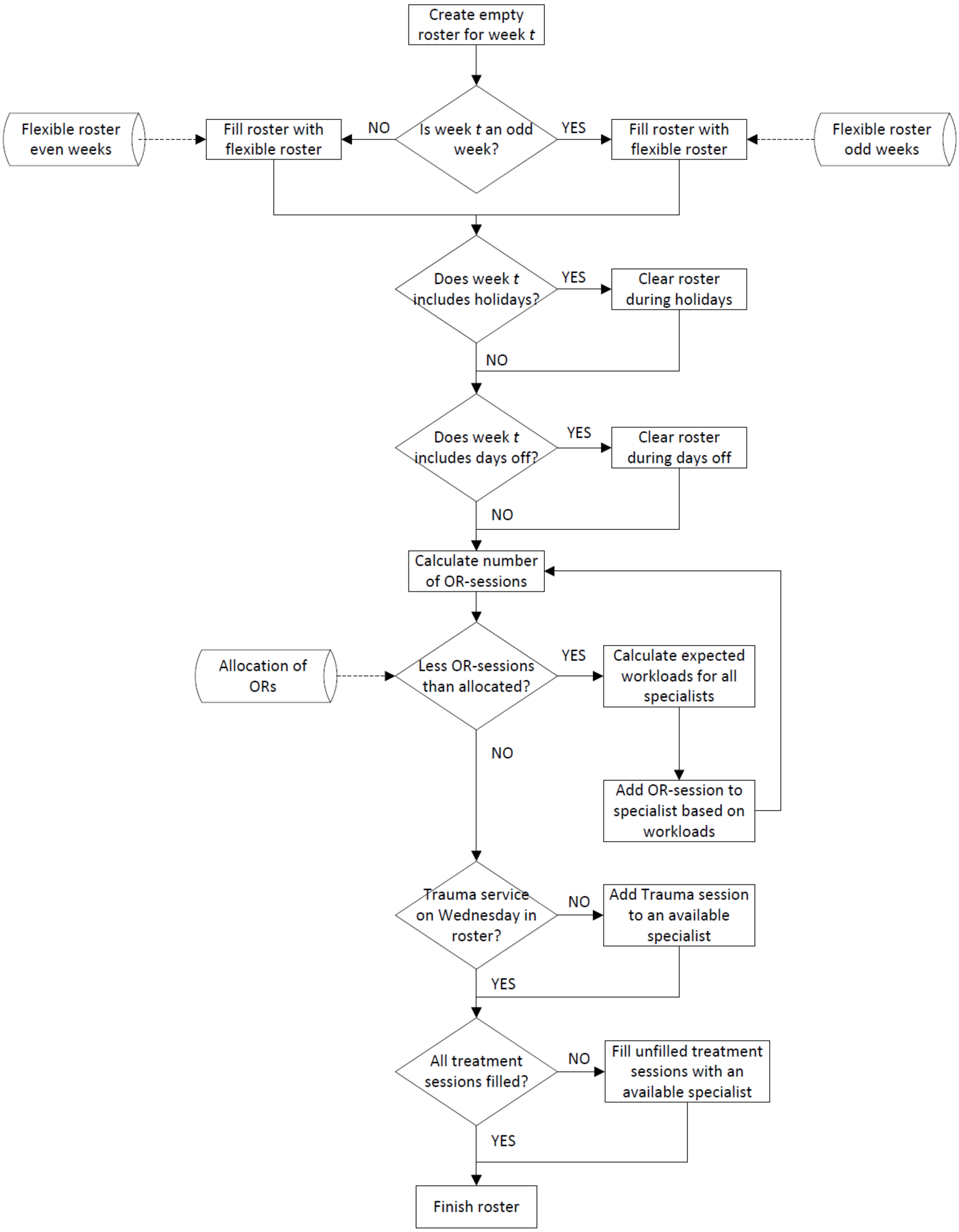
