Scheduling all patients within their desired access time by determining a reservation level for the consultation hours

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ZIEKENHUIS ST ANTONIUS

UNIVERSITY OF TWENTE.

Scheduling all patients within their desired access time by determining a reservation level for the consultation hours

A case study for dermatology and urology

Master thesis

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Management summary

This thesis presents the research conducted at the St. Antonius Hospital Utrecht/Nieuwegein. It determines a reservation level for the consultation hours to be able to schedule all patients within their desired access time. The research is conducted as a case study for the dermatology and urology departments.

Problem description

Outpatient clinics are becoming a more essential part in health care since more attention has been paid to preventive medicine practices and shorter lengths of stay. The St. Antonius Hospital also experiences a growing pressure on the outpatient clinics, which expresses itself in long access times for the patients to the consultation hours. Timely access is important for realising good medical outcomes and is also an important determinant of patient satisfaction. Since patients with a lower priority arrive before patients with a higher priority (like emergency patients), lower priority patients are booked before higher priority patients. This may result in a consultation hour full with lower priority patients, and no space for higher priority patients anymore. Besides long access times, the utilisation of the consultation hours does not always match the target. This shows there is an inefficient use of capacity.

Research objective

To realise a more efficient use of the capacity of the outpatient clinics, the St. Antonius Hospital should have more insight in their processes in the first place. As the hospital distinguishes several patient types each with its own access time target, the hospital should define how many appointment slots can still be scheduled and how many should be reserved for future appointment requests. This results in the following research objective:

"To define a reservation level for the consultation hours for the eight coming weeks to be able to schedule all patients within their desired access time.

Based on this reservation level, the St. Antonius Hospital will be able to manage their capacity: they will know whether they have insufficient capacity, sufficient capacity, or underutilisation of the consultation hours for the coming eight weeks, and can take actions respectively. As a result, the hospital can increase timely access for patients, which improves medical outcomes, improves patient satisfaction and provides financial stability.

Method

The mathematical model developed in this research has the main objective of decreasing access times to the outpatient clinic, while optimising the utilisation. Therefore, the weighted average of access time, overtime and idle time is minimised in the model. The model first determines the expected future demand for the coming eight weeks, which is the total expected demand minus the already booked demand. The total expected demand is forecasted by an average approach from historical data. Then, the model suggests an optimal booking policy for the expected future demand. This means that the demand is not actually booked, because it has not arrived yet, but the model suggests an optimal booking composition. The model allocates the future demand in a way that the weighted average is minimised. Figure 1 shows a flowchart of the process.

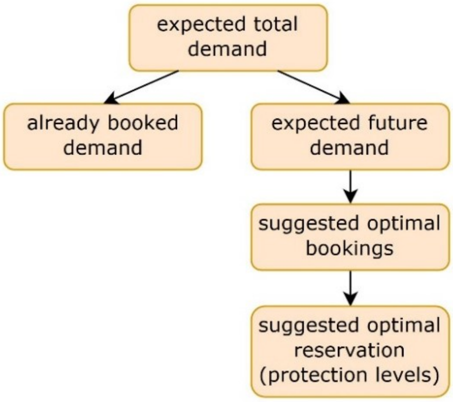


Figure 1: Flowchart mathematical model

Furthermore, we have developed a stochastic heuristic approach to model the uncertain character of the appointment mix. The uncertainty in demand is modelled by assigning a probability to ranges of possible demands. As such, this stochastic heuristic approach balances accuracy and computational ease by incorporating the inherent uncertainty of demand as a finite number of scenarios. This enables results beyond the possibilities of a deterministic model.

Results

The model shows that the access time to the outpatient clinic is decreased for all patient types and matches the targets. Especially emergency and new patients have much shorter access times, while the utilisation of the consultation hours stays the same compared to the current situation. Table 1-Table 2 show that for dermatology, all emergency patients are being served within 1 week (6% improvement) and all new patients are being served within 2 weeks (30%

improvement). Table 3-Table 4 show that for urology, all emergency and new patients are being scheduled within 1 week, which is an improvement of respectively 20% and 60%.

emergency patients (S) ***dermatology***	≤ 1 week	≤ 2 weeks	≤ 3 weeks	≤ 4 weeks
target	100%	-	-	-
current situation	94%	98%	99%	100%
model situation	100%	-	-	-

Table 1: Access time of emergency patients dermatology in current and model situation

new patients (N) ***dermatology***	≤ 1 week	≤ 2 weeks	≤ 3 weeks	≤ 4 weeks
target	-	100%	-	-
current situation	40%	70%	88%	94%
model situation	96%	100%	-	-

Table 2: Access time of new patients dermatology in current and model situation

emergency patients (S) ***urology***	≤ 1 week	≤ 2 weeks	≤ 3 weeks	≤ 4 weeks
target	100%			
current situation	80%	90%	95%	100%
model situation	100%	-	-	-

Table 3: Access time of emergency patients urology in current and new situation

new patients (N) ***urology***	≤ 1 week	≤ 2 weeks	≤ 3 weeks	≤ 4 weeks
target	100%			
current situation	40%	58%	74%	82%
model situation	100%	-	-	-

Table 4: Access time of new patients urology in current and new situation

Conclusion

The output of the model gives the St. Antonius Hospital 'reservation levels' per patient type for the upcoming eight weeks: an optimal amount of capacity to reserve each week. This reservation level will be used as a target for the planned utilisation during a TPO (Tactical Planning Meeting) and will serve as a basis for tactical decisions, like expansion of available capacity. The output of the model shows that in a basic scenario, the utilisation matches the current utilisation for both specialties. Moreover, all patients have access to the consultation sessions within their prescribed access time. The model is constructed to fit the characteristics of the St. Antonius Hospital and in particular the specialties dermatology and urology, but can be generalised and adapted to fit other settings.

Further research can be done to further develop the heuristic, improve the approximation of the arrival patterns and lastly, take patient preferences into account.

Management samenvatting

Deze thesis presenteert het onderzoek uitgevoerd in het St. Antonius Ziekenhuis te Utrecht/Nieuwegein. Het onderzoek bepaalt een percentage van de spreekuren dat gereserveerd moet worden, zodat alle patiënten binnen de voor hun gestelde toegangseis gepland kunnen worden. Het onderzoek is opgezet als een casestudy voor dermatologie en urologie.

Probleemdefinitie

Poliklinieken worden een steeds belangrijker onderdeel in de gezondheidszorg, omdat er steeds meer aandacht wordt besteed aan preventieve zorg en korte verblijfduur. Ook het St. Antonius Ziekenhuis ondervindt een toenemende druk op de polikliniek, wat zich uit in lange toegangstijden voor de patiënten tot de spreekuren. Tijdige toegang is belangrijk voor goede medische resultaten en tevens voor de mate van tevredenheid van de patiënt. Aangezien patiënten met een lagere prioriteit eerder binnenkomen dan patiënten met een hogere prioriteit (zoals spoed patiënten), worden lage prioriteit patiënten eerder geboekt. Dit kan resulteren in een spreekuur vol met lage prioriteit patiënten en geen plek voor hoge prioriteit patiënten meer. Naast lange toegangstijden komt de benutting van de spreekuren niet altijd overeen met de norm. Dit toont een inefficiënt gebruik van capaciteit aan.

Doel van het onderzoek

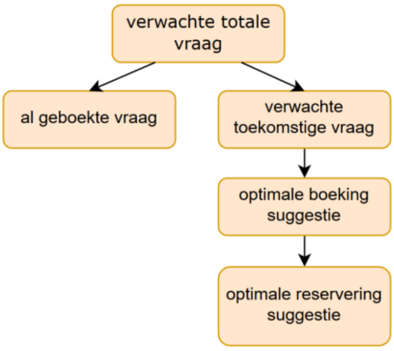
Om de capaciteit van de poliklinieken efficiënter te gebruiken, zal het St. Antonius Ziekenhuis in eerste instantie meer inzicht moeten hebben in hun lopende processen. Aangezien het ziekenhuis meerdere patiënt types onderscheidt met elk zijn eigen toegangseis, zal het ziekenhuis moeten bepalen hoeveel plekken al gevuld kunnen worden en hoeveel er gereserveerd moeten worden voor toekomstige afspraken. Het doel van de thesis is:

"Definieer een percentage van de spreekuren dat gereserveerd moet worden de komende acht weken, zodat alle patiënten binnen hun gewenste toegangstijd gepland kunnen worden."

Op basis van dit percentage kan het St. Antonius Ziekenhuis hun capaciteit reguleren: ze weten of ze te weinig, voldoende of te veel (onderbenutting) capaciteit hebben voor de komende acht weken en kunnen hierop acties ondernemen. Dit resulteert in een kortere toegangstijd, wat de medische resultaten en de tevredenheid van de patiënt verbetert en financiële stabiliteit biedt.

Methode

Het wiskundige model dat ontwikkeld is in dit onderzoek heeft als hoofddoel de toegangstijd tot de polikliniek te verlagen, terwijl de benutting van het spreekuur wordt geoptimaliseerd. Het gewogen gemiddelde van de toegangstijd, overtijd en onbenutte capaciteit wordt daarom geminimaliseerd. Het model bepaalt eerst de verwachte toekomstige vraag voor de komende acht weken (totale verwachte vraag min de al geboekte vraag). De totale verwachte vraag wordt voorspeld aan de hand van gemiddelde bepaling uit historische data. Vervolgens geeft het model een suggestie voor een optimale boeking van de verwachte toekomstige vraag. Dit betekent dat de patiënten niet daadwerkelijk geboekt worden, omdat deze vraag nog niet is binnengekomen, maar het model geeft een suggestie voor een optimale compositie. Het model wijst de toekomstige vraag zodanig toe dat het gewogen gemiddelde van toegangstijd, overtijd en onbenutte tijd geminimaliseerd wordt. Figuur 1 toont een stroomdiagram van het wiskundig model.



Figuur 1: Stroomdiagram wiskundig model

Een stochastische heuristische benadering is ontwikkeld om de onzekerheid in de afsprakenmix te modelleren. De onzekerheid in de vraag is gemodelleerd door een kans te geven aan mogelijke (vraag) intervallen. De stochastische benadering balanceert hierbij nauwkeurigheid en rekentijd door de vraag als een aantal scenario's te modelleren. Deze methode kan resultaten opleveren welke niet mogelijk zijn met een deterministisch model.

Resultaten

Het model laat zien dat de toegangstijd tot de polikliniek voor alle patiënttypes is afgenomen en overeenkomt met de norm. Voornamelijk spoed- en nieuwe patiënten hebben een korte toegangstijd, terwijl de benutting van de spreekuren nagenoeg gelijk is als in de huidige situatie. Tabel 1-Tabel 2 tonen dat alle spoedpatiënten van dermatologie binnen 1 week geholpen kunnen worden (6% verbetering) en alle nieuwe patiënten binnen 2 weken (30%

verbetering). Tabel 3-Tabel 4 tonen dat alle spoed- en nieuwe patiënten van urologie binnen 1 week geholpen kunnen worden. Dit is een verbetering van respectievelijk 20% en 60%.

spoedpatiënten (S) ***dermatologie***	≤ 1 week	≤ 2 weken	≤ 3 weken	≤ 4 weken
doel	100%	-	-	-
huidige situatie	94%	98%	99%	100%
model situatie	100%	-	-	-

Tabel 1: Toegangstijd voor spoedpatiënten dermatologie in huidige en model situatie

nieuwe patiënten (N) ***dermatologie***	≤ 1 week	≤ 2 weken	≤ 3 weken	≤ 4 weken
doel	-	100%	-	-
huidige situatie	40%	70%	88%	94%
model situatie	96%	100%	-	-

Tabel 2: Toegangstijd voor nieuwe patiënten dermatologie in huidige en model situatie

spoedpatiënten (S) ***Urologie***	≤ 1 week	≤ 2 weken	≤ 3 weken	≤ 4 weken
doel	100%			
huidige situatie	80%	90%	95%	100%
model situatie	100%	-	-	-

Tabel 3: Toegangstijd voor spoedpatiënten urologie in huidige en model situatie

nieuwe patiënten (N) ***Urologie***	≤ 1 week	≤ 2 weken	≤ 3 weken	≤ 4 weken
doel	100%			
huidige situatie	40%	58%	74%	82%
model situatie	100%	-	-	-

Tabel 4: Toegangstijd voor nieuwe patiënten urologie in huidige en model situatie

Conclusie

De output van het model geeft het St. Antonius Ziekenhuis 'reserveringniveaus' per patiënttype voor de komende acht weken: een optimale hoeveelheid capaciteit dat elke week gereserveerd moet worden. Dit reserveringsniveau kan gebruikt worden als norm voor de geplande benutting tijdens een TPO (Tactisch PlanningsOverleg) en is de basis voor tactische beslissingen, zoals uitbreiding van beschikbare capaciteit. Uit de output van het model blijkt dat in het basisscenario de benutting overeenkomt met de huidige situatie. Daarnaast is de toegangstijd tot de polikliniek voor alle patiënten binnen de norm. Het model is ontwikkeld voor het St. Antonius Ziekenhuis en in het bijzonder voor dermatologie en urologie, maar kan worden gegeneraliseerd en aangepast worden voor andere specialismes/ziekenhuizen. Nader onderzoek kan worden gedaan om de heuristiek verder te ontwikkelen, de benadering van de aankomstpatronen te verbeteren en tenslotte, patiëntvoorkeuren te modelleren.

Preface

My study path started at the Industrial Design Engineering department at the University of Twente. However, after completing my Bachelor and organising a study tour to South-Africa, my interest shifted towards solving logistical problems. A choice that brought me to Lisbon and finally to a graduation assignment at the St. Antonius Hospital in Nieuwegein. A choice I never regretted, as I was warmly welcomed by Marc, Renée and Marjolein. I would like to thank them for the great time at the St. Antonius Hospital and for the possibility they are giving me now: continuing to work with them and to further develop my research.

I also would like to thank Derya and Erwin for their guidance and supervision during this Master thesis completion, for the time they spend helping me developing both professionally and personally.

Lastly, I would like to thank my family and close friends for their support during my whole study path and in particular during this Master assignment.

Irene Hof
May, 2017

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List of abbreviations

AIMMS	Advanced Interactive Multidimensional Modelling System
C	Check-up (Dutch: "Controle") (patient)
DB	Day treatment (Dutch: "Dagbehandeling")
DER	dermatology
LZ	Lean and Healthcare logistics (Dutch: "Lean en Zorglogisitiek")
N	New (Dutch: "Nieuw") (patient)
OR	Operating Room (Dutch: "OK", "Operatie Kamer")
S	Emergency (Dutch: "Spoed") (patient)
SAZ	St. Antonius Hospital
TC	Telephonic Consultation (Dutch: "Telefonisch Consult") (patient)
TPO	Tactical Planning Meeting (Dutch: Tactisch PlanningsOverleg)
UG	UltraGenda
URO	urology
V	Outpatient procedure (Dutch: "Verrichting") (patient)

Chapter 1 Introduction

Health care providers are under great pressure to reduce costs and improve quality of service (Cayirli & Veral, 2003). Last years, more attention has been paid to preventive medicine practices and shorter lengths of stay, which results in the outpatient clinic to be a more essential part in health care. The St. Antonius Hospital also experiences a growing pressure on the outpatient clinics, which expresses itself in long access times for patients to the consultation hours.

Many literature studies have been done on appointment scheduling. Appointment scheduling systems have the objective of matching demand with capacity, and lie at the intersection of efficiency and timely access to health services. Those systems thus contribute to reducing costs and improving quality. Timely access to the outpatient clinic is important to realise good medical outcomes, as well as patient satisfaction. The ability to provide timely access is determined by a variety of factors that include what rules best determine which patients receive higher priority access to resources, and how appointments are scheduled. Appointment systems also smooth workflow, reduce crowding in waiting rooms and allow health systems to take care of patient and provider preferences while matching supply and demand (Gupta & Denton, 2008).

This report describes the research executed at the St. Antonius Hospital. The St. Antonius Hospital experiences long access times for patients to the consultation hours of the outpatient clinics, but at the same time, the utilisation of the consultation hours is not as it is targeted. This shows there is an inefficient use of capacity. To gain more insight in their use of capacity, the hospital wants to know how many appointment slots still can be scheduled and how many need to be reserved for future appointment request, for the eight coming weeks. This is mainly important since patients have different priorities depending on the urgency of their disease.

The remainder of this chapter shows an introduction to this research. Section 1.1 gives an overview of the hospital. Section 1.2 and 1.3 elaborate on the research motivation and objective. The chapter ends with giving a scope description in Section 1.4 and stating the research questions in Section 1.5.

1.1. The St. Antonius Hospital

The St. Antonius Hospital is a large regional hospital and has 5 locations in the centre region of the Netherlands (Utrecht, Nieuwegein, Overvecht, Houten and De Meern). The 5 locations have 850 beds and 22 operating rooms in total and they receive around 550,000 outpatient visits every year. The hospital houses around 5,000 employees, 300 medical specialists, 200 resident physicians and around 600 volunteers. The St. Antonius Hospital is known for its expertise in the field of cardiovascular diseases, lung diseases and cancer and is the largest non-academic teaching hospital in the Netherlands. The St. Antonius Hospital strives to a "continuous improvement of quality, such that the patient receives the best medical treatment, care and service in a comfortable and safe hospital." The 4 core values of the hospital are 'together', 'involvement', 'continuous improvement' and 'innovation' (St. Antonius Ziekenhuis, 2017).

The project is executed at the department 'Lean and Healthcare Logistics' (Dutch: 'Lean en zorglogistiek'). This department pursues development and implementation of healthcare logistics and capacity management.

1.2. Research motivation

Currently, the St. Antonius Hospital experiences long access times to the outpatient clinic. Timely access to health services is important for realising good medical outcomes and is also an important determinant of patient satisfaction (Gupta & Denton, 2008). The St. Antonius strives to give patients the best medical care and service, which includes short access times to the outpatient clinic. Furthermore, delays in treatments can cause inefficiencies in the use of expensive resources (Sauré, Patrick, Tyldesley, & Puterman, 2012). Lastly, long access times influence the financial performance of the hospital (Goldsmith, 1989), as patients might go to other hospitals in the neighbourhood when they refuse to wait.

To comply with their vision and their core values, the hospital wants to improve their quality of care and wants to improve continuously. Therefore, the hospital should have more insight in their ongoing processes. In this research, the focus is on the process of capacity management in the outpatient clinics. If the St. Antonius Hospital has more insight in their capacity management, they can track down bottlenecks and try to organise their processes more efficient and effective. In this way, the hospital can increase timely access to patients, which improves medical outcomes, improves patient satisfaction and provides financial stability.

1.3. Research objective

To realise a more efficient use of the capacity of the outpatient clinics, the St. Antonius Hospital should have more insight in their processes in the first place. This results in a research objective of defining a threshold, which will give information about the planned utilisation of the consultation hours. The hospital needs to know at each moment of time how many appointment slots still can be scheduled and how many need to be reserved for future appointment requests. This is mainly important since patients with a lower priority arrive before patients with a higher priority (like emergency patients), which results in booking lower priority patients before higher priority patients. This may result in a consultation hour full with lower priority patients, and no space for higher priority patients anymore. A threshold for the planned utilisation defines a maximum amount that can be booked each week, such that all patients (lower and higher priority) can have access to the outpatient clinic within their prescribed access target. This threshold ensures low access times but at the same time a high utilisation of the consultation hours. Therefore, the objective of this research is:

"To define a reservation level for the consultation hours for the eight coming weeks, to be able to schedule all patients within their desired access time.

Based on this reservation level, the St. Antonius Hospital can manage their capacity: they know whether they have insufficient capacity, sufficient capacity, or underutilisation of the consultation hours for the coming weeks.

1.4. Scope

This research concerns the development of a threshold for the *outpatient clinic*. The utilisation of the Operation Room (OR) department is out of scope. The research is executed as a case study, which means a threshold range is defined for only 2 specialties of the St. Antonius Hospital. dermatology and urology are chosen to be in the case study, as these specialties are already executing capacity management at an advanced stage and are ahead of other specialities. Besides, dermatology is a specialty with only an outpatient facility, while urology has an OR-facility next to the outpatient-facility. Although this research specifically focuses on the outpatient clinic, it would be interesting to see if there is any difference in thresholds for the outpatient clinic between an OR and a non-OR speciality. Later on, this research can be extended to other specialities as well.

1.5. Research questions

To fulfil the research objective, the following research questions will be answered. The main research question is as follows:

Which percentage of the consultation hours should the St. Antonius Hospital reserve for the coming eight weeks to be able to schedule all patients within their desired access time?

The main research question is divided into the following sub questions:

1. **What is the current method of scheduling outpatient clinics of the specialties dermatology and urology in the St. Antonius Hospital? [Chapter 2]**
    1.1. How does the hospital perform the planning and control of supply and demand currently?
    1.2. What are the KPIs of the hospital relating to scheduling?
    1.3. What is the performance of the current scheduling at the St. Antonius Hospital?
    1.4. Which problems do stakeholders encounter?
    1.5. How does the St. Antonius Hospital try to optimise the scheduling of the consultation hours currently?

2. **What does literature say about scheduling consultation hours of outpatient clinics? [Chapter 3]**
    2.1. What are the characteristics of planning and control in healthcare?
    2.2. What approaches on reservation planning are presented in literature?

3. **How can a reservation level for the consultation hours be modelled? [Chapter 4]**
    3.1. Which input parameters and decision variables have to be defined?
    3.2. Which planning horizon is useful (to what extent can we say something about it with some certainty)?
    3.3. How much time can be scheduled beforehand such that all patients can get an appointment on time and such that the utilisation is optimised?

4. **What is the impact of the model? [Chapter 5]**
    4.1. What is the new performance in terms of scheduling of the specialties dermatology and urology?
    4.2. What parameters influence the performance of the model?
    4.3. How does the model react to different scenarios?
    4.4. What are the most relevant changes experienced?
    4.5. How can this model be applied to other specialties?

5. **What is recommended for the hospital? [Chapter 6]**

Question 1 and 2 are part of the research design. The research design involves a literature study and a data analysis. The data analysis can be used as input for the design process, which is part of question 3 and 4. The design process involves a simulation model and model analysis.

The remainder of this report will provide a context analysis in Chapter 2, whereas Chapter 3 gives an overview of the relevant literature. Chapter 4 describes the model and Chapter 5 presents the computational results. Finally, Chapter 6 gives some conclusions and recommendations.

Chapter 2 Context analysis

In the previous chapter, the wish of the St. Antonius Hospital for insight and support in the planning process is explained. In this chapter, the current method of scheduling in the St. Antonius Hospital will be analysed. Section 2.1 explains the characteristics of the current scheduling process and Section 2.2 shows the performance of this scheduling. Section 2.3 describes the problems experienced by the different stakeholders in the hospital. Section 2.4 elaborates on the ongoing outpatient clinic optimisation program of the St. Antonius Hospital. Lastly, Section 2.5 gives a demarcation of the core problem.

2.1. Process of supply and demand

This section describes the current scheduling process of the St. Antonius Hospital. It focuses on the patient types of the hospital, the different types of appointments and the appointment scheduling process.

2.1.1. Patient and appointment types

The St. Antonius Hospital distinguishes five main *patient types*, see Table 5.

abbreviation	definition	description
N	new	a new patient has his or her first appointment with a specialist at a particular specialty in the St. Antonius Hospital.
C	check-up	a check-up patient has an appointment that is not his or her first appointment. For instance, a patient that is coming back after a first appointment, or has annual recurring check-up meetings, or has a meeting with the doctor after a surgery.
V	outpatient procedure	an outpatient procedure patient needs a small surgery done by either the specialist or the medical assistant.
TC	telephone consult	a patient who needs a telephone consult is called by the specialist or medical assistant to get informed, to be given some test results, or to agree on further treatment.

DB	day treatment	a day treatment patient has to spend the day in the clinic (minimum of two hours), but does not have to spend the night.

Table 5: Patient types of the St. Antonius Hospital

Within those five main patient types, many different *appointment types* can be distinguished. Those appointment types are based on the diagnosis of the patient. dermatology has around 90 different appointment types and urology has around 67. The appointment types of dermatology and urology are shown in Appendix I Complete list of appointment types. The duration of the appointment depends on the type of appointment and varies from 5 to 60 minutes.

Furthermore, 'CSPOED' and 'NSPOED' are special appointment types within the check-up and new patient types. Those appointment slots are reserved for emergency patients, who should have an appointment on a very short notice.

As day treatment patients are not completely part of the outpatient clinic, but rather part of the ward, this patient type is out of scope.

2.1.2. Appointment scheduling

Appointments are scheduled in the patient planning system of the St. Antonius Hospital, UltraGenda (UG). This system contains the available consultation sessions per specialist. For each day, you can see the available consultation hours per specialist. Those consultation hours are divided into several slots, characterised by appointment type. Patients must be allocated to a specific slot matching the patient's type of appointment. This means you can allocate for example a check-up patient only to an available check-up consultation slot. In UltraGenda, the possible consultation hour combinations are as follows:

- A regular consultation session: a combination of check-up and new patient slots;
- An outpatient procedure (V) consultation session: a combination of check-up, new and outpatient procedure patient slots, or only outpatient procedure patient slots;
- An emergency (S) consultation session: at dermatology every specialist has 2 available emergency slots per day, while at urology there is one doctor that has 'emergency duty' from 8.00 till 10.00 o'clock and from 13.00 till 14.30 o'clock every day.

- A telephone consult (TC) consultation session: an amount of telephone consult slots at the beginning or/and at the end of a regular, outpatient or emergency consultation hour.

This section shows how the system is created, but in practice the appointment scheduling process is often performed differently.

An example of a scheduled day in UG is shown in Figure 2.

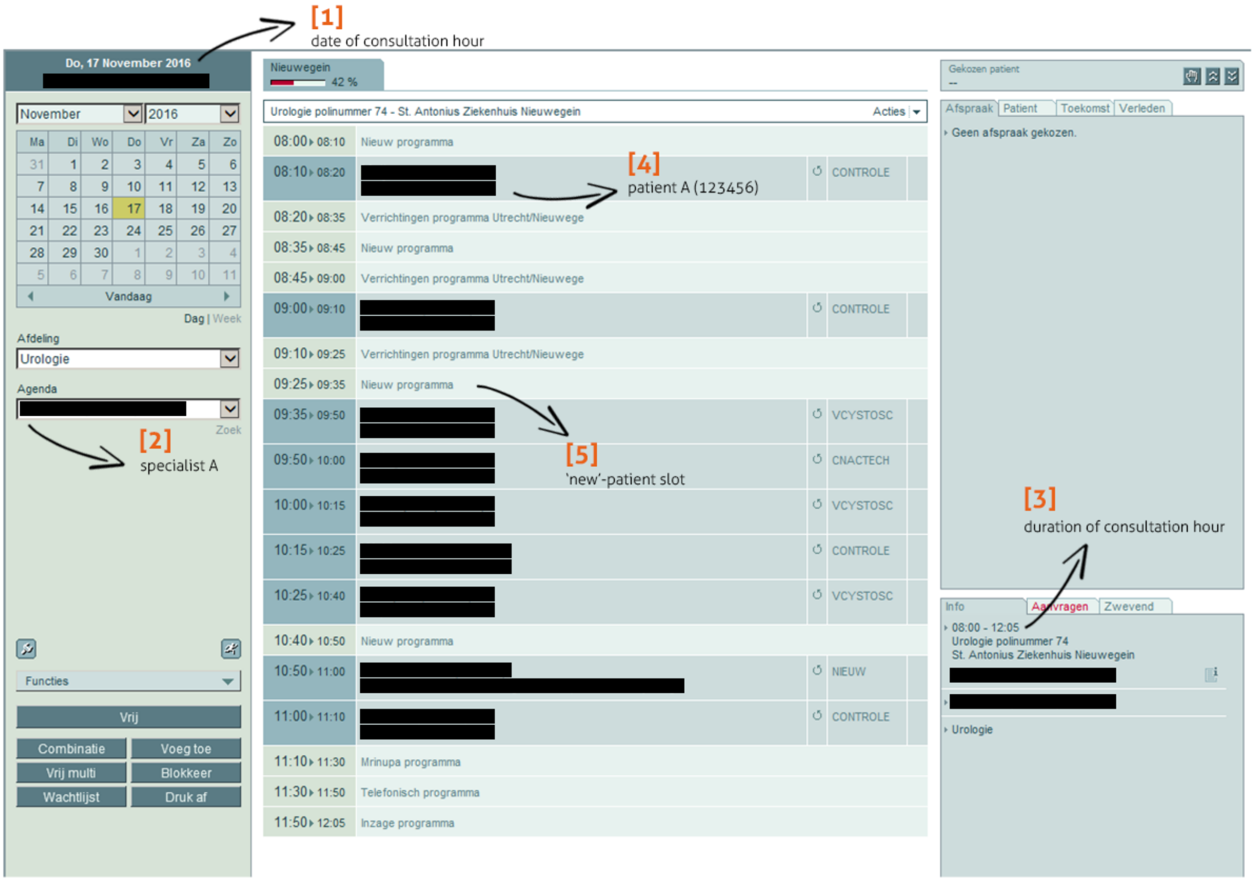

Figure 2: Scheduling in Ultragenda (UG)

As you can see in Figure 2, this consultation session is on Thursday, 17th of November (1). Specialist A (2) has its consultation session in the morning from 08.00-12.05 o'clock (3). Patients are already scheduled on different slots (4), but there are still a few free slots. Furthermore, the system shows the type of appointment (5).

A patient can request an appointment at the desk of the outpatient clinic or by phone (or in some cases online on the website of the hospital). When a patient requests an appointment two things can happen (described below), based on the period of time between now and the requested appointment. This rolling horizon is specialty-dependent: for some specialties the standard for a check-up appointment is 3 months, so these specialties have a planning horizon of 12 weeks. All specialties with the standard for a check-up appointment lower than 8 weeks, have an 8-week planning horizon.

The two things that can happen when a patient asks for an appointment are as follows:

1. The patient requests an appointment beyond the planning horizon.
   In this case, either the patient himself calls the outpatient clinic 8-12 weeks in advance to schedule the appointment or the patient is placed on a waiting list in UG and is scheduled by the planner when possible (8-12 weeks in advance). In the last scenario, the patient gets a letter when he or she is scheduled.
2. The patient requests an appointment within the planning horizon.
   In this case, the planner plans the appointment and has the following tasks:
   1. Looking up the patient in the *patient database* (EPD/Intrazis);
   2. Deciding which *specialist* will treat the patient;
   3. Deciding which *type of appointment* the patient needs (C, N, V, DB, TC);
   4. Deciding at which *location* the patient needs an appointment (depending on presence of special equipment, presence of specialist and preference of patient);
   5. Deciding on *what period of time* the patient needs an appointment;
   6. Scheduling the appointment.

   The patient gets an appointment either based on the first available spot for that type of appointment (new and outpatient procedure patients), or on a date prescribed by the specialist (check-up and telephonic consult patients).

It may happen that a patient needs an appointment within a specific period, but there is no available spot. This can for example happen due to a very long waiting list for that type of appointment. This problem can be solved with the following solutions, in order of most frequently occurring:

- The patient is added to the schedule outside the regular consultation session;
  Remark: this results in a working day longer or more crowded than usual for the specialist and a longer waiting time for the patient(s).
- The patient is scheduled at a spot for another type of appointment. For example: a check-up patient is planned at a new patient appointment slot;

Remarks: there may occur capacity difficulties in terms of rooms, equipment, assistants, etc. Besides that, this results in fewer available slots for the other patient types (in this example: new patients).

- The planner discusses with the specialist whether the period between the appointments can be changed;
- The patient is scheduled at another specialist;
  Remarks: this is not always possible due to specific skills of the specialist; and this takes more effort for the specialist due to reading the dossier of the patient.
- The appointment of another patient is changed and this released spot goes to the patient really in need of an appointment;
  Remark: moving a patient is not desirable, as it is hard to give the patient another appointment. The other patient gets probably frustrated and disappointed.

2.1.3. Scheduling of specialists

The amount of consultation sessions that are added in UG is based on agreements with health insurers. Those agreements are translated to required capacity, which subsequently is translated to a basic schedule for the specialists. In practice, the basic schedule depends also on the preferred working days of all specialists of a department and on the planning of the OR department (if applicable). For dermatology, this schedule is made yearly, for urology a new schedule is made every quartile. Basically, every specialist works according to their basic planning. However, 8 weeks in advance, the specialists communicate their irregular activities, such as Congresses and holidays, to the planner of the specialists' schedule such that it can be added in UG. The scheduling of specialists and thus the available capacity is an input for the study conducted in this report.

The planner of the specialists' schedule takes the following remarks into account when establishing the basic schedule:

- Consultation sessions should be proportionally divided among all specialists;
- The number of sessions should be proportionally divided among consultation sessions and OR-sessions (if applicable);
- The amount of consultation hours should be quite the same among the different locations (due to staff-reasons);
- Some OR-sessions must be done by 2 specialists;
- Specialists should keep their skills and agility.

Sometimes ad-hoc changes to the basic schedule are made due to an unforeseen extra need for capacity. The options in that case are as follows, in order of most frequently occurring:

- Extending the duration of the consultation hour (last longer than usual or starting earlier than usual);
- Switching specialists or medical assistants. This can be done when there are a few patients waiting for a particular specialist and another specialist has a long waiting queue;
- Changing the appointment type slot in UG. If there are many new patients waiting and less waiting check-up patients, the hospital can decide to change a check-up appointment slot into a new appointment slot (or the other way around).
- Switching a consultation session with an OR-session or the other way around. This can be done when there are a few patients waiting for an appointment for the consultation sessions and a significant number of patients waiting for an OR-sessions (or the other way around). This is only applicable for surgical specialties;
- Planning patients at another specialist. This can be done preferably for new patients, as they do not have their 'own' specialist yet. However, if the need is high, check-up patients can also be scheduled at another specialist than their 'own';

However, above options are not always desirable, for several reasons:

- Patients are more satisfied if they are seen by their 'own' specialist;
- Specialist should practise all their skills to keep their skills up-to-date and;
- The hospital needs to maintain a healthy combination of new and check-up patients to keep financial stability.

2.2. Performance

This section focuses on the performance of the appointment scheduling process described in Section 2.1. The KPIs of the St. Antonius Hospital are stated and the current performance is discussed.

Performance is often measured by means of access time and utilisation (Cayirli & Veral, 2003). The St. Antonius Hospital defined 3 main KPIs for the performance of their outpatient clinics:

- The access times to the outpatient clinics;
- The realised utilisation of the consultation hours and;
- The number of cancellations of consultation sessions.

As the number of cancellations is out of scope for this research, it is not examined during the performance analysis. Besides, the unplanned extension of the consultation hours, the waiting time in the waiting room and the number of moved appointments are out of scope and therefore also not analysed in this performance analysis.

Data analysis has been done for the specialties dermatology and urology for the period of January, 2015 till December, 2015. Every section below describes per KPI the target and performance on this KPI. Section 2.2.1 describes the KPIs and current performance of access times, Section 2.2.2 discusses the production, Section 2.2.3 discusses the occupation and Section 2.2.4 covers the key figures of the utilisation of the outpatient clinic.

2.2.1. Access times

The access time to the outpatient clinic is of growing importance as is stated by Cayirli & Veral (2003). The St. Antonius Hospital defines their targets for the access times based on a national target, the 'Treeknorm'. This Treeknorm is an agreed standard for every patient type and defines prescribed access requirements (Ministerie van Volksgezondheid, Welzijn en Sport, 2014). The Treeknorm for outpatient access time is 4 weeks. Furthermore, according to the Treeknorm, 80% of the patients should be consulted within 3 weeks (Ministerie van Volksgezondheid, Welzijn en Sport, 2003). Emergency patients should get access within 24 hours.

In practice, specialties also define their own targets. The main reason is that they want to make a difference in targets for the different patient types. Those targets are defined by the head of the outpatient clinic together with the logistics consultant of the Lean and Healthcare Logistics department. In Table 6 and Table 7 the access targets are described for dermatology and urology.

patient type	target (days)
N - new	14
C - check-up	21
V - outpatient clinic	21

Table 6: Access target dermatology

For check-up and outpatient clinic patients, the target is the same as the 80%-target of the Treeknorm. Furthermore, dermatology thinks new patients should have access to the outpatient clinic within 2 weeks.

patient type	target (days)
N - new	7
C - check-up	14
V - outpatient clinic	14

Table 7: Access target urology

The targets defined by the urology department are shorter than the Treeknorm and for new patients the desired access time is only 1 week.

We now present the current access time performance of the dermatology and urology department. The access time can be measured by counting the number of days between registration and actual appointment:

Access time = actual appointment date – registration date (date of appointment request)

Only the access time for *new* patients is useful, as for example check-up patients often need an appointment exactly after 6 weeks. This means above formula does not make sense for other patient types than new patients.

Table 8 shows the average access times in 2015 for new patients for dermatology and urology.

speciality	average access time (days)	standard deviation
dermatology (n=41,308 patients)	12	3.7
urology (n=39,860 patients)	16	4.6

Table 8: Average access time for new patients of dermatology and urology (T=52 weeks, source: Cognos, 2015)

It shows that for dermatology an average access time of 12 days is in line with the KPI of the St. Antonius Hospital (21 days) and the specialty itself (14 days). For urology, an average access time of 16 days is in line with the hospital-wide target (21 days), but by far not in line with the KPI of the specialty itself (7 days).

If the access time for new patients of the St. Antonius Hospital is compared with the targets of the Treeknorm, it shows the following (Table 9):

specialty	average access time ≤ 1 week	average access time ≤ 2 weeks	average access time ≤ 3 weeks	average access time ≤ 4 weeks
dermatology (n=41,308 patients)	40%	70%	88%	94%
urology (n=39,860 patients)	40%	58%	74%	82%

Table 9: % of new patients – average access time for dermatology and urology compared with Treeknorm (T=52 weeks, source: Cognos, 2015)

For dermatology, it shows that 88% of the patients is taken care of within 3 weeks, which is in line with the Treeknorm. However, only 94% is being handled within 4 weeks, instead of 100%, which is not in line with the Treeknorm.

It shows that for urology 74% of the patients is being consulted within 3 weeks, which is not in line with the target. The 82% within 4 weeks is also less than the target prescribes.

We conclude that the targets for dermatology are in line with the KPIs of the hospital, but not completely in line with the Treeknorm. For urology the situation is worse, the performance does not match the targets in any case.

2.2.2. Production

The second performance factor discussed is the "production" of the outpatient clinic: the number of patients served. The production of the outpatient clinic is the number of patient appointments (in hours or in numbers) during the consultation hours. In other words, the production says something about the demand side, coming from the patients.

The St. Antonius Hospital measures the production of the outpatient clinic per patient type. The target for the production is based on last year's production, as well on financial agreements within the hospital. Those financial agreements are included in the annual production plan and basic schedule of the specialists.

Figure 3 shows the total production of the outpatient clinic in 2015 for dermatology. Figure 4 shows the ratio of the five patient types.

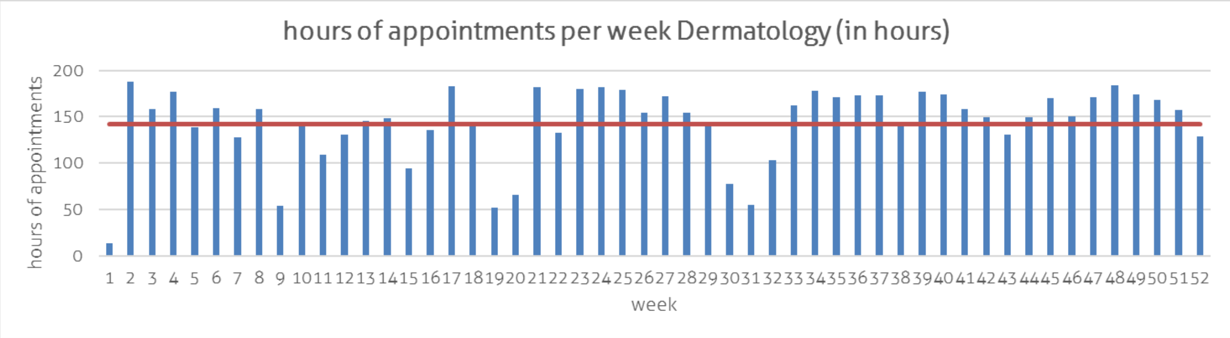

Figure 3: Hours of appointments per week (in hours) dermatology (n=41,308 patients and 8,345 hours, T=52 weeks, source Cognos 2015)

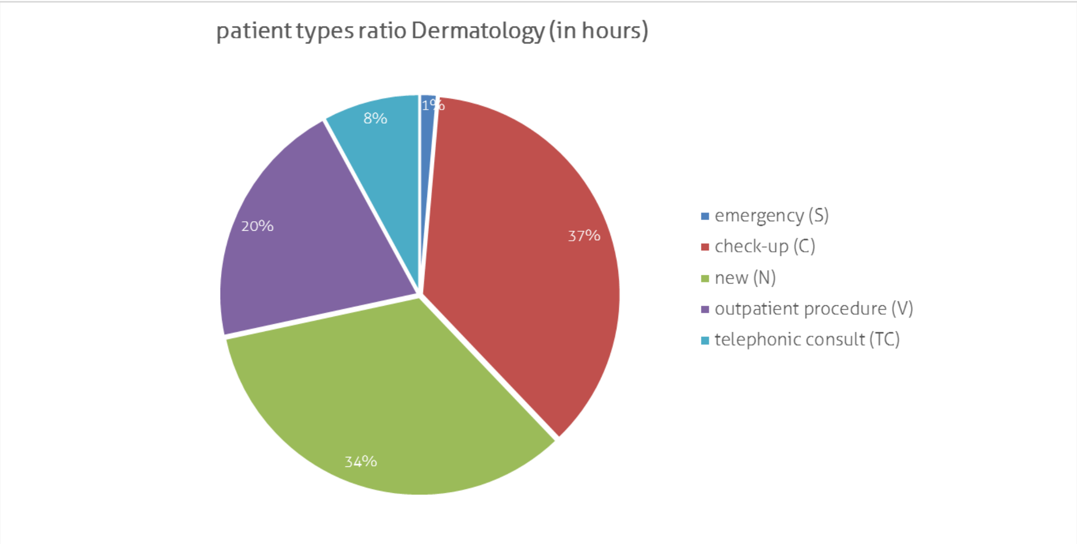

Figure 4: Ratio of patient types (in hours) dermatology (n=8,345 hours, T=52 weeks, source Cognos 2015)

We conclude that during holidays less patients are having an appointment (for example see week 1 and week 9 in Figure 3). The average total production is 142 hours of patient appointments per week. From Figure 4 we conclude that check-up and new patients are the biggest part of the total production, while emergency patients are only a small part.

For urology, the production numbers of 2015 are shown in Figure 5 and Figure 6.