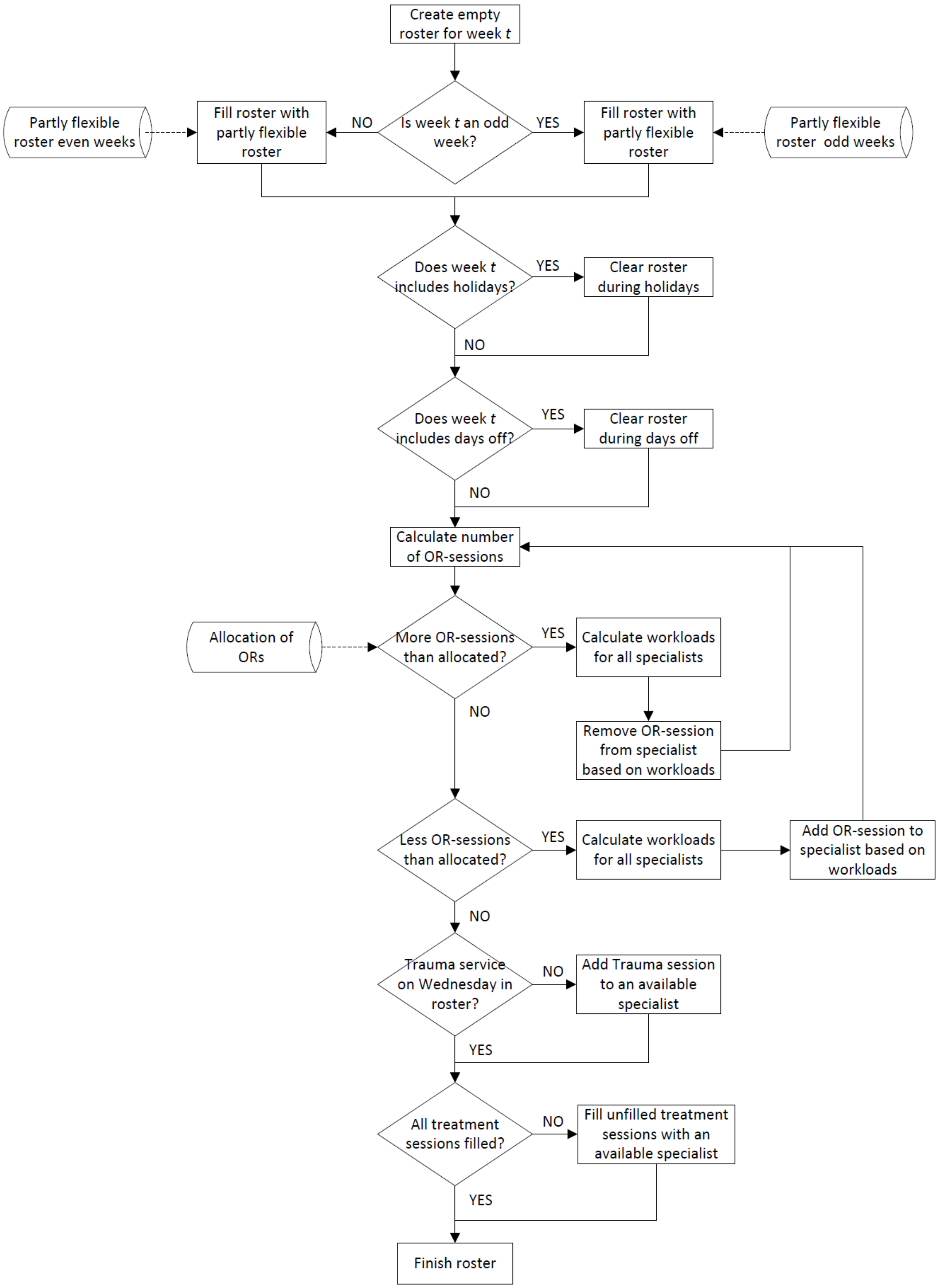