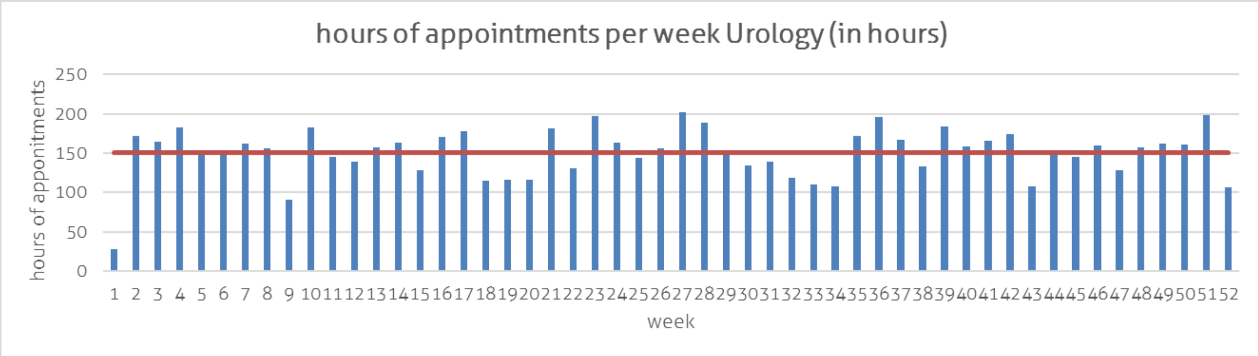

Figure 5: Hours of appointments per week (in hours) urology (n=39,860 patients and 7,830 hours, T=52 weeks, source Cognos 2015)

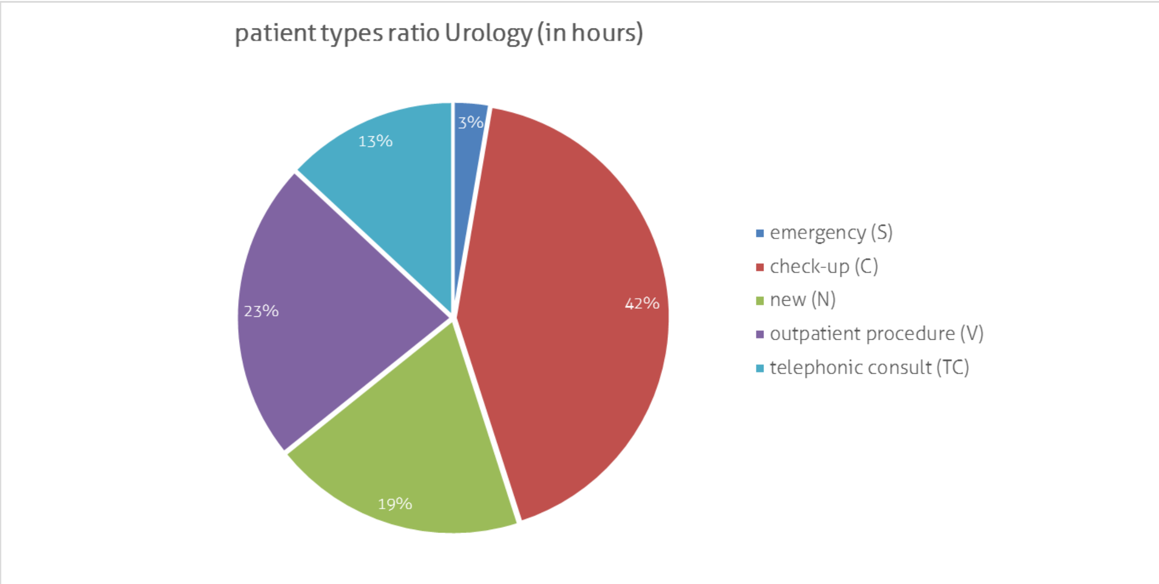

Figure 6: Ratio of patient types (in hours) urology (n=7,830 hours, T=52 weeks, source Cognos 2015)

Again, we conclude that during holidays less patients are having an appointment (for example see week 1 and week 9 in Figure 5). The average production is 151 hours of patient appointments per week. Figure 6 shows that the check-up patients are by far the biggest part of the total production for urology, while the incoming demand of emergency patients is the smallest part.

2.2.3. Available capacity

The next performance indicator is about the available capacity of the outpatient clinic: the number of available consultation hours, in hours. In other words, the available capacity says something about the supply side, coming from the hospital. The St. Antonius Hospital measures both planned and realised available capacity.

The hospital discusses their planned available capacity every week and measures it over the coming 1-4 weeks and over the coming 5-8 weeks. The target for the planned available capacity is defined based on the annual plan made by the outpatient clinic itself. This annual plan is based on the basic schedule described in Section 2.1.3 Scheduling of specialists. Thus, the target for the planned available capacity changes every week.

The realised available capacity is also discussed every week and is measured from the current year, January first, until the last week realised. The hospital compares the realised available capacity both with the annual plan and the realised available capacity of last year.

Below, the realised available capacity per week is shown in Figure 7 for dermatology and in Figure 8 for urology.

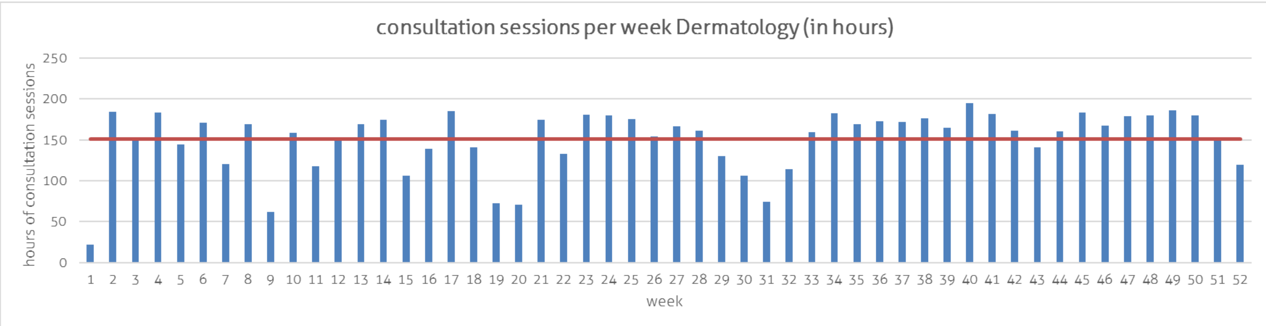

Figure 7: Available consultation hours per week (in hours) dermatology (n=7829 hours, T=52 weeks, source: Cognos 2015)

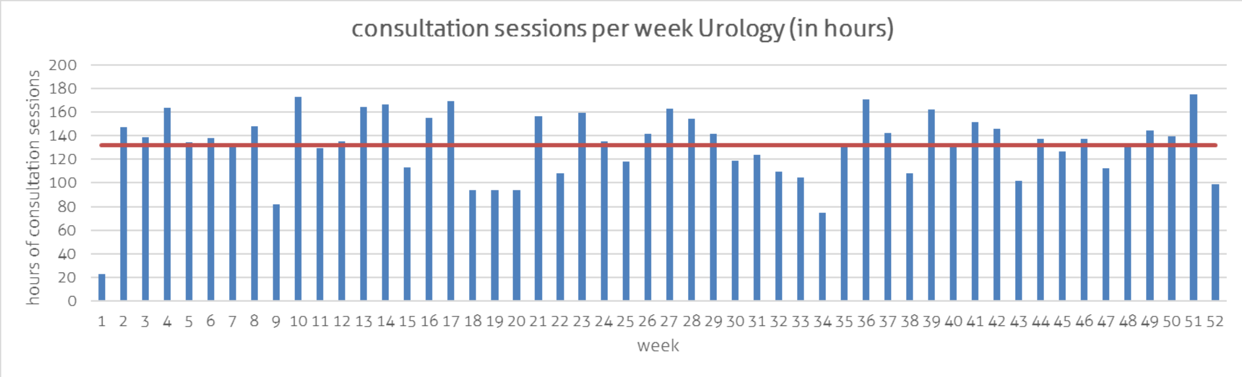

Figure 8: Available consultation hours per week (in hours) urology (n=6849 hours, T=52 weeks, source: Cognos 2015)

The average number of available capacity for dermatology is 151 hours a week, for urology 132 hours a week. During official holidays (for example week 1 and 9), the available capacity drops due to holiday of (a part of) the medical staff.

2.2.4. Utilisation

The last discussed KPI concerns the utilisation of the outpatient clinic. The utilisation of the consultation hours is defined as the production divided by the occupation. In formula:

Utilisation = production / occupation

= # appointments (in hours) / # consultation hours (in hours) * 100%

The St. Antonius Hospital measures their performance on utilisation both on utilisation for the coming weeks (8 weeks into the future) and utilisation in the past. The hospital discusses their planned utilisation every week and measures it for the 8 coming weeks. The target for the planned utilisation is not yet defined, but is the objective of the research described in this report. The past utilisation is also discussed every week and is measured from the current year, January first, till the last week realised. The hospital defines a target for the past utilisation based on the past utilisation of last year. dermatology and urology stated their target for the past utilisation to be 90%.

The utilisation in 2015 for dermatology and urology is shown in Figure 9 and Figure 10.

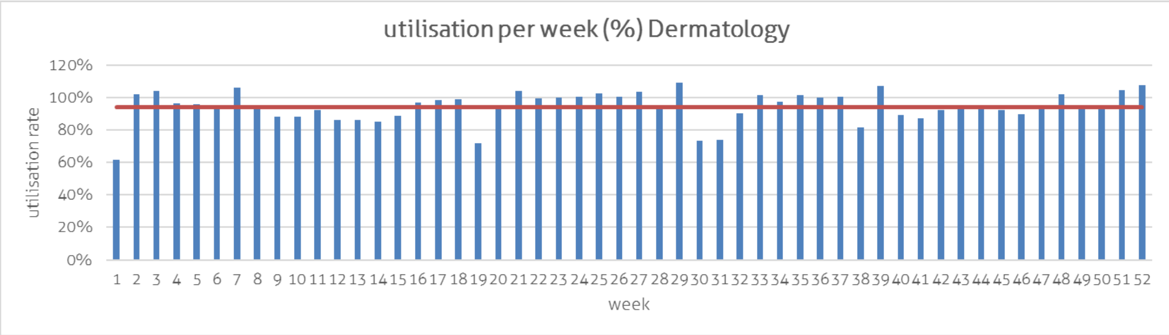

Figure 9: Utilisation per week dermatology (T=52, source: Cognos 2015)

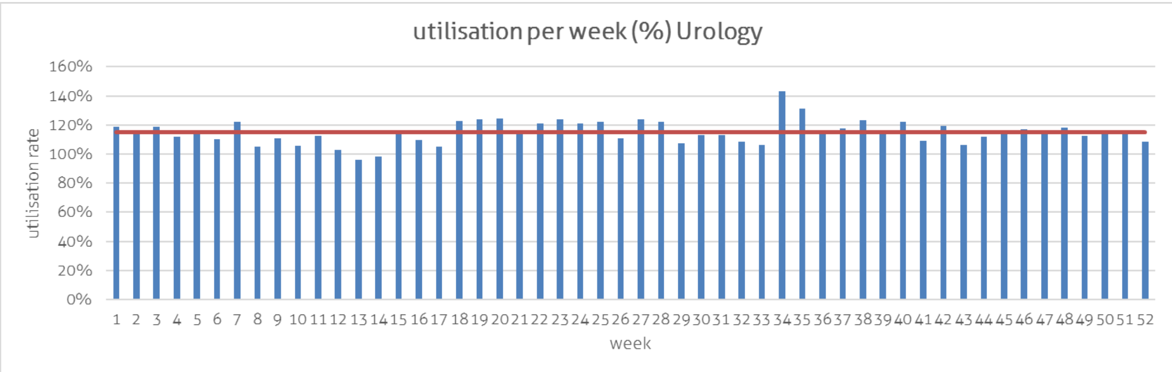

Figure 10: Utilisation per week urology (T=52, source: Cognos 2015)

We conclude that the utilisation of dermatology is on average quite high, 94%. For urology, the utilisation is above 100% (115%). This means the system is overloaded, there is significant amount of pressure on the outpatient clinic and much overtime used. The overloaded system can arise due to problems with specialist scheduling, but also due to a lack of rooms, materials and equipment. The outpatient clinic already knows this problem and tries to find ways to lower the utilisation by for example purchasing more equipment.

Several remarks on above performance analysis:

- During the data analysis, only the specialists are taken into account, no medical assistants;
- Not all appointment types are taken into account when executing the data analysis. This because several appointment types are done by medical assistants, which is not taken into account in both the production and occupation measures;
- The same yields for the DB (day-care) and SEH (first aid department) category as this category results in significant noise in the data;

- The negative access times are deleted, as those are seen as noise (only 1% of the data). Negative access times are caused by incorrect registration.

2.3. Problems in planning of the outpatient clinic

In Section 2.2 the performance analysis of the outpatient clinic is discussed. Next to those key figures, there are several stakeholders in the hospital who are involved in the scheduling process and who experience a set of problems. Those problems are discussed in this section. The stakeholders are among others managers and consultants, the planners of patients, the planners of specialists, specialists and most importantly, the patients themselves.

The managers and the consultants execute capacity management on strategic and tactical level. They experience from the specialist a high work pressure, unused consultation hours and incorrect utilisation rates compared to the Treeknorms and the KPIs of the hospital. The utilisation rate ends up incorrect due to system abnormalities, incompatible types of scheduling or wrong scheduling.

The planners of patients execute capacity management on operational level: they schedule the patients. The planners experience that planning takes more effort than assumed necessary. They experience undesirable limitations in planning options (like incompatibilities with the guidelines, moving patients around or hours blocked on specialist' request), the challenge of keeping all planning rules in mind and occasional anger from unsatisfied patients (A. Herweijer-van den Hurk, personal communication, September 14, 2016). This gives the impression that supply and demand are not coordinated well.
The planners of the specialists' schedules take care of the available capacity by making the schedule for the specialists. They experience only a few problems to get the planning around, but they do not perceive many problems in context of this research.

The specialists are the ones who are actually taking care of the patients, but they are also executing administrative work. Specialists experience a high work pressure: breaks are always filled up, consultation sessions are extended quite often, some patients are just getting a call instead of an appointment due to time pressure and sometimes there are unused spots (K. Gisolf, personal communication, September 22, 2016). Again, this gives the impression that supply and demand are not coordinated well.

The patients are visiting the hospital to consult the specialist. Patients experience long access times to the consultation session, sometimes long waiting times in the waiting room of the hospital and sometimes they notice there are unutilised spots, while they had to wait a very long time for their appointment. Those problems lead to frustrated patients.

The performance analysis in Section 2.2 together with the problems discussed above show that there is room for improvement. An ongoing process is done by the Lean and Healthcare Logistics department, which pursues development and implementation of healthcare logistics, and capacity management. The department is constantly working to improve the logistics in the hospital and started the outpatient clinic optimisation program. This program will be explained in the next section.

2.4. Outpatient clinic optimisation program

As stated in the previous sections, the St. Antonius Hospital experiences several problems in the outpatient clinics. The Lean and Healthcare Logistics department pursues development and implementation of capacity management.

"We provide a barrier-free accessibility and make sure that care pathways are fully integrated. We do not want to cause unnecessary suffering, uncertainty or inconvenience caused by waiting, uncertainty, confusion, or additional operations that do not add value to the process. We avoid highs and lows in workload of medical staff and we enable them to carry out their planning and coordination activities with the least possible wastage. We improve the planning integrally: the care pathway of the patient is taken into account from beginning to end." (van Houten & van Swinderen, Uitrol en doorontwikkeling poli-optimalisatie, 2016).

The department is already developing an outpatient clinic optimisation program. This program consists of 2 approaches: Specialty-TPO (1) and organisation of consultation sessions (2).

1. Specialty-TPO

   Specialty-TPO (Dutch: 'Specialisme TPO', 'Tactisch PlanningsOverleg') is a tactical planning consultation for active adjustment of supply and demand of consulting hours and if applicable OR. The goal of this specialty-TPO is to have shorter access times to the outpatient clinics and OR together with a good utilisation rate.

The specialty-TPO started at the departments of plastic surgery and surgery. However, the hospital wants this program to be developed further, such that it can be used in other outpatient clinics as well. The objective of this specialty-TPO is to have less ad hoc responses, a better utilisation of consulting hours, a better utilisation of OR, less process waste (for both outpatient clinics employees to plan appointments as well for planners to fill up the OK), and a bigger change to fill up the OR in relation to the rules of the planning. Thus, the specialty-TPO results in a better control of supply and demand, and in a more efficient way of deployment of staff outpatient clinic and OR.

The implementation of the Specialty-TPO consists of 5 phases:

0. The implementation has not started yet.
1. The implementation will start quite soon.
2. The basis is set, the preparation and execution of the TPO is done together with a consultant of the LZ-department.
3. The basis is set, the preparation of the TPO is done by the specialty itself, the execution of the TPO is done together with a consultant of the LZ-department.
4. The preparation and execution of the TPO is done by the specialty itself. Once a month the consultant joins to take care of continuous improvement.

Table 10 shows the implementation phase per specialty.

specialty	phase 0	phase 1	phase 2	phase 3	phase 4
Plastic Surgery					x
Surgery				x	
urology				x	
Orthopaedics			x		
dermatology				x	
Internal Medicine		x			
Ophthalmology		x			
Paediatrics		x			
Gynaecology		x			
other specialties	x				

Table 10: Implementation phases of Specialty-TPO per specialty (van Houten, Groot TPO sept 2016, 2016)

Important to know is that a specialty must be motivated to work with this TPO before implementation starts. An example of a TPO-sheet can be found in Appendix II TPO sheet example.

2. Organisation of consultation sessions
   Organisation of consultation sessions (Dutch: 'Agenda/Spreekuurinrichting') is a program to better organise the consultation sessions. The objective is to have more flexibility in the mix of patients per consultation session (so to achieve the goal of the Specialty-TPO) and less process waste around planning of appointments.

2.5. Demarcation of core problem

In this last section, the scope of the research is narrowed down. As described in the previous sections, the St. Antonius Hospital experiences several problems at the consultation sessions of the outpatient clinics. Those problems can be traced back to the following two problems:

1. For urology, the utilisation rate is too high.
2. **At each moment of time it is unknown how many appointment slots can be scheduled and how many need to be reserved for future appointment requests.**

As this research focuses on defining a threshold for the planned utilisation, the main problem is problem 2. The hospital is making decisions ad-hoc instead of forecasting. However, the solution for problem 2 should be applicable to a situation where problem 1 still exists, but also to a situation where problem 1 is solved and the utilisation rate is below 100%. The core problem is a capacity planning problem and is positioned at the tactical level of resource capacity planning (see Figure 11).

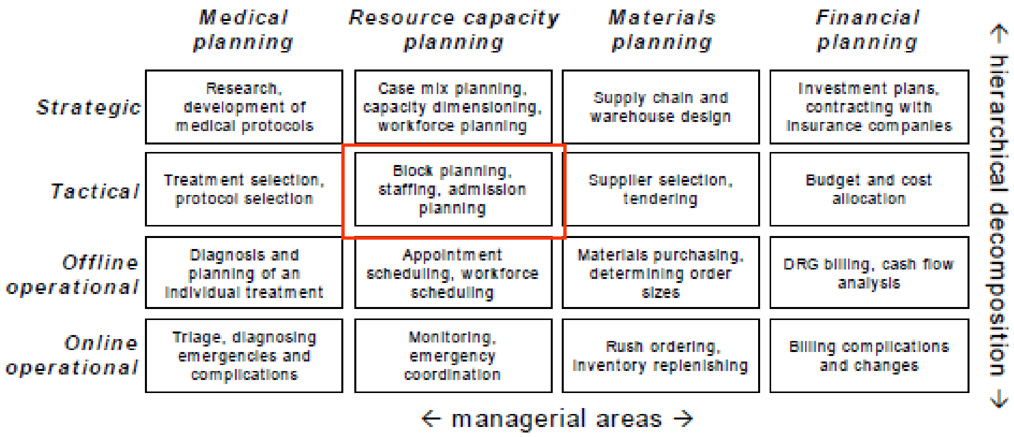

Figure 11: Healthcare planning and control framework (Hans, van Houdenhoven, & Hulshof, 2011)

Furthermore, the focus of this research is on approach 1 described in the previous section: specialty-TPO. During a specialty-TPO, the process of supply and demand is discussed every week and more insight in the processes is desired. Therefore, the objective of this research fits well in the specialty-TPO approach. Besides, as said before, this research is conducted in 2 specialties: urology (with OR) and dermatology (without OR).

Lastly, the focus of the research is on singular appointments. Patients can have several appointments on different days, but those kinds of appointments are beyond the scope of this project. Furthermore, several problems are *beyond* the scope of this project:

- The waiting times are quite long (in the waiting room);
- Noise/disruptions during consultation hours.

2.6. Conclusions

This chapter presented an analysis of the context of our research. Summarised, the St. Antonius Hospital distinguishes five main patient types: emergency (S), new (N), check-up (C), outpatient procedure (V) and telephone consult (TC) patients. During the appointment scheduling process, many ad-hoc decisions are made, such as: adding patients to the consultation hours outside the regular sessions, scheduling patients at an appointment slot for another type of patient or changing the agreed period between the appointments. Moreover, the main targets of access time and utilisation are not completely achieved. We conclude that the access times for dermatology patients are in line with the KPIs of the hospital, but not completely in line with the Treeknorm. For urology, the situation is worse, the access time performance does not match the targets in any case. Furthermore, we conclude that the utilisation of dermatology is on average quite high, 94%. For urology, the utilisation is above 100% (115%), which means the system is overloaded. The outpatient clinic already knows this problem and tries to find ways to lower the utilisation by for example purchasing more equipment.

Our problem can be demarcated to the following: at each moment of time it is unknown how many appointment slots can be scheduled and how many need to be reserved for future appointment requests. An answer to this problem should provide the hospital with a better forecast, which should result in less ad-hoc decisions.

In the remainder of this report an answer will be found for the core problem of this research: how much capacity should be reserved for future appointments? The next chapter shows the literature review and a solution approach to the problem. Furthermore, Chapter 4 describes the solution in detail. In Chapter 5 experiments will be conducted to verify the performance of the solution. Chapter 6 concludes the research.

Chapter 3 Literature review

Chapter 3 gives an overview of relevant literature on appointment scheduling systems in outpatient clinics and the use of protection levels and booking limits in revenue management.

Section 3.1 gives a general introduction on revenue management. Section 3.2 shows an introduction on planning and control in health care. Section 3.3 focuses on appointment scheduling processes in outpatient clinics, where Section 3.4 gives an overview of literature on reservation planning. Section 3.5 summarises the theoretical framework and presents the basis for the solution approach. The queries can be found in Appendix III Literature review queries.

3.1. Revenue management

Revenue management is a strategy where available resources are aligned with the expected demand and where the pricing strategy is adjusted to recent sales trends. The optimal amount of resources is offered to the optimal number of customers for the optimal price. Revenue management is applied in many industries, with the main goal of maximising profit, reducing cost and increasing utilisation. It is mainly used in the manufacturing industry, aviation industry and hotel industry. For example, production plants have to allocate their capacity to different orders with different priorities, hotels have to allocate their rooms to different customers in different price ranges and airlines have to allocate their capacity to different passengers again in different prince ranges. However, revenue management is getting more and more attention in the hospital field (Born, et al., 2004). For example, a hospital should decide how to allocate appointment slots to patients with different needs. Main objectives are reducing cost, increasing utilisation, decreasing access time times and improving the quality of the care process.

3.2. Planning and control

As stated in the previous section, revenue management in healthcare is receiving more and more attention, but the processes have a unique character. One way to deal with revenue management in healthcare is by the hierarchical decomposition of the healthcare planning and control framework according to Hans, van Houdenhoven and Hulshof (2011). The framework is shown in Figure 12.

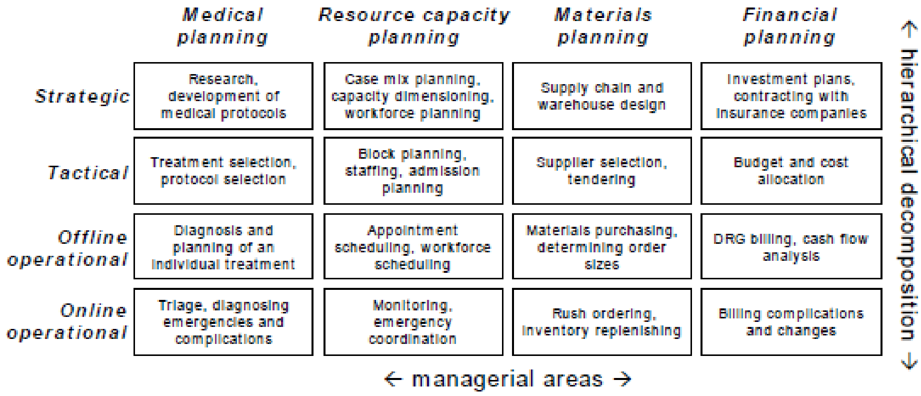

Figure 12: Framework for health care planning and control (Hans, van Houdenhoven, & Hulshof, 2011)

The Production Control Framework deals with the balance between service (delay in access) and efficiency (capacity utilisation), at all levels of planning and control (Vissers, Bertrand, & de Vries, 2001). The three levels 'Strategy', 'Tactics' and 'Operational' represent the long to short term planning issues of a plant. As said before, this research is placed in the resource capacity planning on the tactical level. The tactical planning concerns the medium-long term of matching available resource capacity with the required capacity. While strategic planning addresses structural decision making, tactical planning addresses the organisation of the operations and execution of the health care delivery process. In comparison with the operational level, the tactical level shows more flexibility, less detail and less demand certainty. Goals on the tactical level focus for example on staffing, capacity, etc. In outpatient clinics, this involves mainly the scheduling of sessions several weeks or months ahead. For example, in tactical planning decisions are made on temporary capacity expansions like overtime or hiring staff.

3.3. Appointment scheduling processes

Appointment scheduling systems are used to address revenue management in health care: the appointment scheduling process is the process by which available treatment capacity is assigned to incoming demand (Sauré, Patrick, Tyldesley, & Puterman, 2012). Scheduling outpatient clinics is quite difficult since one should decide on today's arrivals with almost no information about the future job arrivals. Furthermore, you have to make a trade-off between committing the capacity to a lower priority job that is available today and reserving the capacity for a potential higher priority job that may arrive tomorrow (Sauré, Patrick, Tyldesley, & Puterman, 2012).

Gerchak, Gupta and Henig (1996) state: "A hospital devotes a random portion of each day to emergency surgery sessions. The remainder, if any, can be used to perform scheduled (elective) surgery. New requests for bookings of elective surgery arrive each day. Such procedures preferably would be performed as soon as possible, since delays cause losses in productive work days, might worsen the patient's health status, and/or delay the hospital's revenue, but scheduling too many cases results in exceeding the day's capacity."

Most literature on appointment scheduling covers access rules, deciding which patients are scheduled when. Gupta and Denton (2008) and Cayirli and Veral (2003) summarise key issues in designing and managing patient appointment systems for health care in their papers. Related to this thesis, the interesting part in appointment scheduling is about reservation planning, which will be discussed in the next section.

3.4. Reservation planning

Reservation planning is a much-discussed subject in revenue management. It concerns capacity allocation where limited resources are shared among several classes of customers with different priorities. Most literature on reservation planning has been done in the field of airline industries. Here, reservation planning makes a trade-off between committing the aircraft's capacity to economy class passengers that want to book today (but are paying less), and reserving seat capacity for business class clients that *may* arrive tomorrow (but are paying more). In this way, the airline can decide how many seats they want to make available for each class. This strategy maximises revenue based on the calculated 'protection levels' or 'booking limits'. For example, Bertsimas and de Boer (2005) determine booking limits for airlines. They address the stochastic and dynamic character of the demand and the nested character of booking-limit control in a network environment. They do this by using a stochastic gradient algorithm and approximate dynamic programming. Although this paper is quite similar to the problem in this thesis, there are some significant differences in airline revenue management compared to patient scheduling. First, airlines are looking at a finite horizon, while patient scheduling deals with an infinite horizon as the booking horizon is continuously evolving. Second, passengers can 'choose' which priority they would like (first, business or economy class), while patients 'are' a priority class, depending on the urgency of their disease. Finally, "airline revenue management does not consider the impact of a given policy on passenger waiting time." (Patrick, Puterman, & Queyranne, 2008).

One of the earliest papers addressing reservation planning in health care concerns the advance scheduling of elective surgery when the operating room's capacity utilisation by emergency surgery, as well as by elective procedures, is uncertain (Gerchak, Gupta, & Henig, 1996). Similar studies have been done by Wang and Gupta (2008), Patrick, Puterman and Queyranne (2008), Sauré, Patrick, Tyldesley and Puterman (2012), Barz and Rajaram (2015) and Erdelyi and Topaloglu (2009). Many of them decide on a policy for allocating available treatment capacity to incoming demand. However, most of them fail to calculate actual protection levels.

First, Gerchak et al. (1996) characterise the structure of an optimal policy. Rather than computing performance measures for given policies, they attempt to model the essential trade-offs explicitly from the start and then characterise the nature for the optimal policies by stochastic dynamic programming. They also show that an optimal policy is often not one of a cutoff number, but they point out that the relative loss in profit from using the best cutoff number policy is small and that finding the optimal policy, which would 'suggest' a good cutoff number, could reduce the computational effort. However, this paper has two main limitations. Firstly, the authors fail to provide an algorithmic method to compute protection levels for large problems. Secondly, the paper considers only two priority classes, while the research in this report considers five different levels.

Second, Gupta and Wang (2008) also develop a decision process model for the appointment-booking problem, but focus on modelling the patients' choice behaviour explicitly. The paper differs with our research as Gupta and Wang maximise revenue with a focus on a single day rather than the entire planning horizon. In this thesis, the focus is on reducing access times assuming decisions made on one day will impact the decisions that can be made on other days. This forces us to look at a planning horizon instead of a single day. Besides, a focus on the presence of patient choice is not the main goal of this research and makes the paper of Gupta and Wang less relevant.

Third, Patrick et al. (2008) present a method for dynamically scheduling multi-priority patients to a diagnostic facility in a public health care setting. They consider an infinite planning horizon and seek optimal scheduling policies using approximate dynamic programming. The goal is to minimise the number of patients whose access time is longer than recommended for each priority class. The authors give an answer to the question how much demand must be removed (either through overtime or rejection) as well as what type of demand (which priority class) and when to remove it. However, they do not consider protection levels or booking limits.

Sauré et al. (2012) also study policies for allocating available treatment capacity to incoming demand while reducing access times in a cost-effective manner. However, this paper focuses mostly on multi-appointment patient scheduling, which is not related to our research.

Barz and Rajaram (2015) decide on how many elective (non-emergency) patients to accept, postpone or reject under multiple resource constraints. Their goal is to assist decision makers with patient admission and scheduling. Their patient mix resulting from their model should be viewed as an input to daily OR scheduling or bed assignment decisions (and does not replace it). However, the authors fail to account protection levels.

Lastly, Erdelyi and Topaloglu (2009) compute in their paper protection level policies for dynamic capacity allocation. It involves allocating a fixed amount of daily processing capacity among jobs of different priority levels that arrive randomly over time. They want to decide which jobs should be scheduled on which days and jobs that are waiting incur a holding cost depending on their priority level. The goal is to minimise the total expected cost over a planning horizon. They compute the protection levels using stochastic approximation methods and focus on a class of policies that are characterised by a set of protection levels. The approach of Erdelyi and Topaloglu is highly relevant for the research described in this report because they calculate actual protection levels, account a planning horizon (instead of a single day) and minimise total costs (which include waiting costs depending on the patient's priority level).

3.5. Solution approach

In the previous sections, the theoretical framework for the research in this report is set. The next step is to determine what kind of solution approach would fit the problem stated in this research.

As Law (2006) describes that physical models are of no interest in Operations Research, a mathematical method is used to develop the model. A mathematical method can be either an analytical solution approach or a simulation approach. An analytical model can be used if the model is simple enough, as a too complex model is not able to be solved numerically within polynomial time. An analytical model gives an exact solution. Methods used in analytical modelling are for example mathematical programming and queuing theory (Cayirli & Veral, 2003). On the contrary, a simulation approach can be used for a more complex system, as a simulation study can model complex outpatient queueing systems (Cayirli & Veral, 2003). A simulation model does not give an optimal solution, but creates the possibility to experiments with model inputs and observe how they affect output measures of performance (Law, Simulation Modeling and Analysis, 2006).

The mathematical program in this thesis is based on the models used by Erdelyi and Topaloglu (2009) and Patrick et al. (2008): minimising the number of patients whose access time is longer than recommended for each priority class. Erdelyi and Topaloglu translate this into minimising total costs, which consists of holding costs of waiting patients, depending on their priority level. However, there are differences between those papers and the approach used in this thesis. First, in contrast with Patrick et al., actual protection levels will be calculated. Second, both papers use an approximation method, while in this thesis a linear program is developed to find an optimal solution (deterministic). Lastly, in this thesis no patients will be rejected, but only overtime and postponement will be used if capacity is scarce.

Chapter 4 Model

Chapter 3 set the foundation for the development of a mathematical model by giving a literature overview and solution approach. This chapter, Chapter 4, describes the developed model of this research in detail.

The model is formulated by means of the Seven-Step approach of Law, see Figure 13 (Law, 2009). It starts with the problem definition (step 1), followed by the model construction (steps 2-5) and it ends with an experiment design (steps 6-7). In this chapter the problem definition (step 1) will be described in Section 4.1, and the conceptual model formulation, assumptions document and data collection (step 2) in Section 4.2. Section 4.3 describes the programmed model formulation (step 4), where Section 4.4 shows the validation of the model (step 5). The experiment design (step 6) and analysis of results (step 7) will be explained in Chapter 5.

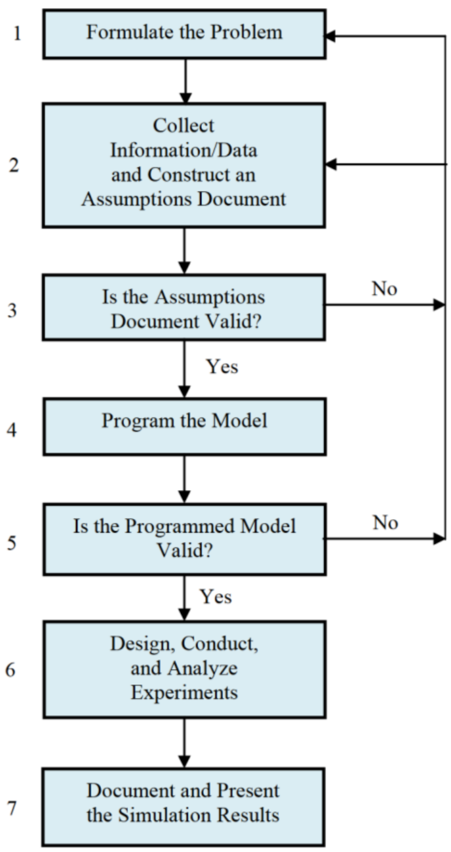

Figure 13: The Seven-Step approach for conducting a study by Law (2009)

4.1. Problem definition

The first step in the development of a model is to formulate the problem. Chapter 2 already presented an analysis of the context and the problems experienced. In the current chapter, only the research question is repeated. The mathematical model gives an answer to the main research question:

"Which percentage of the consultation hours should the St. Antonius Hospital reserve for the coming eight weeks to be able to schedule all patients within their desired access time?"

The performance of the system is evaluated by measuring the main KPIs of the St. Antonius Hospital. Those KPIs are described in Chapter 2 as well: access time and utilisation. Next sections explain the mathematical model further.

4.2. Conceptual model

This section describes the basic concepts of the developed model (Section 4.2.1) and the assumptions that are made during development (Section 4.2.2). This section also elaborates on the input data for the model, such as incoming demand and available capacity (Section 4.2.3).

4.2.1. Conceptual model description

The mathematical model formulated in this chapter is based on literature found in Chapter 3. In literature, problems like the one discussed in our research are formulated both as minimisation and maximisation functions. The ones with a minimisation function mostly minimise total costs, which consists of holding costs of waiting patients and penalty costs of rejecting patients (Erdelyi & Topaloglu, 2009). The ones with a maximisation function mostly maximise profit. This profit consists of profit for elective patients as well as emergency patients, and penalty costs for postponement of a patient and for exceeding a day's capacity (Gerchak, Gupta, & Henig, 1996). The main objective of our research is to decrease the access times to the outpatient clinic, but simultaneously optimising the utilisation. Optimising utilisation can be achieved by minimising overtime and idle time. Therefore, the objective function of the model is a minimisation function. **In this research, the weighted average of access time, overtime and idle time, is minimised.** This approach also matches the main KPIs of the St. Antonius Hospital (described in Chapter 2.2 Performance).

Input for the model is the total weekly available capacity, the expected total weekly demand and the already booked demand. The expected total demand is defined as of the date that the patient requests an appointment (registration date), *not* the actual appointment date. The model first determines the expected future demand for the coming eight weeks: which is the total expected demand minus the already booked demand. The total expected demand is forecasted by an average approach of historical data. Then, the model suggests an optimal booking policy for this expected future demand. This means the demand is not actually booked, because it has not arrived yet, but the model *suggests* an optimal booking composition. The model books the future demand in a way that the weighted average is minimised: all patients are booked with an access time as short as possible, and an amount of overtime and idle time as small as possible. Figure 14 shows a flowchart of the process.

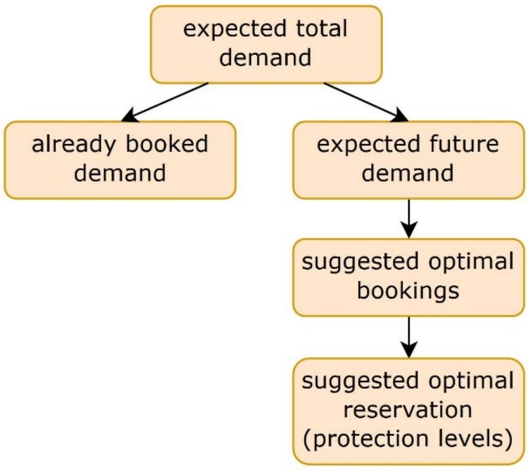

Figure 14: Flowchart mathematical model

The optimal booking allocation suggests how to schedule demand. A hospital can anticipate on this suggestion by allocating their amount and availability of personnel capacity. With future demand in mind, precautions can be made in the scheduling in advance. Figure 15 shows an example. The figure shows the coming eight weeks, where the upper line shows the total available capacity per week (which can vary per week). The orange areas show the output of the developed model: the amount to protect each week. The white areas show the amount of capacity that is already booked or is still free to book for any type of patient. The amount to protect each week is an aggregated number for all priority levels. We expect that the further in the future, the more should be reserved, as most patients still need to arrive. On the other hand, for next week we expect that for example only emergency patients still need to arrive, so the amount to protect is smaller. Besides, the amount to protect is also dependent on the amount of capacity available each week.

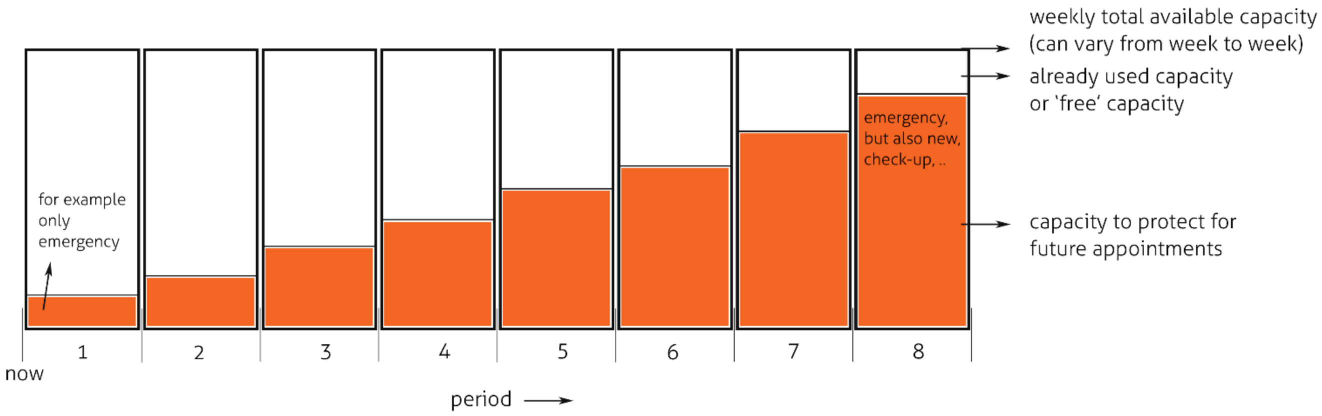

Figure 15: Example protection level

The model is constructed to fit the characteristics of the St. Antonius Hospital and in particular the specialties dermatology and urology, but can be generalised and adapted to fit other settings. For example, available capacity can be easily modified, as well as the weights in the objective function. In this way, the model can be applied to other specialities or hospitals.

The mathematical model is programmed in the software system AIMMS (Advanced Interactive Multidimensional Modelling System). AIMMS is an optimisation modelling software and is free for research purposes and is easy in use. Next to developing mathematical models, AIMMS is able to create a (graphical) user interface to guide and inform the end-user. The solver used to solve the mathematical model of our research in AIMMS is CPLEX.

4.2.2. Assumptions

The model is developed under several assumptions. The assumptions made throughout the modelling process are specified below.

- We do not take patient choice into account. This means that patients are always scheduled on the first possible date for the hospital.
- Patients are being planned in the order of arriving (FCFS: First Come First Serve).
- Cancelled appointments, either by the patient or hospital, are neglected.
- We assume that all patients are on time for their appointment.
- We assume that all specialists and medical assistants are on time for their consultation sessions.

- The model does not distinguish specialists and medical assistants. We assume that both can perform all types of consultations.
- We assume that the amount of frequent reoccurring appointments needed is constant. For example, we assume that check-up patients who will make an appointment this week for over 6 months is equal to the number of patients who made an appointment 6 months ago for this week. As such, those reoccurring incoming requests incoming on a short timescale represent the amount of appointments considered from history (a long timescale).

4.2.3. Data collection

This section describes the necessary information needed as input for the model. The input includes the arrival process of the patients per week, the available capacity per week and the weights for the objective function components: overtime, idle time and waiting. Furthermore, the length of the planning horizon should be decided.

Arrival process

The arrival process is the incoming demand of patients. Patients can be divided into five categories (described in Chapter 2.1.1 Patient and appointment types): emergency (S), new (N), check-up (C), outpatient procedure (V) and telephonic consult (TC) patients. For simplicity, patients are modelled in terms of hours instead of in number of patients. After all, the available capacity is modelled in terms of hours as well. The arrival pattern shows the week that patients request an appointment (not the actual appointment date). Lastly, the incoming demand is based on data of 2015.

Below, the input data for incoming demand is shown in Table 11 – Table 13. To determine the number of patients requesting an appointment per week in *hours*, the average number of patients in *numbers* is multiplied by the average appointment duration (in hours). First, the average number of patients requesting an appointment per week is shown in Table 11 (in numbers).

patient type	average # of patients dermatology n=41,308 patients, T=52 weeks	average # of patients urology n=39,860 patients, T=52 weeks
S - emergency	12	17
N - new	235	133
C - check-up	330	323
V - outpatient procedure	45	126
TC - telephonic consult	127	177

Table 11: Average number of patients per week (in numbers) (source: Cognos 2015)

The average (planned) appointment duration per patient type is shown in Table 12.

patient type	average appointment duration dermatology	average appointment duration urology
S - emergency	11 min = 0.183 hour (n=600 hours)	15 min = 0.25 hour (n=891 hours)
N - new	13 min = 0.217 hour (n=12,220 hours)	14 min = 0.233 hour (n=6,849 hours)
C - check-up	10 min = 0.167 hour (n=17,160 hours)	12 min = 0.2 hour (n=16,571 hours)
V - outpatient procedure	35 min = 0.583 hour (n=2,340 hours)	18 min = 0.3 hour (n=6,476 hours)
TC - telephonic consult	5 min = 0.083 hour (n=6,604 hours)	5 min = 0.083 hour (n=9,073 hours)

Table 12: Average appointment duration per patient type (T=52 weeks, source: Cognos 2015)

Lastly, the average demand per week in hours is shown in Table 13, which is calculated by the average number of patients a week (in numbers) times the average appointment duration described in Table 11 and Table 12.

patient type	average demand dermatology (in hours)	average demand urology (in hours)
S - emergency	2.2	4.3
N - new	51.0	31.0
C - check-up	55.1	64.6
V - outpatient procedure	26.2	37.8
TC - telephonic consult	10.5	14.7

Table 13: Average demand per patient type per week (in hours)

Seasonal trends can be added in the model. Data analysis shows that in school holiday weeks the demand drops by 40% (Appendix IV 40% holiday drop calculation). In the model this is declared as an 'seasonal multiplication factor' that can be altered from 1. Alteration to 0.6 would for instance decrease the expected future demand by 40%.