Diagram for allocation technique based on a hybrid roster using workloads to allocate unfilled OR-sessions to specialists:



Appendix H Determination warm-up period

In this appendix the determination of the warm-up period of the simulation using Welch's procedure is presented.

When running multiple experiments it is important to determine the smallest warm-up period (for statistical reasons each experiment should be run with the same warm-up period) such that the output parameters of all experiments do not depend on the initial conditions. It turns out that the output parameter with respect to the average access time before surgery needs most time to warm up. Therefore we chose to use this output parameter for determining the warm-up period for all experiments.

Furthermore, it turns out that the output parameters with respect to the access time before the first consult do not converge to a steady-state for the experiments with the current fixed roster (the experiments 1 and 2), see Paragraph 6.7. In these experiments the system explodes, i.e. for some specialists the capacity is not sufficient to meet the demand for consultation. As a result, these systems have an infinite warm-up period because the output parameters depend on the initial state of the system infinitely.

We made graphs of the moving average of the output parameters using Welch's procedure for the other experiments. Welch's graphical procedure for determining the warm-up period is based on making *n* independent replications with length *m* of the simulation (Law, 2007). Out of these graphs we can conclude that the warm-up time is very similar for the different experiments. As an example the steps for determining the warm-up period is shown for the outcome parameter with respect to the access time before surgery of experiment 10**.**

Here, we made 10 independent runs with a run length of 500 weeks. We let Y_{ij} be the *i*-th observation from the *j*-th replication (*i* = 1,2,...,10 ; *j* = 1,2,...,500). Then, we calculated the average observation using the formula:

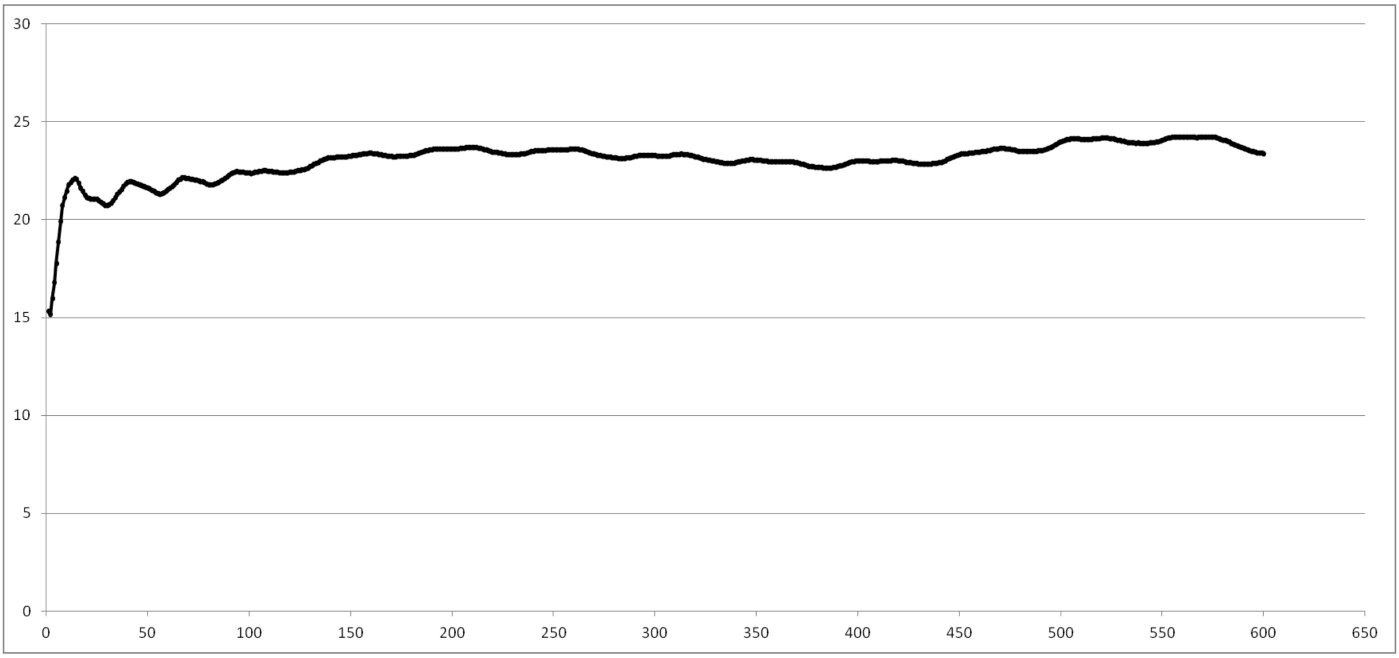
$$\overline{Y_i} = \sum_{j=1}^{n} \frac{Y_{ji}}{n}$$

for *i* = 1,2,...,10.