Available capacity

The second input parameter is the available capacity. When the model is applied in practise, the capacity will be real time data for the coming 8 weeks. However, for verification, validation and experimenting, the average weekly occupation over 2015 is taken as input. In Table 14 the available average capacity is shown for both specialities. This amount is decreased with the amount blocked in the schedule for other purposes (unforeseen day off, illness, etc.).

available capacity	dermatology	urology
hours per week	151 (n=6,849 hours)	132 (n=6,849 hours)

Table 14: Average available capacity per week (in hours) (T=52 weeks, source: Cognos 2015)

Weights for the objective function

Next, the weights for overtime, idle time and patient access time must be determined. Both the overtime and idle time have a weight of 1 point. They are equally weighted because they are considered equally undesirable by the outpatient clinic (F. van Dijk, A.T. Brandwijk, E. Voogd, personal communication, February 21, 2017). Overtime results in more pressure on specialists, but idle time is wasted capacity.

The waiting weight is determined based on the target for the access time. Patients have different medical priority levels and the target for the access time also differs. This target is already explained in Chapter 2.2 Performance, in Table 15 the target for the access times are repeated.

patient type	target dermatology (in weeks)	target urology (in weeks)
S - Emergency	≤ 1 week	≤ 1 week
N - New	≤ 2 weeks	≤ 1 week
C - Check-up	≤ 3 weeks	≤ 2 weeks
V - outpatient procedure	≤ 3 weeks	≤ 2 weeks
TC - telephonic consult	≤ 1 week	≤ 1 week

Table 15: Target access times

Table 16 shows the weights for dermatology and urology. Those weights are determined per patient type, giving them each a specific starting moment and intensity. All of them however start with no costs for 0 weeks of waiting, increase exponentially and have a maximum at seven weeks. The weights are based on the target for the access type of the patient type. An emergency patient should be served within a week, since a longer access time is sure to cause quick degradation of health. Whilst patients from a telephonic consult are also targeted to be served within one week, the consequences of postponing this type of patient are less severe. Therefore, the weights of their access time are much less than for emergency patients. Weights for all patients increase exponentially since it is – for instance – less desirable to have one patient waiting six weeks, than two patients waiting three weeks.

# weeks waiting	dermatology					urology				
	S	N	C	V	TC	S	N	C	V	TC
0	-	-	-	-	-	-	-	-	-	-
1	4	-	-	-	1	4	2	-	-	1
2	8	2	-	-	2	8	4	2	2	2
3	16	4	2	2	4	16	8	4	4	4
4	32	8	4	4	8	32	16	8	8	8
5	64	16	8	8	16	64	32	16	16	16
6	128	32	16	16	32	128	64	32	32	32
7	256	64	32	32	64	256	128	64	64	64

Table 16: Weights waiting

Planning horizon

A **planning horizon** is the forecast window where in decisions are made. The length correlates with the degree of certainty: the more uncertain the expectations are, the shorter the planning horizon should be. While there is limited historical data and uncertainty is thus still significant, the planning horizon could not be determined based on this uncertainty without similar material to compare. Therefore, the main conclusion is simply to keep a rather short planning horizon. The specific length of the horizon has been set for practical reasons. Both the existing planning horizon in the hospital, and the Tactical Planning Meeting (TPO) act in the scope of the upcoming 8 weeks. Any larger scope would deal with an unknown capacity and thus adds more uncertainty to our model. As such, we assume that the practise of considering 8 weeks is also a reasonable horizon for the level of uncertainty and still makes the model effective.

In addition, a rolling horizon is built in the model. A **rolling horizon** is a method in which the model is solved in several sub models. Rolling horizon decision making is a common business practice for making decisions in a dynamic stochastic environment. It involves making decisions that must be made in the first period (the most immediate decisions), which are based on a forecast for a certain number of periods in the future. The number of forecasted periods in the future determines the optimal first period decisions. When the first period is over, the second period decisions become most immediate. For optimal decision making, forecasts for additional periods in the future may be required or existing forecasts may be revised. This process repeats every period (in our research: week), which justifies the term rolling horizon decision making for the practice (Sethi & Sorger, 1991). In practical applications, however, caution is needed: a short planning horizon may not be sufficient to take the relevant future into account. As said, our planning horizon of 8 weeks is assumed sufficient for our demand fluctuations.

4.3. Mathematical model

This section describes the mathematical model, which involves the model formulation with the input parameters, decision variables, objective function and constraints. Furthermore, the stochastic nature of some of the input parameters is explained.

4.3.1. Model formulation

The model formulation consists among others input parameters and decision variables. Table 17 shows the ones that are used in the mathematical model.

type	entity	symbol
horizon	planning horizon	$t \in T$
sets	priority levels	$i \in I$
	waiting weeks	$n \in N$
parameters	total capacity available in week t (in hours)	C_t
	total demand (requesting an appointment) of priority i patients in week t (in numbers)	$D_{t,i}$
	demand of priority i patients already booked in week t (in hours)	$B_{t,i}$
	duration of an appointment of a priority i patient	p_i
	weight of 1 hour of patients of priority i waiting n weeks before being served	$Wwt_{n,i}$
	weight of 1 hour of overtime in week t	Wot_t
	weight of 1 hour of idle time in week t	Wit_t
decision variables	capacity already booked in week t (in hours)	Cb_t
	remaining capacity in week t (in hours)	Cf_t
	expected future demand of priority i patients in week t (in numbers)	$F_{t,i}$
	number of patients of priority i waiting for n weeks in week t	$WT_{t,n,i}$
	amount of overtime used in week t (in hours)	OT_t
	amount of idle time in week t (in hours)	IT_t
	number of patients of priority i booked in week t, waiting for n weeks	$x_{t,n,i}$
	amount to reserve for patients of priority i on week t (in hours)	$\lambda_{t,i}$

Table 17: Input parameters and decision variables

The objective function is shown in Equation 1 and minimises the total weighted average of the overtime (in hours), the idle time (in hours) and the waiting patients (in hours) per week *t*, per priority level *i* and per weeks of waiting *n*.

$$min \sum_{t,n,i} Wot_t * OT_t + Wit_t * IT_t + Wwt_{n,i} * (WT_{t,n,i} * p_i) \qquad (1)$$

s.t.

$$\sum_{n,i} x_{t,n,i} * p_i + IT_t = Cf_t + OT_t \qquad \forall\, t \in T \qquad (2)$$

$$x_{t,n,i} * p_i \leq WT_{t,n,i} * p_i \qquad \forall\, t \in T, i \in I, n \in N \qquad (3)$$

$$\sum_{t,n} (x_{t,n,i} * p_i) = \sum_{t} (F_{t,i} * p_i) \qquad \forall\, i \in I \qquad (4)$$

$$Cb_t, Cf_t, WT_{t,n,i}, OT_t, IT_t, x_{t,n,i}, \lambda_{t,i} \geq 0 \qquad \forall\, t \in T, n \in N, i \in I \qquad (5)$$

Constraint 2 manages the total capacity formation for every time period: the total number of booked patients plus the idle time should be equal to the capacity still available plus overtime. Constraint 3 ensures that no more patients can be booked than there are waiting (which yields for every time period and every priority level). Constraint 4 ensures that every patient is booked: the sum of all the booked patients should be equal to the sum of the expected future demand, for every priority level. Lastly, the constraint in equation 5 makes sure all decision variables are nonnegative.

4.3.2. Deterministic versus stochastic

The model determines an optimal booking policy for the expected future demand, this expectation can however be modelled in different ways. In the basic version, the input 'demand' is modelled deterministic: it is assumed to be a specific number of hours to be demanded per patient type. In this way, input values are taken, assuming each is certain to happen, and the model provides the optimal output for this demand. This model is easy to understand and can provide a first approximation. There is however another way: stochastic modelling. Stochastic modelling incorporates the uncertainty that comes with future demand. This uncertainty is modelled along with the possible values demand can get by assigning probabilities to each demand value. Since the number and distribution of the type of appointments (the 'appointment mix') and the number of urgent or non-urgent appointments has inherent uncertainty, this way can give a better fit with reality.

To balance accuracy and computational ease a stochastic heuristic approach is chosen. This incorporates the inherent uncertainty of demand as a finite number of scenarios, and is thereby likely to provide better results than the deterministic model. Erdelyi and Topaloglu (2009) confirmed stochastic approximation methods perform consistently better than deterministic approximation for protection levels. The distribution is approximated by providing each scenario with a probability.

In our stochastic heuristic approach, the demand is approximated by forming a scenario tree with low, medium and high scenarios, as can be seen in Figure 16.

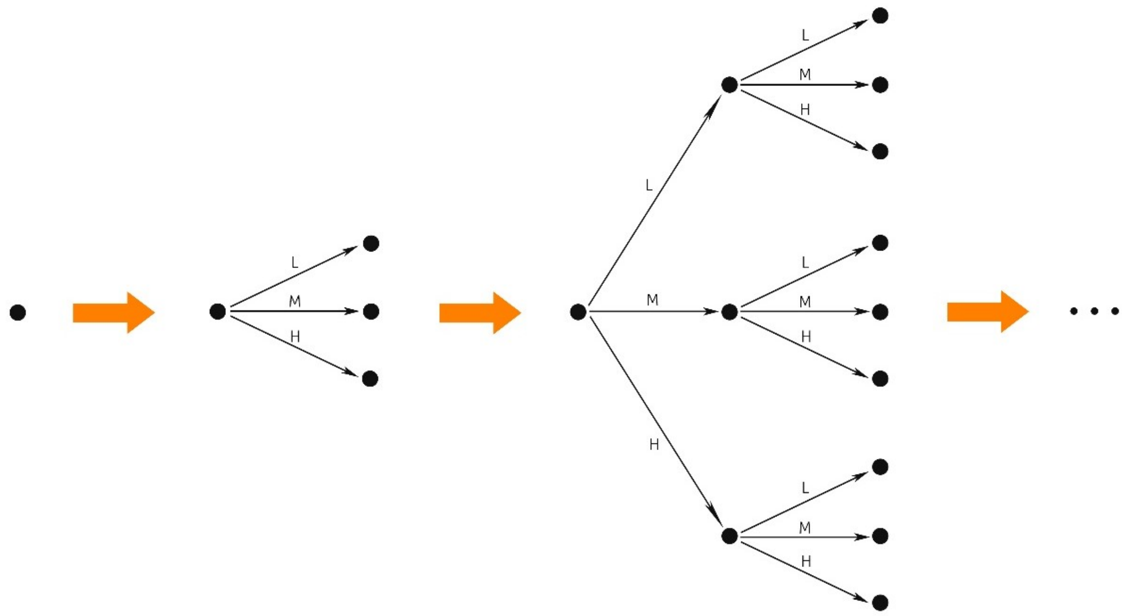

Figure 16: Example of the generated scenario tree

The approximate representation of the demand is generated from historical demand. Emergency patients are taken as standard, as those kinds of patients have the highest priority. Figure 17 shows the histogram of emergency patients of urology in 2015. Looking at the histogram, capturing demand between 10 and 24 arrivals per week seems most relevant. This corresponds with a coverage of 85%.

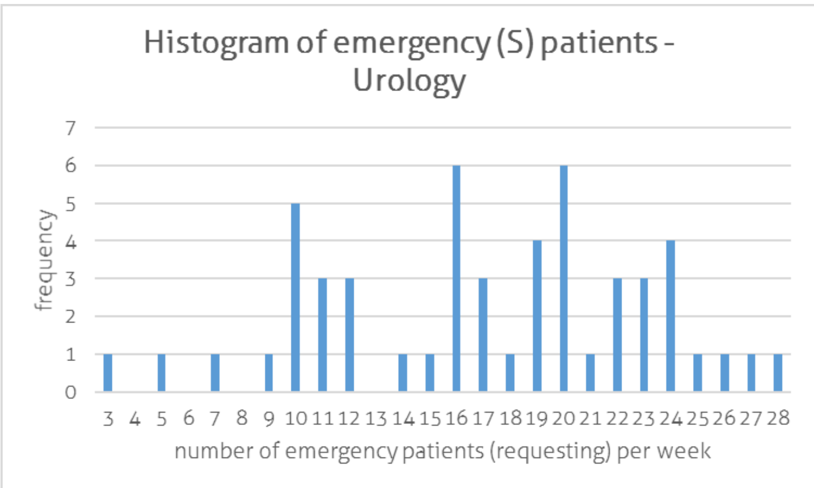

Figure 17: Histogram of emergency patients urology

The range can be divided into three scenarios, resulting in a representation of a low (L), medium (M) and high (H) demand scenario. These scenarios have different branch changes, which are calculated in Table 18. A low scenario covers the range from 10 to 15 patients per week, which corresponds with a 0.3 probability. In the same way, a medium scenario occurs with a 0.4 probability and a high scenario occurs with a 0.3 probability.

scenario	range arrivals (emergency)	total # of patients	probability
low (L)	10 - 15	200	200/813=0.3
medium (M)	16 - 20	361	361/813=0.4
high (H)	21 - 24	252	252/813=0.3
total	*10 - 24*	*813*	*1*

Table 18: Example of calculation branch probabilities

Within those scenarios, the demand is approximated with a uniform distribution. This is shown in Figure 18 and Figure 19. The histograms for the other patient types can be found in Appendix V Histogram chances for all patient types.

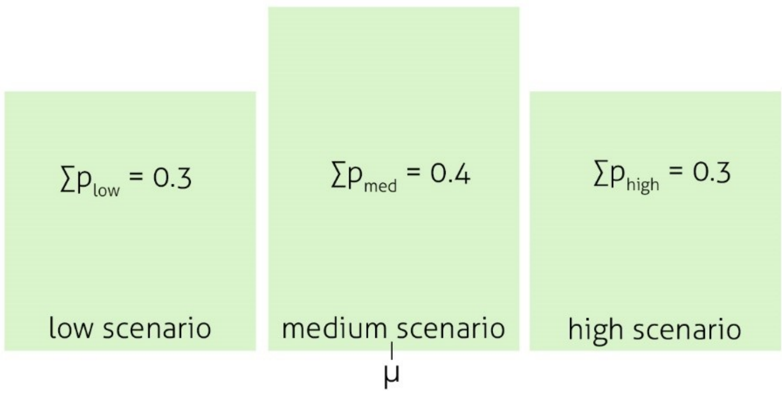

Figure 18: Distribution low, medium and high scenario

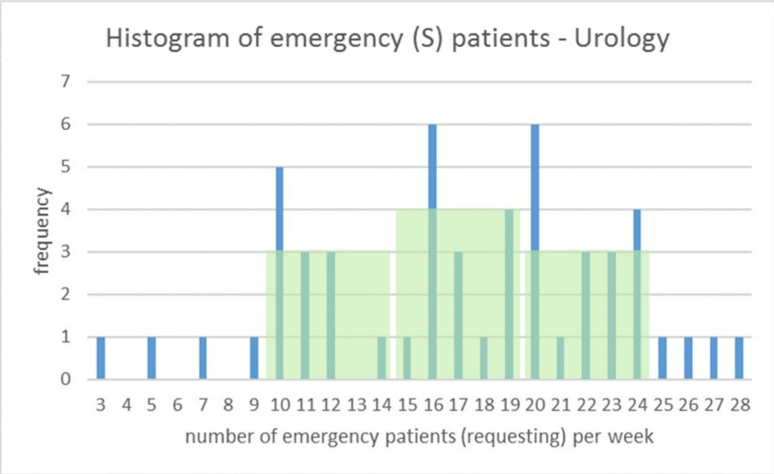

Figure 19: Histogram of emergency patients urology

Furthermore, for each of the three scenarios the interval is presented by a lower bound (LB) and upper bound (UB) probability. The values for the lower and upper bound are determined such that the scenarios capture all demand between 10 and 24 hours per week. The corresponding branch probabilities, lower bound and upper bound values are shown in Table 19. For example, the average number of emergency patients requesting (urology) is 17 (Chapter 4.2.3, Table 11). When multiplying this with the lower and upper bound multipliers, the range becomes 0.6*17=10 and 1.4*17=24 patients per week. This corresponds with the 85% coverage described above.

scenario	branch probability	LB multiplier	UB multiplier
low (L)	0.3	0.6	0.867
medium (M)	0.4	0.867	1.134
high (H)	0.3	1.134	1.4

Table 19: Branch probabilities, lower bound (LB) and upper bound (UB) probabilities

In Figure 20 an example of a scenario tree is given for the first three periods in the planning interval.

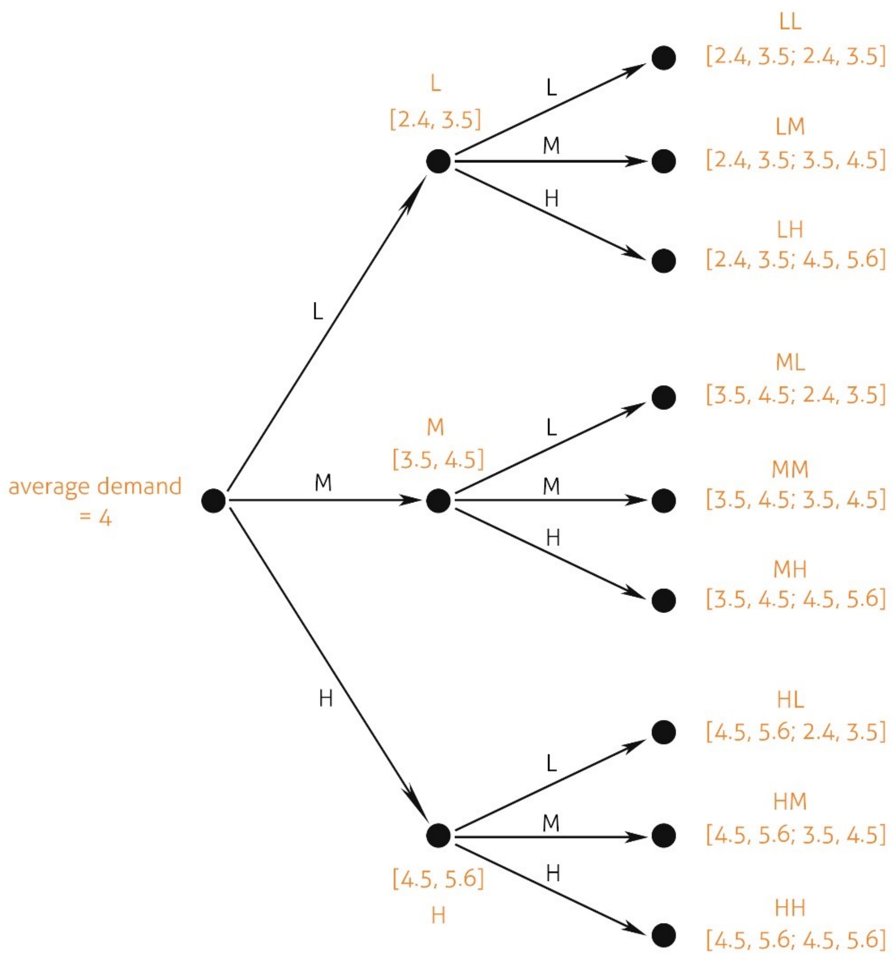

Figure 20: Example of first periods of scenario tree with an average demand of 4 hours

Let's assume that the expected demand in period 1 is 4 hours. For the next period, period 2, three scenarios exist: a low, medium and high scenario. The low scenario has 0.3 probability of happening, and results in a lower bound of 4*0.6=2.4 hours and an upper bound of 4*0.867=3.5 hours. The expected demand in the low scenario lies therefore between 2.4 and 3.5 hours and has 0.3 probability of happening. In the same way, the expected demand in the medium scenario lies between 3.5 and 4.5 hours, and in the high scenario between 4.5 and 5.6 hours. Overall, the deterministic demand of 4 hours results in a possible stochastic demand between 2.4 and 5.6 hours in the second period. In the third period, the demand in the LL scenario is composed of the demand range in the low scenario of the first period plus the demand range in the low scenario of the second period. This result in a range of [2.4, 3.5; 2.4, 3.5].

For each patient type, the stochastic demand is calculated based on the lower and upper bound chance times the deterministic demand (for the deterministic demand see Section 4.2.3). Translating these chances to demand gives the stochastic demand shown in Table 20 and Table 21. For example, at the dermatology specialty, the average expected demand for emergency patients is 2.2 hours. When translating this to stochastic demand, the lower bound for the low scenario becomes 2.2*0.6=1.3 hours. The upper bound for the high scenario becomes 2.2*1.4=3.1 hours. This means the demand of emergency patients is approximated by the interval from 1.3 to 3.1 hours.

patient type	*deterministic demand per week (in hours)*	stochastic demand per week (in hours)					
		low scenario		medium scenario		high scenario	
		LB	UB	LB	UB	LB	UB
S - emergency	*2.2*	1.3	1.9	1.9	2.5	2.5	3.1
N - new	*51.0*	30.6	44.2	44.2	57.8	57.8	71.4
C - check-up	*55.1*	33.1	47.8	47.8	62.5	62.5	77.1
V - outpatient procedure	*26.2*	15.7	22.7	22.7	29.7	29.7	36.7
TC - telephonic consult	*10.5*	6.3	9.1	9.1	11.9	11.9	14.7

Table 20: Demand per week in hours DER for all scenarios

patient type	*deterministic demand per week (in hours)*	stochastic demand per week (in hours)					
		low scenario		medium scenario		high scenario	
		LB	UB	LB	UB	LB	UB
S - emergency	*4.3*	2.6	3.7	3.7	4.9	4.9	6.0
N - new	*31.0*	18.6	26.9	26.9	35.2	35.2	43.4
C - check-up	*64.6*	38.8	56.0	56.0	73.3	73.3	90.4
V - outpatient procedure	*37.8*	22.7	32.8	32.8	42.9	42.9	52.9
TC - telephonic consult	*14.7*	8.8	12.7	12.7	16.7	16.7	20.6

Table 21: Demand per week in hours URO for all scenarios

The input demand in Table 20 and Table 21 together form the set of scenarios that the optimisation model will run. The model calculates the optimal booking formation and the corresponding amount of capacity to reserve for all scenarios. In addition, the model shows the scenario probability: the probability that a particular scenario will happen. Finally, the exact amount to protect each week is calculated by multiplying the scenario output times the probability that this scenario will happen.

4.4. Verification and validation

After building the model, it should be verified and validated. In Figure 21 the difference between verification and validation is shown.

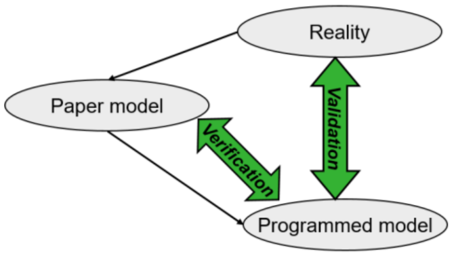

Figure 21: Difference between verification and validation (Mes, 2012)

"Verification is the evaluation whether the system complies with the specification or imposed condition. It is often an internal process." (Project Management Institute, 2008). The verification is done while programming the model (debugging), to make sure all variables are programmed in a correct way. "Validation is the assurance that a system meets the operational needs of the customer and other identified stakeholders. It often involves acceptance and suitability with external customers." (Project Management Institute, 2008). During validation, system output of the model is compared with comparable output data collected from the actual system (Law, 2009).

The model can be validated by means of a data comparison with real data: access time and utilisation. This is presented in Section 5.1. Furthermore, when the model was constructed, regular feedback was gained from stakeholders inside the hospital to validate the choices and constraints. Lastly, the mathematical model is validated by calculating small examples by hand and comparing the results with the mathematical model.

4.5. Conclusions

The mathematical model developed in this research has the main objective of decreasing access times to the outpatient clinic, while optimising the utilisation. Therefore, the weighted average of access time, overtime and idle time is minimised in the model. The model first determines the expected future demand for the coming eight weeks, which is the total expected demand minus the already booked demand. Then, the model suggests an optimal booking policy for this expected future demand. Furthermore, we have developed a stochastic heuristic approach to model the uncertain character of the appointment mix. The demand is approximated by creating a scenario tree with possible demand scenarios.

In the next chapter, the last two steps of the Seven-Step approach will be presented: the experiment design and analysis of the results.

Chapter 5 Experiments

The previous chapter described the first five steps of the Seven-Step approach of Law (the problem definition and model construction). This chapter will elaborate on the last two steps: the experiment design (step 6) and the analysis of the results (step 7) (see Figure 22).

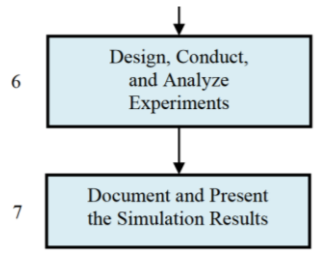

Figure 22: Step 6 and 7 of Seven-Step approach of Law (2009)

The basic scenario and its results are described in Section 5.1. Section 5.2 shows the experiment design (step 6) and Section 5.3 shows the results of the study (step 7). Lastly, Section 5.4 demonstrates practical implementation: a short simulation of the model 'replaying' the past (simulating a part of the year 2015 while using the model).

5.1. Basic scenario

Section 5.1 presents the zero-measurement of the mathematical model. This zero-measurement shows the results of the model when the basic input scenario is used. These results are partly used to validate the mathematical model, as well as to compare the results of the sensitivity analysis with the results of the basic scenario.

5.1.1. Input basic scenario

Table 22 shows the characteristics of the input for the basic scenario. These characteristics are already (partly) presented in the previous chapter but are repeated in this section; a reference to the relevant section is stated in the last column of Table 22 as well.

parameter	data	reference Chapter 4
planning horizon	8 weeks (no holiday weeks)	Section 4.2.3
total available capacity per week	DER: 151 hours URO: 132 hours	Section 4.2.3 Table 14
total expected demand per week	shown in Table 23	Section 4.2.3 Table 13
demand already booked per week	shown in Table 24	-
weight overtime	1 (-)	Section 4.2.3
weight idle time	1 (-)	Section 4.2.3
weight parameters for access time	shown in Table 25	Section 4.2.3 Table 16
scenario probabilities	shown in Table 26	Section 4.3.2 Table 19

Table 22: Input data basic scenario

specialty	emergency (S)	new (N)	check-up (C)	outpatient procedure (V)	telephonic consultation (TC)
dermatology	2.2	51.0	55.1	26.2	10.5
urology	4.3	31.0	64.6	37.8	14.7

Table 23: Total demand per patient type per week in hours

The already booked demand is based on real data. The amount of bookings already made for the 8 coming weeks (in hours) has been extracted from a week in 2015. Those 8 weeks do not concern a holiday week.

week	dermatology					urology				
	S	N	C	V	TC	S	N	C	V	TC
1	-	20	40	25	4	-	12	55	37	3
2	-	15	38	20	2	-	8	44	27	2
3	-	4	34	18	1	-	4	38	20	2
4	-	2	19	15	-	-	2	32	15	1
5	-	2	10	8	-	-	2	19	8	1
6	-	1	5	5	-	-	1	10	5	-
7	-	1	2	2	-	-	1	5	2	-
8	-	1	1	1	-	-	1	2	1	-

Table 24: Already booked demand per patient type per week in hours

# weeks waiting (n)	dermatology					urology				
	S	N	C	V	TC	S	N	C	V	TC
0	-	-	-	-	-	-	-	-	-	-
1	4	-	-	-	1	4	2	-	-	1
2	8	2	-	-	2	8	4	2	2	2
3	16	4	2	2	4	16	8	4	4	4
4	32	8	4	4	8	32	16	7	7	8
5	64	16	7	7	16	64	32	10	10	16
6	128	32	10	10	32	128	64	15	15	32
7	256	64	15	15	64	256	128	25	25	64

Table 25: Weight parameters for access time

scenario	branch chance	LB multiplier	UB multiplier
low (L)	0.3	0.6	0.867
medium (M)	0.4	0.867	1.134
high (H)	0.3	1.134	1.4

Table 26: Scenario probabilities

5.1.2. Results basic scenario

The results of the basic scenario are displayed in the following tables. The main KPIs (Chapter 2.2 Performance) of the St. Antonius Hospital are reviewed: the access time and the utilisation rate.

The access time for dermatology is shown in Table 27 and Table 28. The access time is shown in percentage of respectively total emergency and total new patients. The target for emergency and new patients is being scheduled within 1 and 2 weeks respectively.

emergency patients (S) dermatology	≤ 1 week	≤ 2 weeks	≤ 3 weeks	≤ 4 weeks
target	100%	-	-	-
current situation	94%	98%	99%	100%
model situation	100%	-	-	-

Table 27: Access time of emergency patients dermatology in current and model situation

new patients (N) dermatology	≤ 1 week	≤ 2 weeks	≤ 3 weeks	≤ 4 weeks
target	-	100%	-	-
current situation	40%	70%	88%	94%
model situation	96%	100%	-	-

Table 28: Access time of new patients dermatology in current and model situation

As can be seen in Table 27 and Table 28, the access time in the new situation for dermatology is significantly improved, especially for new patients (from 40% to 96%). In this situation, no overtime is used and the utilisation is 95%. Those results are caused by the weights in the objective function of the model and the optimal booking suggestion. Both patient types fit their target for access time: all emergency patients are being served within 1 week and all new patients are being scheduled within 2 weeks. Lastly, it also fits the target of the Treeknorm.

The access time for urology is shown in Table 29 and Table 30. Both emergency and new patients should be scheduled within 1 week. Again, the access time is shown in percentage of respectively total emergency and total new patients.

emergency patients (S) urology	≤ 1 week	≤ 2 weeks	≤ 3 weeks	≤ 4 weeks
target	100%			
current situation	80%	90%	95%	100%
model situation	100%	-	-	-

Table 29: Access time of emergency patients urology in current and new situation

new patients (N) urology	≤ 1 week	≤ 2 weeks	≤ 3 weeks	≤ 4 weeks
target	100%			
current situation	40%	58%	74%	82%
model situation	100%	-	-	-

Table 30: Access time of new patients urology in current and new situation

Table 29 and Table 30 show that the access time is significantly improved in the new situation. 100% of the emergency patients are scheduled within 1 week and 100% of the new patients can be scheduled within 1 week instead of only 40%. Moreover, the target in the new situation for urology is achieved for both emergency and new patients (both scheduled within 1 week). Lastly, the new situation also matches the targets of the Treeknorm.

For check-up (C), outpatient procedure (V) and telephonic consultation (TC) patients, the access time for the model situation are shown in Table 31-Table 33 (dermatology) and Table 34-Table 36 (urology). The access time in the current situation is not measurable, as those patient types can request an appointment for over for example six weeks. As such, the actual access time for those types of patients cannot be traced down in the current system. However, as said before, we assume that the number of patients who make an appointment this week for over six months is equal to the number of patients who made an appointment six months ago for this week. Therefore, for the modelled situation, we can show the access times and compare it with the target set by the St. Antonius Hospital.

check-up patients (C) dermatology	≤ 1 week	≤ 2 weeks	≤ 3 weeks	≤ 4 weeks
target	-	-	100%	-
check-up (C)	90%	98%	100%	-

Table 31: Access time of check-up patients in model situation dermatology

outpatient procedure patients (V) dermatology	≤ 1 week	≤ 2 weeks	≤ 3 weeks	≤ 4 weeks
target	-	-	100%	-
outpatient procedure (V)	86%	97%	100%	-

Table 32: Access time of outpatient procedure patients in model situation dermatology

telephonic consultation patients (TC) dermatology	≤ 1 week	≤ 2 weeks	≤ 3 weeks	≤ 4 weeks
target	100%	-	-	-
telephonic consultation (TC)	100%	-	-	-

Table 33: Access time of telephonic consultation patients in model situation dermatology

check-up patients (C) urology	≤ 1 week	≤ 2 weeks	≤ 3 weeks	≤ 4 weeks
target	-	100%	-	-
check-up (C)	68%	100%	-	-

Table 34: Access time of check-up patients in model situation urology

outpatient procedure patients (V) urology	≤ 1 week	≤ 2 weeks	≤ 3 weeks	≤ 4 weeks
target	-	100%	-	-
outpatient procedure (V)	68%	100%	-	-

Table 35: Access time of outpatient procedure patients in model situation urology

telephonic consultation patients (TC) urology	≤ 1 week	≤ 2 weeks	≤ 3 weeks	≤ 4 weeks
target	100%	-	-	-
telephonic consultation (TC)	100%	-	-	-

Table 36: Access time of telephonic consultation patients in model situation urology

Table 31-Table 37 shows that most of the check-up and outpatient procedure patients of dermatology are being served within 1 week. The remainder is scheduled within 2 and 3 weeks, which means the access time for those types of patients fits the target of the St. Antonius Hospital. In Table 34-Table 36 the access time for check-up, outpatient procedure and telephonic consultation patients of urology is shown. The target for check-up and outpatient procedure patients is 2 weeks, which is achieved in the new situation. The target for telephonic consultation patients is achieved as well (1 week). Lastly, all access times for both dermatology and urology fit the Treeknorm as well.

The second KPI of the St. Antonius Hospital is the utilisation rate. The utilisation rates for both the current and model situation for dermatology and urology are shown in Table 37.

specialty	current situation	model situation
dermatology	94%	95%
urology	115%	115%

Table 37: Utilisation rate current and new situation

As shown in the table above, the utilisation rate is (almost) the same for the current and new situation for both specialties. An equal utilisation is expected since the same number of patients is seen in the same amount of time and therefore it demonstrates a validation of the mathematical model.

The access time to the outpatient clinic is significantly improved as shown in this section, while the utilisation stayed the same. However, the mathematical model should also function when the utilisation rate for urology is below 100%. Therefore, in the next sections several experiments will be performed to test the sensitivity of the model.

5.2. Experiment design

A sensitivity analysis will be performed on the programmed model to see which factors have the greatest impact on the performance measures. Moreover, we would like to know whether the programmed model is useful when the utilisation of urology drops.

We expect that the arrival rate has a large effect on the access time to the outpatient clinic and that the available capacity has a large effect on the utilisation of the consultation session. Furthermore, we want to analyse the effect of the weights in the objective function on the overall performance. Therefore, the following nine experiments will be executed (Table 38):

experiment	parameter	intervention
1	arrival rate	- 10%
2	arrival rate	+ 10%
3	available capacity	- 10%
4	available capacity	+ 10 %
5	weight overtime	-1 (-)
6	weight idle time	-1 (-)
7	weights overtime and idle time	+ 2 (-)
8	weight parameters for access time	- 1 week
9	weight parameters for access time	+ 1 week

Table 38: Design of experiments

Experiments 1 and 2 concern the incoming demand. These experiments are performed to identify the sensitivity of this parameter to the access time, by changing the parameter with

10% less or 10% more patient arrivals each week. Experiments 3 and 4 concern the available capacity per week. These experiments are performed to measure the effect in case the hospital has respectively 10% less and more capacity available (in terms of available specialists, rooms, equipment, materials, etc.). As said before, these experiments are also needed to evaluate a situation where urology has on average enough capacity, and their weekly demand does not exceed their weekly capacity anymore. The model should function when the average utilisation of a specialty is above 100%, but also when it is below 100%. Experiments 5 – 9 regard the weights of overtime, idle time and access time. These experiments are executed to review the sensitivity of the model according to the weights in the objective function.

Section 5.3 discusses the results of the experiment design.

5.3. Results

The results of the experiment design are discussed per pair of experiments (experiment 1-2, 3-4 and 5-9). The results are compared with the results of the basic scenario and with the targets of the St. Antonius Hospital.

Experiments 1 and 2 model a situation where 10% less and 10% more patients arrive every week. Table 39 and Table 40 show the experiment results for dermatology.

dermatology	patient type	≤ 1 week	≤ 2 weeks	≤ 3 weeks	target
Exp. 1 10% less demand	S	100%	-	-	≤ 1 week
	N	99%	100%	-	≤ 2 week
	C	96%	99%	100%	≤ 3 week
	V	94%	99%	100%	≤ 3 week
	TC	100%	-	-	≤ 1 week
Exp. 2 10% more demand	S	100%	-	-	≤ 1 week
	N	91%	100%	-	≤ 2 week
	C	83%	97%	100%	≤ 3 week
	V	76%	96%	100%	≤ 3 week
	TC	100%	-	-	≤ 1 week

Table 39: Access time in Exp. 1 and Exp. 2 dermatology

dermatology	**utilisation**
Exp. 1	89%
Exp. 2	102%

Table 40: Utilisation in Exp. 1 and Exp. 2 dermatology

The experiments for dermatology show that in both Exp. 1 (10% less patients) and Exp. 2 (10% more patients) all patients are scheduled within their target. Furthermore, compared with the basic scenario, in Exp. 1, the average access time is shorter, and in Exp. 2 the average access time is a bit longer. When fewer patients arrive, the utilisation drops by 6%, while the utilisation increases with 9% when 10% more patients arrive (> 100%). The change in access time and utilisation rate is expected since respectively fewer and more patients should be served in the same amount of available capacity, which will result in respectively a less or more loaded system.

Table 41 shows the access time in these scenarios for urology and Table 42 shows the utilisation rate for urology in these scenarios.

urology	**patient type**	**≤ 1 week**	**≤ 2 weeks**	**≤ 3 weeks**	target
Exp. 1 10% less demand	S	100%	-	-	≤ 1 week
	N	100%	-	-	≤ 1 week
	C	50%	100%	-	≤ 2 week
	V	50%	100%	-	≤ 2 week
	TC	100%	-	-	≤ 1 week
Exp. 2 10% more demand	S	100%	-	-	≤ 1 week
	N	100%	-	-	≤ 1 week
	C	88%	100%	-	≤ 2 week
	V	84%	100%	-	≤ 2 week
	TC	100%	-	-	≤ 1 week

Table 41: Access time in Exp. 1 and Exp. 2 urology

urology	**utilisation**
Exp. 1	108%
Exp. 2	124%

Table 42: Utilisation in Exp. 1 and Exp. 2 urology

Table 41 and Table 42 show that if fewer patients are arriving per week (Exp. 1), the access times for emergency (S), new (N) and telephonic consultation (TC) patients stay the same compared to the basic scenario. The access times also comply with the target of the St. Antonius Hospital and the Treeknorm. Less check-up (C) and outpatient procedure (V) patients are scheduled within 1 week, but the access times still fit the target of the hospital and the Treeknorm. The utilisation rate drops by 7% when fewer patients arrive. When more patients arrive each week (Exp. 2), the access time for emergency (S), new (N) and telephonic consultation (TC) patients again stays the same compared to the basic scenario. More check-up (C) and outpatient procedure (V) patients are being served within 1 week. However, the utilisation increases with almost 10% compared to the basic scenario and the current situation. Again, the change in access time and utilisation rate is expected since respectively fewer and more patients should be served in the same amount of available capacity.

We conclude that the model is sensitive to fluctuations in the arrival rate. The utilisation changes with 6-10% for both specialties when incoming demand varies. However, the access times of all patient types still fit the target in both experiments and for both specialities.
Table 43 - Table 46 show the results of experiment 3 and 4: respectively 10% less and more capacity.

dermatology	patient type	≤ 1 week	≤ 2 weeks	≤ 3 weeks	target
Exp. 3	S	100%	-	-	≤ 1 week
10% less capacity	N	90%	100%	-	≤ 2 week
	C	70%	93%	100%	≤ 3 week
	V	70%	93%	100%	≤ 3 week
	TC	100%	-	-	≤ 1 week
Exp. 4	S	100%	-	-	≤ 1 week
10% more capacity	N	96%	100%	-	≤ 2 week
	C	97%	100%	-	≤ 3 week
	V	93%	99%	100%	≤ 3 week
	TC	100%	-	-	≤ 1 week

Table 43: Access time in Exp. 3 and Exp. 4 dermatology

dermatology	utilisation
Exp. 3	107%
Exp. 4	87%

Table 44: Utilisation in Exp. 3 and Exp. 4 dermatology

The tables above show that with 10% less capacity (Exp. 3), the utilisation increases with 12% because all patients need to have access within their target. When 10% more capacity is available (Exp. 4), the utilisation drops by 8%. All patients are being served within their prescribed access time, however, they are more spread out than in the basic scenario. The change in access time and utilisation rate is expected since the same number of patients should be served within respectively less or more capacity, which will result in respectively a less or more loaded system.

urology	patient type	≤ 1 week	≤ 2 weeks	≤ 3 weeks	target
Exp. 3 10% less capacity	S	100%	-	-	≤ 1 week
	N	100%	-	-	≤ 1 week
	C	94%	100%	-	≤ 2 week
	V	92%	100%	-	≤ 2 week
	TC	100%	-	-	≤ 1 week
Exp. 4 10% more capacity	S	100%	-	-	≤ 1 week
	N	100%	-	-	≤ 1 week
	C	73%	100%	-	≤ 2 week
	V	71%	100%	-	≤ 2 week
	TC	100%	-	-	≤ 1 week

Table 45: Access time in Exp. 3 and Exp. 4 urology

urology	utilisation
Exp. 3	129%
Exp. 4	105%

Table 46: Utilisation in Exp. 3 and Exp. 4 urology

Table 45 and Table 46 show that with 10% less capacity (Exp. 3)), the utilisation increases with more than 10%, as expected. In the case of an increase in capacity of 10% (Exp. 4), the results show that fewer patients are scheduled within 1 week, but all results still fit the targets.

In experiment 4, the utilisation rate drops with 10%. This is particularly interesting since (outside this thesis) the goal for urology is to decrease their utilisation. The model shows that all patients are scheduled within their target when utilisation drops with 10% (10% extra capacity). The change in access time and utilisation rate is also expected here, since the same number of patients should be served within respectively less or more capacity.

We conclude that the model is sensitive to the available amount of capacity every week. When the amount of capacity is decreased, the utilisation increases; and the other way around. However, all patients are being scheduled within their target.