To smooth out the high-frequency oscillations in $\overline{Y_i}$ we further defined the moving average $\overline{Y_i}(w)$ with *w* being the moving average window as follows:

$$\overline{Y_i}(w) = \begin{cases} \dfrac{\sum_{s=-w}^{w} \overline{Y_{i+s}}}{2w-1} & if\ i = w+1, \dots, m-w \\ \\ \dfrac{\sum_{s=-(i-1)}^{i-1} \overline{Y_{i+s}}}{2i-1} & if\ i = 1, \dots, w \end{cases}$$

Finally we plotted $\overline{Y_i}(w)$ for multiple values of w and chose w such that we obtained a smooth graph. Out of this graph we determined that the warm-up period should be 150 weeks (using a window length equal to 100 (w = 100), graph is shown below).



Appendix I Determination number of replications

In this appendix the calculations needed for determining the required number of replications per experiment for obtaining statistical significant results are presented using a sequential procedure.

In order to obtain point estimates with 95-percent confidence intervals for the outcome parameters, it is possible to do only one single replication. However, this results in very unreliable measures. Law (2007) recommends to start with at least ten replications. Therefore, we start the sequential procedure with ten replications ($n = 10$) with a length of 650 weeks (the outcome parameters belonging to the warm-up period, the first 150 weeks, are deleted), resulting in 500 data points for each outcome parameter per replication.

Next, the mean and the confidence-interval half length are calculated. The mean is simply the average of the average of the first n outcome parameters,

$$\overline{\mathrm{X}}(n) = \sum_{i=1}^{n} X_i \ .$$

While the confidence interval half length is calculated using the following formula:

$$\delta(n, \alpha) = t_{n-1,1-\frac{\alpha}{2}} \sqrt{\frac{S^2(n)}{n}}$$

Where $t_{n-1,1-\frac{\alpha}{2}}$ is the critical point for Student's *t* distribution with *n-1* degrees of freedom and *1-α/2* as significance level (for a 95-percent confidence interval we use *α=0.05*, *α* is divided by two because we calculate the half length of the confidence interval).

Since we want to determine the number of replications required to obtain a given relative error, we estimate the relative error $\gamma = |\bar{X} - \mu|/\mu$ by estimating $\gamma = |\bar{X} - \mu|/\bar{X}$. However, if γ is used as relative error the actual relative error is at most $\gamma/(1-\gamma)$. In order to reach an actual error of γ, we use the corrected target value $\gamma' = \gamma/(1+\gamma)$ (Law, 2007). In this analysis we chose the actual relative error to be at most γ*=0.025.*

Next, we calculate the current error by dividing the confidence interval half width by the mean,

$$\frac{\delta(n, \alpha)}{|\overline{\mathrm{X}}(n)|} = \frac{t_{n-1,1-\frac{\alpha}{2}} \sqrt{\frac{S^2(n)}{n}}}{|\overline{\mathrm{X}}(n)|} .$$

If $\delta(n, \alpha)/|\overline{\mathrm{X}}(n)| \leq \gamma'$, $\overline{\mathrm{X}}(n)$ is used as point estimate for the mean and we stop the procedure. Otherwise, we add an additional replication (*n=n+1*) and start the procedure again.

Using this procedure we calculated the number of replications required for each outcome parameter of each experiment.

Experiment	Average access time before consult new patient	Average access time before surgery	Average access time before recurring consult	Average number of consults	Average number of consults new patients	Average number of surgeries
1	*	*	10	10	10	10
2	*	*	10	10	10	10
3	10	10	10	10	10	10
4	10	13	10	10	10	10
5	10	10	10	10	10	10
6	10	14	10	10	10	10
7	10	19	10	10	10	10
8	10	13	10	10	10	10
9	10	19	10	10	10	10
10	10	**20**	10	10	10	10

* As explained in Paragraph 7.1, the outcome parameters with respect to access times of the experiments 1 and 2 do not reach a steady state at all.

Out of these calculations we conclude that the maximum number of replications required for constructing 95-percent confidence intervals is 20.

Appendix J Patient data (Confidential)

Appendix K Capacity data (Confidential)