Table 49 and Table 50 show the results of experiment 5-9 regarding the weights in the objective function.

dermatology	patient type	≤ 1 week	≤ 2 weeks	≤ 3 weeks	target
Exp. 5 weight OT - 1	S	100%	-	-	≤ 1 week
	N	96%	100%	-	≤ 2 week
	C	90%	99%	100%	≤ 3 week
	V	85%	98%%	100%	≤ 3 week
	TC	100%	-	-	≤ 1 week
Exp. 6 weight IT - 1	S	100%	-	-	≤ 1 week
	N	96%	100%	-	≤ 2 week
	C	90%	98%	100%	≤ 3 week
	V	85%	98%	100%	≤ 3 week
	TC	100%	-	-	≤ 1 week
Exp. 7 weight OT & IT + 2	S	100%	-	-	≤ 1 week
	N	96%	100%	-	≤ 2 week
	C	90%	98%	100%	≤ 3 week
	V	85%	98%	100%	≤ 3 week
	TC	100%	-	-	≤ 1 week
Exp. 8 weight parameters for access time - 1 week	S	100%	-	-	≤ 1 week
	N	100%	-	-	≤ 2 week
	C	86%	99%	100%	≤ 3 week
	V	84%	99%	100%	≤ 3 week
	TC	100%	-	-	≤ 1 week

Exp. 9 weight parameters for access time + 1 week	S	95%	100%	-	≤ 1 week
	N	94%	99%	100%	≤ 2 week
	C	93%	99%	100%	≤ 3 week
	V	87%	99%	100%	≤ 3 week
	TC	95%	100%	-	≤ 1 week

Table 47: Access time in Exp. 5-9 urology

dermatology	**utilisation**
Exp. 5	96%
Exp. 6	96%
Exp. 7	96%
Exp. 8	96%
Exp. 9	96%

Table 48: Utilisation in Exp. 5-9 urology

For dermatology, when the weight of overtime (Exp. 5) or idle time (Exp. 6) is decreased, or increased (Exp. 7), it has almost no impact on the output of the model. Patients are scheduled in the same way as the basic scenario, and the utilisation stays the same. When the weight for waiting is shifted 1 week up (the target is shifted with 1 week such that patients need to be scheduled sooner) (Exp. 8), we conclude that all patients can be scheduled within the shorter access time target, while the utilisation still stays the same. Also, when the target for the access time is postponed with 1 week (Exp. 9), all patients are scheduled a bit later, while the utilisation rate stays the same.

urology	**patient type**	**≤ 1 week**	**≤ 2 weeks**	**≤ 3 weeks**	target
Exp. 5 weight OT - 1	S	100%	-	-	≤ 1 week
	N	100%	-	-	≤ 1 week
	C	68%	100%	-	≤ 2 week
	V	66%	100%	-	≤ 2 week
	TC	100%	-	-	≤ 1 week
Exp. 6 weight IT - 1	S	100%	-	-	≤ 1 week
	N	100%	-	-	≤ 1 week
	C	50%	100%	-	≤ 2 week
	V	50%	100%	-	≤ 2 week
	TC	100%	-	-	≤ 1 week

Exp. 7 weight OT & IT + 2	S	100%	-	-	≤ 1 week
	N	100%	-	-	≤ 1 week
	C	70%	100%	-	≤ 2 week
	V	68%	100%	-	≤ 2 week
	TC	100%	-	-	≤ 1 week
Exp. 8 weight parameters for access time - 1 week	S	100%	-	-	≤ 1 week
	N	100%	-	-	≤ 1 week
	C	100%	-	-	≤ 2 week
	V	100%	-	-	≤ 2 week
	TC	100%	-	-	≤ 1 week
Exp. 9 weight parameters for access time + 1 week	S	72%	100%	-	≤ 1 week
	N	82%	100%	-	≤ 1 week
	C	74%	94%	100%	≤ 2 week
	V	69%	92%	100%	≤ 2 week
	TC	82%	100%	-	≤ 1 week

Table 49: Access time in Exp. 5-9 urology

urology	**utilisation**
Exp. 5	116%
Exp. 6	108%
Exp. 7	116%
Exp. 8	116%
Exp. 9	116%

Table 50: Utilisation in Exp. 5-9 urology

For urology, when the weight for overtime (Exp. 5) or idle time (Exp. 6) is decreased with 1 (it has no weight now anymore), the results are almost the same as in the basic scenario. The utilisation has slightly increased (1%) when the weight for overtime is decreased. When the weight for idle time is decreased with 1, the utilisation is decreased with 7%. This is expected since the schedule contains more idle time, which results in a lower utilisation. Second, when the weight for overtime and idle time is both increased with 2 (Exp. 7), is has almost no impact on the results. Experiment 7 results in almost the same access times for all patient types (slightly more check-up patients scheduled within 1 week) and almost the same utilisation rate (1% increase) as in the basic scenario. Lastly, experiment 8 and 9 respectively shorten and postpone the weights for waiting with 1 week. In experiment 8, all patients are scheduled within 1 week. This is expected as 1 week waiting gives already a weight for all patient types. The utilisation however, stays almost the same (increase of 1%). If the weight is postponed with 1 week for every patient type (Exp. 9), it shows that fewer patients are being booked within 1 week. However, all patients are being booked within 3 weeks. The utilisation rate stays again almost the same as the basic scenario (1% increase).

We conclude that the model is not very sensitive to the overtime and idle time weights. Both access times and utilisation stay the same as in the basic scenario. More important is the waiting weight, which influences the scheduling of the patients (as expected). However, the utilisation says the same in both experiments (Exp. 8 and 9).

Considering the main KPIs of the St. Antonius Hospital, concluding figures for dermatology and urology are shown in Figure 23 and Figure 24 (access time new patients), and in Figure 25 and Figure 26 (utilisation).

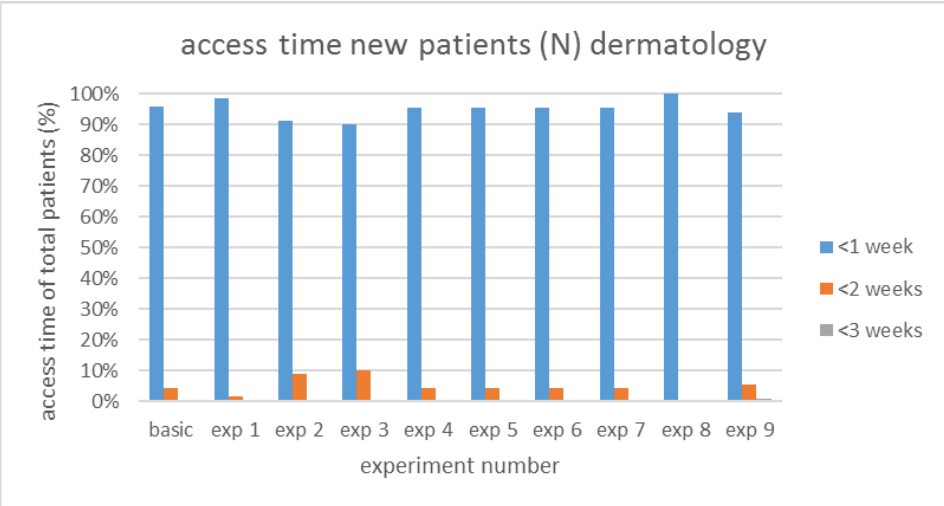

Figure 23: Access time for new patients in % of total patients - per experiment – dermatology

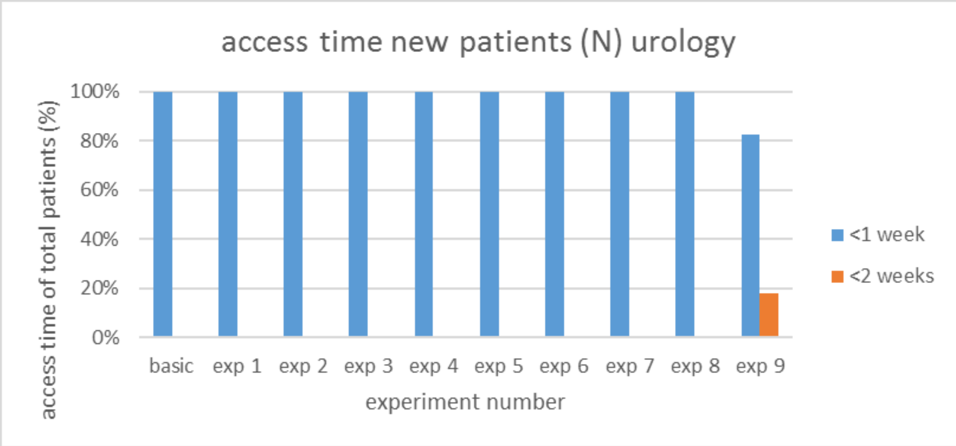

Figure 24: Access time for new patients in % of total patients - per experiment – urology

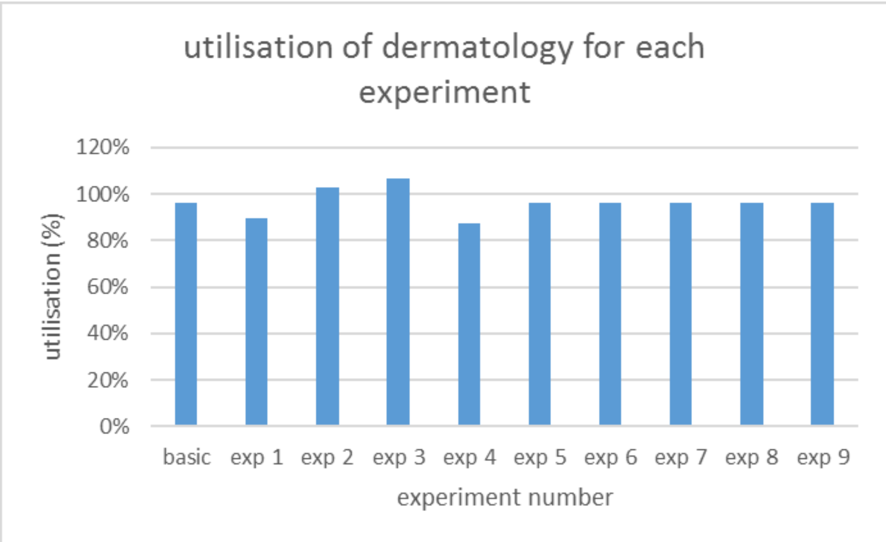

Figure 25: Utilisation rate (%) per experiment – dermatology

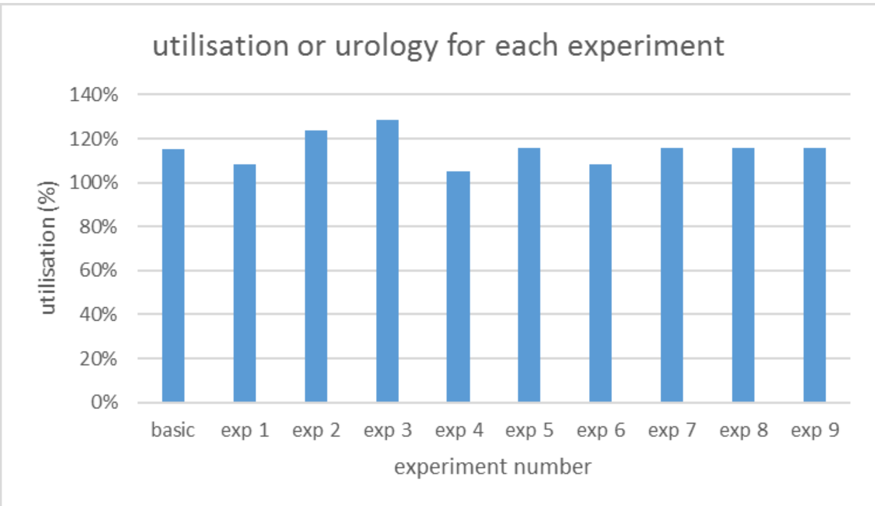

Figure 26: Utilisation rate (%) per experiment – urology

We conclude that in almost all experiments, new patients can be scheduled according to the target (respectively within 2 and 1 week(s)). Only experiment 9 is an exception, however, here the weight is changed and thus the target is shifted by a week. The utilisation of urology remains high (> 100%), but experiment 1 and 4 show a lower rate due to the fact that less patients are arriving (Exp. 1) or that the available capacity is increased (Exp. 4).

5.4. Implementation

For both specialties, a few consecutive weeks are simulated, using data of 2015. Figure 27 shows the first simulation of 8 weeks for dermatology. We start at week 9, which means we are now in week 8 and are simulating for week 9 to 16. A blue line indicates a (school)holiday week. The figure shows the input data in the first columns: the total available capacity (real data from 2015) and the amount already booked per patient type (also real data from 2015: patients who were already booked at week 8 for the 8 coming weeks). The expected future demand is what we expect to still arrive for the coming weeks.

The output of the model is shown in the 'protect' column, which shows the protection level respectively in hours and in percentage of the total available capacity. In the first green column, we see the maximum fill-up (100% minus protection level), which is the target for the fill-up of the outpatient clinic. Based on this target, the outpatient clinic can draw conclusions and take possible actions on the tactical level. In the second green column, the current fill-up is shown (which is the already booked demand divided by the total available capacity). The current fill-up and the target for the fill-up are compared in the last column, where the outpatient clinic can see whether they are on track or some actions should be taken. The meaning of the colour indicators is shown in Figure 28.

	period	total	demand booked						expected demand future						protect		max	fill-up	on track?
		capacity	S	N	C	V	TC	*total*	S	N	C	V	TC	*total*	hours	%	fill-up	now	
now: wk 8	**wk 9**	61,50	0,00	25,50	17,83	1,83	3,08	*48,24*	1,32	5,10	15,23	13,89	3,22	*38,76*	13,26	22%	78%	78%	0%
	wk 10	158,42	0,00	28,00	45,92	17,83	3,50	*95,25*	2,20	23,00	9,18	8,37	7,00	*49,75*	63,05	40%	60%	60%	0%
	wk 11	117,75	0,00	3,58	33,00	21,67	0,17	*58,42*	2,20	47,42	22,10	4,53	10,33	*86,58*	59,33	50%	50%	50%	0%
	wk 12	152,25	0,00	4,25	31,50	16,50	0,83	*53,08*	2,20	46,75	23,60	9,70	9,67	*91,92*	97,8	64%	36%	35%	1%
	wk 13	169,33	0,00	0,67	25,67	16,00	0,42	*42,76*	2,20	50,33	29,43	10,20	10,08	*102,24*	116,82	69%	31%	25%	6%
	wk 14	174,25	0,00	0,00	17,83	0,67	0,00	*18,50*	2,20	51,00	37,27	25,53	10,50	*126,50*	138,42	79%	21%	11%	10%
	wk 15	106,25	0,00	0,00	0,00	1,33	0,08	*1,41*	2,20	51,00	55,10	24,87	10,42	*143,59*	117,85	111%	-11%	1%	-12%
	wk 16	139,50	0,00	0,00	6,83	1,00	0,00	*7,83*	2,20	51,00	48,27	25,20	10,50	*137,17*	169,35	121%	-21%	6%	-27%

Figure 27: Simulation week 9-16 (2015) dermatology

	> 10% underutilisation
	0-10% underutilisation
	10-20% capacity shortage
	> 20% capacity shortage

Figure 28: Colour indicators

In the simulation of the first 8 weeks, the model shows that in week 13 and 14 still some capacity is left. For example, in week 13, 25% of the capacity is already filled, while the outpatient clinic could have scheduled up to 31% according to the model (Figure 29). The green indicator in the last column shows that 6% capacity is still available to schedule right now (week 8). Thus, at this moment (week 8), the outpatient clinic can schedule more patients in week 13 and 14 than they did now already (respectively 6% and 10% more).

max fill-up	fill-up now	on track?
78%	78%	0%
60%	60%	0%
50%	50%	0%
36%	35%	1%
31%	25%	6%
21%	11%	10%
-11%	1%	-12%
-21%	6%	-27%

Figure 29: Zoom in week 13 and 14 dermatology

Furthermore, the figure shows that at the end of the planning horizon, week 15 and 16, we expect capacity shortage (Figure 30). The output shows that the maximum fill-up is below zero (respectively -11% and -21%), which means that we expect more patients to arrive than there is available capacity.

max fill-up	fill-up now	on track?
78%	78%	0%
60%	60%	0%
50%	50%	0%
36%	35%	1%
31%	25%	6%
21%	11%	10%
-11%	1%	-12%
-21%	6%	-27%

Figure 30: Zoom in week 15 and 16 dermatology

Based on these numbers, tactical decisions can be made during a TPO (Tactical Planning Meeting). For example, a possible action for dermatology now is to cancel a few capacity-hours of week 14 (where we expect that the capacity will not be totally filled-up), and add these hours to week 15 or 16 (where we expect to have insufficient capacity). Of course, other factors must be taken into account, such as the schedule of the specialists, available rooms, equipment, etc.

For urology, Figure 31 shows the first simulation round, which presents results similar to the ones of dermatology.

	period	total capacity	demand booked						expected deman future						protect		max fill-up	fill-up now	on track?
			S	N	C	V	TC	*total*	S	N	C	V	TC	*total*	hours	%			
now: wk 8	**wk 9**	81,58	0,00	16,50	36,17	13,58	8,58	*74,83*	2,58	2,10	2,59	9,10	0,24	*16,61*	4,92	6%	94%	92%	2%
	wk 10	172,67	0,00	14,75	50,00	37,67	6,83	*109,25*	4,30	16,25	14,60	0,13	7,87	*43,15*	55,68	32%	68%	63%	4%
	wk 11	129,42	0,00	5,67	41,92	31,33	2,67	*81,59*	4,30	25,33	22,68	6,47	12,03	*70,81*	48,22	37%	63%	63%	0%
	wk 12	135,42	0,00	6,33	35,00	19,00	0,92	*61,25*	4,30	24,67	29,60	18,80	13,78	*91,15*	76,2	56%	44%	45%	-2%
	wk 13	164,33	0,00	3,67	24,58	13,92	0,75	*42,91*	4,30	27,33	40,02	23,88	13,95	*109,49*	117,79	72%	28%	26%	2%
	wk 14	166,42	0,00	2,00	17,75	12,42	0,67	*32,83*	4,30	29,00	46,85	25,38	14,03	*119,57*	129,76	78%	22%	20%	2%
	wk 15	112,92	0,00	0,00	1,33	1,00	0,17	*2,50*	4,30	31,00	63,27	36,80	14,53	*149,90*	128,22	114%	-14%	2%	-16%
	wk 16	155,17	0,00	0,00	0,50	0,00	0,00	*0,50*	4,30	31,00	64,10	37,80	14,70	*151,90*	190,93	123%	-23%	0%	-23%

Figure 31: Simulation week 9-16 (2015) urology

The complete simulation for both specialties can be found in Appendix VI Simulation. The complete simulation run shows that in every simulation period, urology has insufficient capacity to meet the expected arrivals. This matches the idea that urology has a capacity problem (overutilisation).

Concluding, the model shows whether there is a shortage of capacity expected (depending on the amount of demand already booked) and whether there is underutilisation expected. Based on this expectation, the St. Antonius Hospital can make decisions on a tactical level. Moreover, the output can be used to decide on specific cases: is it possible that a specialist has an extra day-off in a particular week? Or does the indicator show that we expect capacity shortage in that week, so it gets worse when this specialist has a day-off? The head of the outpatient clinic can be more critical towards the specialists in those weeks when capacity shortage is expected. Lastly, the output can be used to compare facilities like the OR-facility and the outpatient clinic. If for example the OR-facility has a shortage in week 13, but the outpatient clinic has expected underutilisation in week 13, a movement of a doctor from the outpatient clinic to the OR can help both facilities. Other aspects should be kept in mind of course, like the equipment, available rooms, etc.

Big improvements in terms of access time are possible based on the output of the model. A shortage of capacity will result in longer access times and/or overutilisation, but when this shortage is expected upfront, decisions can be made and actions can be taken to prevent or at least minimise the effect of the shortage. In this way, access times can be decreased, which results in better medical outcomes and higher patient satisfaction.

5.5. Conclusions

This chapter presented the experiment design and results of the analysis. We conclude that the model is sensitive to fluctuations in the arrival rate. The utilisation changes with 6-10% for both specialties when incoming demand varies. However, the access times of all patient types still fit the target in both experiments and for both specialities. We also conclude that the model is sensitive to the available amount of capacity every week. When the amount of capacity is decreased, the utilisation increases; and the other way around. However, all patients are being scheduled within their target. The sensitivity to the arrival rate and available capacity is expected, since it results in respectively a less and more loaded system. Lastly, we conclude that the model is not very sensitive to the overtime and idle time weights. Both access times and utilisation stay the same as in the basic scenario. More important is the waiting weight, which influences the scheduling of the patients. However, the utilisation says the same in both experiments.

The model is tested for practical use for several weeks with real data from 2015. The model shows whether there is a shortage of capacity expected (depending on the amount of demand already booked) and whether there is underutilisation expected. Based on this expectation, the St. Antonius Hospital can make decisions on a tactical level.

Chapter 6 Conclusion

Chapter 6 presents the conclusion of the research (Section 6.1) and gives recommendations for future research (Section 6.2).

6.1. Conclusions

The research in this report had the following objective:

"To define a reservation level for the consultation hours for the coming eight weeks to be able to schedule all patients within their desired access time."

The research was conducted as a case study for the specialities dermatology and urology. First, a context analysis was done which showed that it is unknown how many appointment slots can be scheduled for the coming eight weeks and how many need to be reserved for future appointment requests. Also, the analysis showed that the utilisation of urology is over 100%. However, we took this as an input to the process and defined the model in such a way that it is also applicable in the future, if urology has less than 100% utilisation.

The mathematical model is developed as a stochastic heuristic approach, to deal with the uncertain character of future demand. The output of the model gives the St. Antonius hospital 'protection levels' for the upcoming eight weeks: an amount of capacity they need to reserve each week. The mathematical model is analysed based on the main KPIs of the St. Antonius Hospital: access time and utilisation. The output of the model shows that in a basic scenario, the utilisation matches the current utilisation for both specialties. Moreover, all patients have access to the consultation sessions within their prescribed access time. The access time for emergency and new patients are shown in Table 51-Table 54: for dermatology, all emergency patients are being served within 1 week (6% improvement) and all new patients are being served within 2 weeks (30% improvement). For urology, all emergency and new patients are being scheduled within 1 week, which is an improvement of respectively 20% and 60%.

Experiments show that the mathematical model is most sensitive to the arrival rate and available capacity, as well as to the weight parameters for the access time (based on the target for access time). If the arrival rate or available capacity changes, the thresholds will also change. With less capacity available and/or more demand arriving, the utilisation will increase (sometimes the utilisation becomes more than 100%). With 10% more capacity of 10% less demand, the utilisation increases with 6-10% compared to the basic scenario. On the other hand, with more capacity available and/or less demand arriving, the utilisation decreases with 10-15%.

emergency patients (S) dermatology	≤ 1 week	≤ 2 weeks	≤ 3 weeks	≤ 4 weeks
target	100%	-	-	-
current situation	94%	98%	99%	100%
model situation	100%	-	-	-

Table 51: Access time of emergency patients dermatology in current and model situation

new patients (N) dermatology	≤ 1 week	≤ 2 weeks	≤ 3 weeks	≤ 4 weeks
target	-	100%	-	-
current situation	40%	70%	88%	94%
model situation	96%	100%	-	-

Table 52: Access time of new patients dermatology in current and model situation

emergency patients (S) urology	≤ 1 week	≤ 2 weeks	≤ 3 weeks	≤ 4 weeks
target	100%			
current situation	80%	90%	95%	100%
model situation	100%	-	-	-

Table 53: Access time of emergency patients urology in current and new situation

new patients (N) urology	≤ 1 week	≤ 2 weeks	≤ 3 weeks	≤ 4 weeks
target	100%			
current situation	40%	58%	74%	82%
model situation	100%	-	-	-

Table 54: Access time of new patients urology in current and new situation

The model can be applied to other specialties easily. Input parameters are available capacity (real time data, known at the specialty); already booked demand (real time data, known at the specialty) and weights for overtime, idle time and access time (also determined by the specialty). Furthermore, a data analysis should be done to analyse the arrival rate and model it accordingly.

The suggestion for the St. Antonius Hospital is to use the reservation level as a target for the planned utilisation during a TPO (Tactical Planning Meeting). The hospital now knows how many appointment slots still can be scheduled and how many need to be reserved for future appointment requests. Tactical decisions, like expansion of available capacity, can be made based on this target such that the hospital is able to schedule all patients within their prescribed access time. The model shows whether there is a shortage of capacity expected (depending on the amount of demand already booked) and whether there is underutilisation expected. Based on this expectation, the St. Antonius Hospital can make decisions on a tactical level. Those decisions can decrease the access times to the outpatient clinics, which will result in better medical outcomes, patient satisfaction and financial stability.

6.2. Recommendations

The research presented in this thesis has limitations and further research might improve accuracy and results. Recommendations to further improvements will be discussed in this section.

First, the model developed in our research is a heuristic, which works as an approximation open to further improvement. Our model fails to guarantee the *optimal* solution to reserve each week, as the heuristic only *approximates* the demand probabilities and the corresponding reservation levels. Therefore, the model can be further investigated for optimality. An option for improving is the continuous addition of current data, which will result in an ever-improving forecast. Also, forecasting methods can be used that include additional parameters, like official holidays or weather factors (flu season). Moreover, the number of scenarios can be enlarged (not only a low, medium and high scenario but defining more in-between values), or even development to a fully stochastic optimisation model. Another option is to improve the fit of the current distribution (uniform distribution), which is used to model the demand within each scenario. Lastly, in our research, the same arrival distribution (although with varying averages) is taken for each patient type to balance between specific cases (specific patient types) and a scientific generic case. Specific approximations per patient type would reflect the real world scenarios better, and thus are likely to give more accurate results.

Second, weights in the objective function are determined based on interviews at the outpatient clinic. However, these interviews do not cover all management support for the decision making it reflects. Future research can create wider support from the management of the hospital by wider coverage.

Third, patient preferences are not considered in this research, while in reality patients may ask for specific dates or weeks. Whether and how patient preferences impact planning expectations are recommended to further analyse in future research.

Furthermore, this research is developed as a case study for dermatology and urology. The model should be tested for other specialties and other hospitals to understand the wider applicability of the model.

Lastly, the model should be tested in practise for several weeks. In that way, we can observe to what extent the output fits reality, whether the output of the model is useful and whether the results can help decreasing the access time to the outpatient clinic.

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Appendices

I. Complete list of appointment types

CALLHUID	Controle allergie huiduitslag
CALLINSE	Controle allergie insectensteek
CALLKIND	Controle allergie kind
CALLMEDI	Controle allergie medicijnen
CALLONBE	Controle allergie oorzaak onbekend
CALLVOED	Controle allergie voeding
CHUID	Controle huid
CJAARCON	Controle jaarlijks steunkous
CPDT	Controle PDT
CPLAKPR	Controle plakproef
CSEHDER	Controle spoedeisende hulp (Dermat)
CSPOED	Controle spoed
DBBIOLOG	DB Biological verrichting
DBCJENEC	DB Jeuk/eczeem consult
DBCONBIO	DB Biological controle
DBECZEEM	DB Eczeem behandeling algemeen
DBECZHV	DB Eczeem handen / voeten behandeling
DBPSORIK	DB Psoriasis behandeling kort
DBPSORIL	DB Psoriasis behandeling lang
HERHREC	Herhaalrecept
ICC	Intercollegiaal consult
MOHS	Mohs Chirurgie
NACNE	Nieuw acne
NALGCOL	Nieuw algemeen consult
NALLHUID	Nieuw allergie huiduitslag
NALLINSE	Nieuw allergie insectensteek
NALLKIND	Nieuw allergie kind
NALLMEDI	Nieuw allergie medicijnen
NALLNIES	Nieuw allergie niesbuien/jeukende ogen
NALLONBE	Nieuw allergie oorzaak onbekend
NALLVOED	Nieuw allergie voeding
NCOMBALK	Nieuw combinatie allergie kind
NDVT	Nieuw diep veneuze trombose
NHAARNA	Nieuw haar- of nagelafwijkingen
NHUID	Nieuw huid
NMAGHUID	Nieuw (pre) maligne huidafwijkingen
NPSOECZ	Nieuw psoriasis/eczeem
NSEHDER	Nieuw spoedeisende hulp (Dermat)
NSOA	Nieuw seksueel overdraagb. aandoeningen
NSPOED	Nieuw spoed
NULCUS	Nieuw ulcus cruris
NWRAT	Nieuw wratten
Ormed	DB Orale medicatie
PROVTEST	DB Provocatietest
TCUITSLA	Telefonisch consult uitslagen
TCVRAGEN	Telefonisch consult vragen

VAANMZW1	V aanmeten met zwachtel 1 been
VAANMZW2	V aanmeten met zwachtel 2 benen
VAANZZW1	V aanmeten zonder zwachtel 1 been
VAANZZW2	V aanmeten zonder zwachtel 2 benen
VACNEBEH	V acne behandeling
VAFLDES	V aflezen desensibilisatie
VATOLEES	V aflezen atopietest
VATOTEST	V atopietest
VBIOPT	V biopt afnemen
VBOTOX	V botox
VCAMOTHE	V camouflage therapie
VCOAGUL	V coaguleren
VCURET	V curetteren
VDEROOF	V deroofing
VDESENSI	V desensibilisatie
VEXCISBE	V excisie benigne
VEXCISMA	V excisie maligne
VHECHTVW	V hechtingen verwijderen
VHECHVAI	V Hechtingen verw met arts incl. uitslag
VLICHTHE	V lichttherapie
VLIPBIOP	V lipbiopt
VOEDEEM	V oedeemtherapie/ man lymfedrainage
VPDTLAM1	V PDT belichten 1 veld
VPDTLAMM	V PDT belichten meerdere velden
VPDTZAL1	V PDT inzalven 1 veld
VPDTZALM	V PDT inzalven meerdere velden
VPLAKPR	V plakproef aanbrengen
VPLAKVW	V plakproef verwijderen
VSTEUNPS	V steunkousen passen
VVBEAM	V V-Beam laser behandeling
VVBEAMA	V V-Beam laser behandeling (arts)
VWONDVER	V wondverzorging
VWRAT	V wratten aanstippen
VYAGLAS	V Yaglaser behandeling
VYAGLASA	V Yaglaser behandeling (arts)
VZMW1BAI	V ZW .m wond 1 been arts incl. beleid
VZMW2BAI	V ZW. m wond 2 benen arts incl. beleid
VZWMW1BN	V zwachtelen met wonden 1 been
VZWMW2BN	V zwachtelen met wonden 2 benen
VZWZW1BN	V zwachtelen zonder wonden 1 been
VZWZW2BN	V zwachtelen zonder wonden 2 benen
VZZW1BAI	V ZW. z wond 1 been arts incl. beleid
VZZW2BAI	V ZW.z wond 2 benen arts incl. beleid

Figure 32: Appointment types of dermatology

BBCFYSIO	BBC fysiotherapie
BBCINT	BBC intake
CANDROLO	Controle andrologie
CCONT	Controle continentie
CCYSTECT	Controle na cystectomie OK operateur
CKIND	Controle kind
CKINDINC	Controle kind incontinentie
CMRINUPA	Controle na MRI/Nucleaire/PA
CNACRYON	Controle na cryo nier OK operateur
CNACTECH	Controle na CT-scan/echo/X-foto
CNALANEF	Controle na lap nefrectomie OK operateur
CNAOPNEF	Controle na open nefrectomie OK operateu
CNARALP	Controle na RALP OK operateur
CNOK	Controle na OK eigen uroloog
CNOKIND	Controle na OK kind eigen uroloog
COCYSTEC	Controle onco cystectomie gesprek
COLAPNEF	Controle onco lap nefrectomie gesprek
COLYMDIS	Controle onco lap lymf dissectie gesprek
CONEFREC	Controle onco open nefrectomie gesprek
CONTROLE	Controle
CORALP	Controle onco RALP gesprek
CSEHURO	Controle spoedeisende hulp (uro)
CSPOED	Controle spoed < 24 uur
CTI	Controle ter inzage
KLINPAPO	Klinische patient op poli
MAILCONT	Mailconsult
NANDROLO	Nieuw andrologie
NBBC	Nieuw bekkenbodem
NEXRAD	Nieuw extern radiotherapeut
NIEUW	Nieuw
NKIND	Nieuw kind
NMRINUPA	Nieuw na MRI/Nucleaire/PA
NOCRYON	Nieuw onco cryo nier gesprek
NOCYSTEC	Nieuw onco cystectomie gesprek
NOLAPNEF	Nieuw onco lap nefrectomie gesprek
NOLYMDIS	Nieuw onco lap lymf dissectie gesprek
NONEFREC	Nieuw onco open nefrectomie gesprek
NORALP	Nieuw onco RALP gesprek
NSEHURO	Nieuwe spoedeisende hulp (uro)
NSPOED	Nieuw spoed < 24 uur
NWCONT	Nieuw continentie
TC	Telefonisch consult
TCANDRO	Telefonisch consult andrologie
TCVPK	Telefonisch consult verpleegkundige
UROBPBBC	Urologie beoordeling patiënt BBC
VBTC	Voorbereiding TC
VCATHWIS	Catheterwissel
VCYSDIL	Cystoscopie en dilatatie
VCYSTBS	Cystoscopie na blaasspoeling
VCYSTOSC	Cystoscopie
VCYSTRUM	Cystoscopie en trus min
VCYSTRUP	Cystoscopie en trus plus
VDILATAT	Dilatatie
VDORSALS	Dorsal slit
VFRENULU	Frenulumplastiek
VFRENULU	Frenulumplastiek
VPKANDRO	Prikinstructie Andrologie
VPKBLSSP	Verpleegkundige blaasspoeling
VPKCATHW	Verpleegkundige catheterwissel
VPKONCO	Verpleegkundige onco controle
VPKPTNS	Verpleegkundige PTNS
VPKTI	Verpleegkundige ter inzage
VPKUDO	Verpleegkundige UDO
VTRUSM	Trus min
VTRUSP	Trus plus
VVAS	Vasectomie
VVASSV	Vasectomie single visit

Figure 33: Appointment types of urology

II. TPO sheet example

St. Antonius Ziekenhuis					
TPO Urologie					
Bezetting/Benutting poli					
Week 10					
Vooruit kijken					
		Real	**Plan**		
Bezetting poli # spreekuren (in uren)	Periode 1 (week 11 tm week 14)	707	766	-59	**-7,7%**
	Periode 2 (week 15 tm week 18)	540	567	-28	**-4,9%**
	totaal	*1247*	*1333*	-86	**-6,5%**
Verklaring:					
Blokkades: # uren geblokkeerd	Periode 1 (week 11 tm week 14)	133			
	Periode 2 (week 15 tm week 18)	78			
				Norm benutting:	
		Real	**Norm**	*Uitkomst onderzoek Irene*	
Benutting spreekuren	% Vulling volgende week	87%	?		
	% Vulling over 2 weken	77%	?		
Toegangstijd (in dagen)	Nieuw	13	7		
	Controle	13	7		
Terug kijken (1 januari tm afgelopen week)					
		Real	**Plan**		
Bezetting poli (aanbod)	# Spreekuren 2017 (uren)	1497	1696	-199	**-11,7%**
	# Spreekuren 2016 (uren)	1520	1477	43	**2,9%**
		Real	**Norm**		
Benutting spreekuren (vraag)	% Vulling 2017	102%	90%		
	% Vulling 2016	99%	90%		
		2017	**2016**		
Productie (aantallen)	1e consulten	1296	1571	-275	-17,5%
	Herhaalconsulten	3638	3966	-328	-8,3%
	Verrichtingen	1652	1462	190	13,0%
	# herhaalconsults per 1e consult	2,81	2,52	0,28	11,2%

Figure 34: TPO sheet urology week 10 2017

III. Literature review queries

search engine	query	subject area	# results	included
Google Scholar	outpatient scheduling healthcare review		45.000	(Cayirli & Veral, 2003) (Gupta & Denton, 2008)
Scopus	ALL(protection level scheduling allocating) AND(health care)		15	(Sauré, Patrick, Tyldesley, & Puterman, 2012)
Scopus	ALL(protection level computing) AND(clinic patients) AND (revenue management)	LIMIT-TO (SUBJAREA,"ENGI ") OR LIMIT-TO (SUBJAREA,"COMP ") OR LIMIT-TO (SUBJAREA,"MATH ") OR LIMIT-TO (SUBJAREA,"DECI ")	6	(Erdelyi & Topaloglu, 2009)

Reference search from (Erdelyi & Topaloglu, 2009).

IV. 40% holiday drop calculation

Holiday drop calculation, based on the school holiday weeks in 2015 (n=4). Normal weeks represent the remaining weeks of 2015 (n=48).

dermatology	average appointments per week (in hours)
normal weeks	151
holiday weeks	95
percentage difference	63%
drop due to holiday	37%

Table 55: Holiday drop dermatology

urology	average appointments per week (in hours)
normal weeks	160
holiday weeks	101
percentage difference	63%
drop due to holiday	37%

Table 56: Holiday drop urology

V. Histogram chances for all patient types

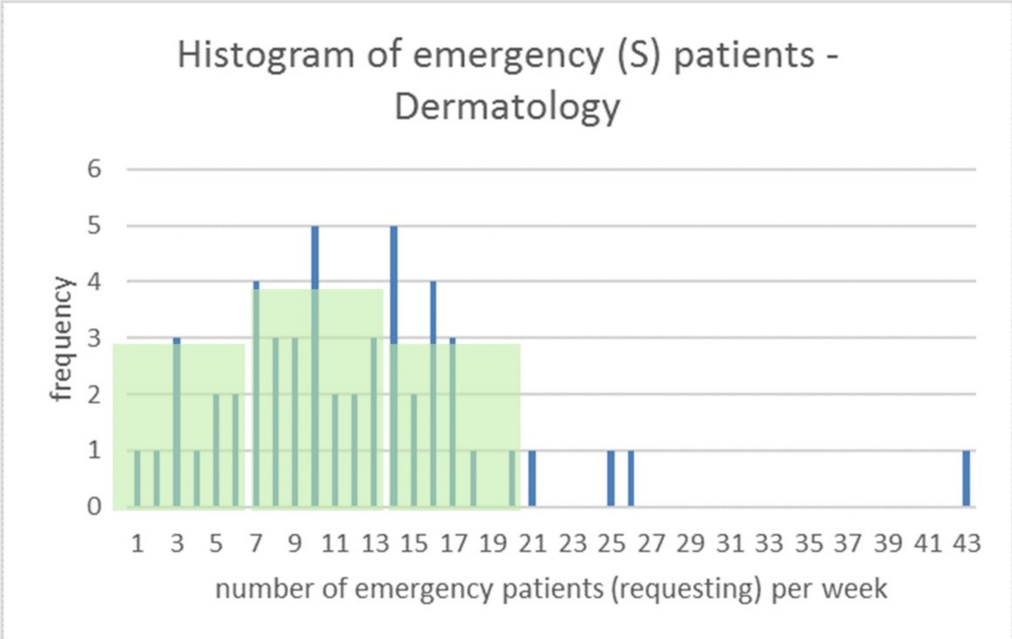

Figure 35: Histogram S dermatology

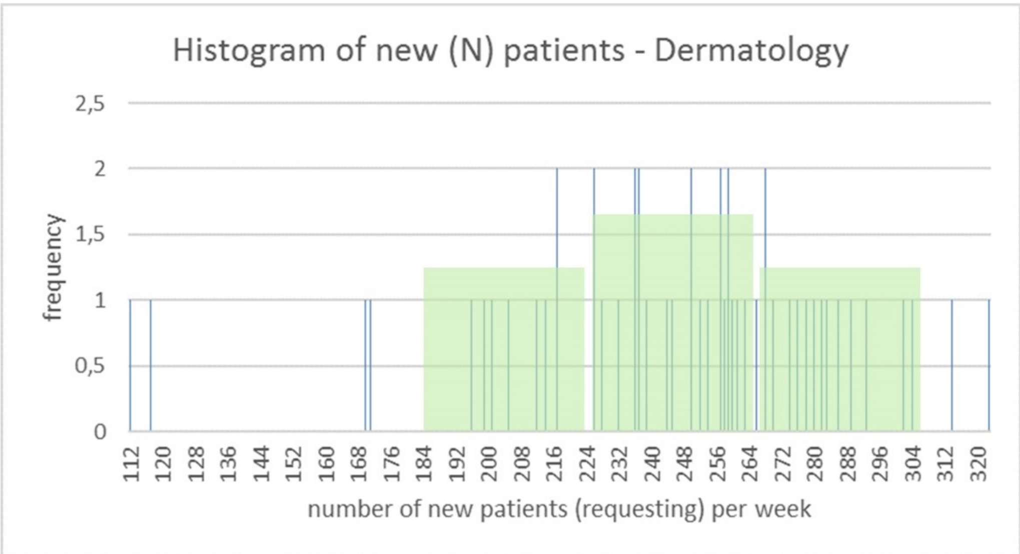

Figure 36: Histogram N - dermatology

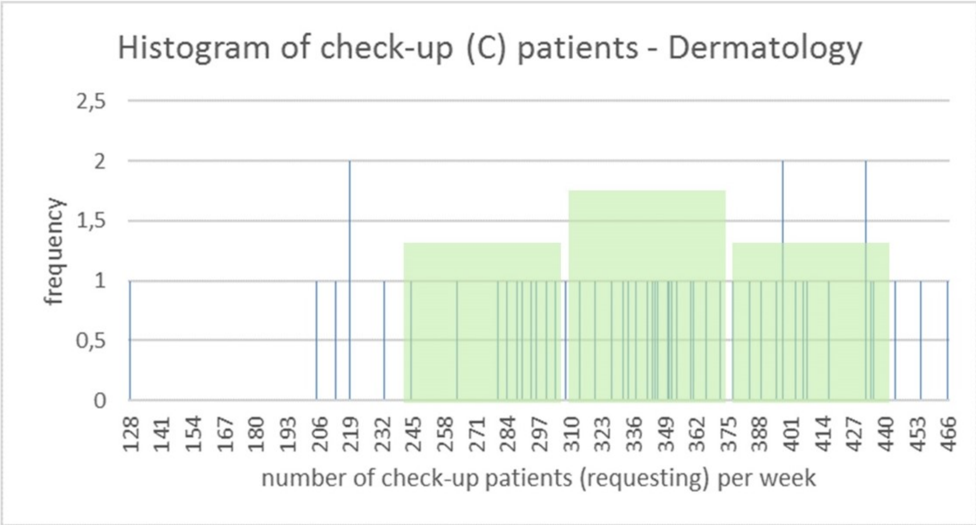

Figure 37: Histogram C - dermatology

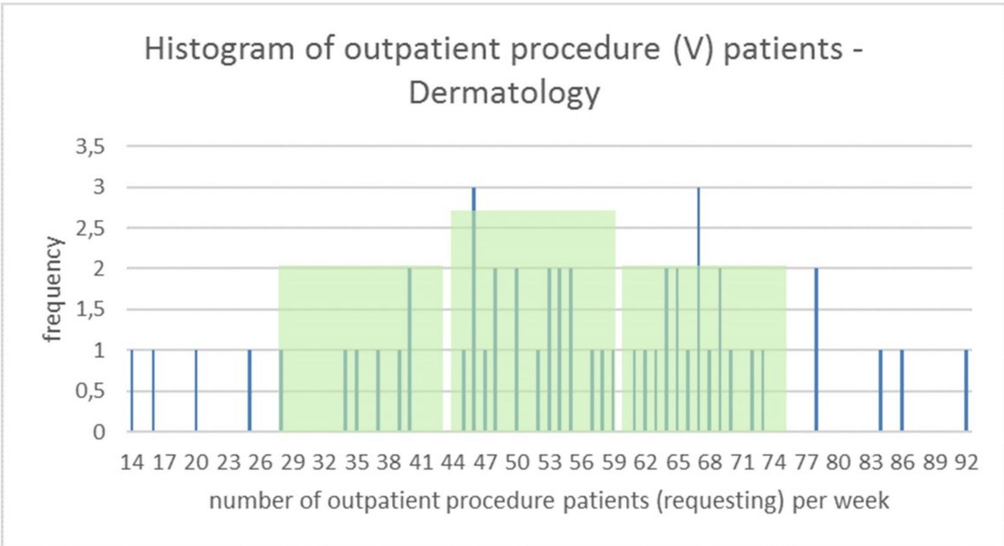

Figure 38: Histogram V - dermatology

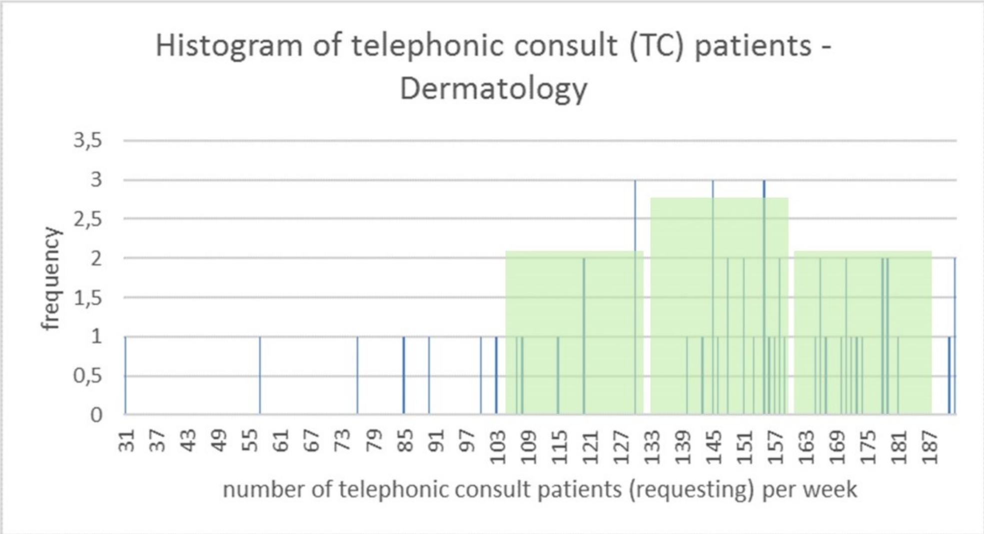

Figure 39: Histogram TC - dermatology

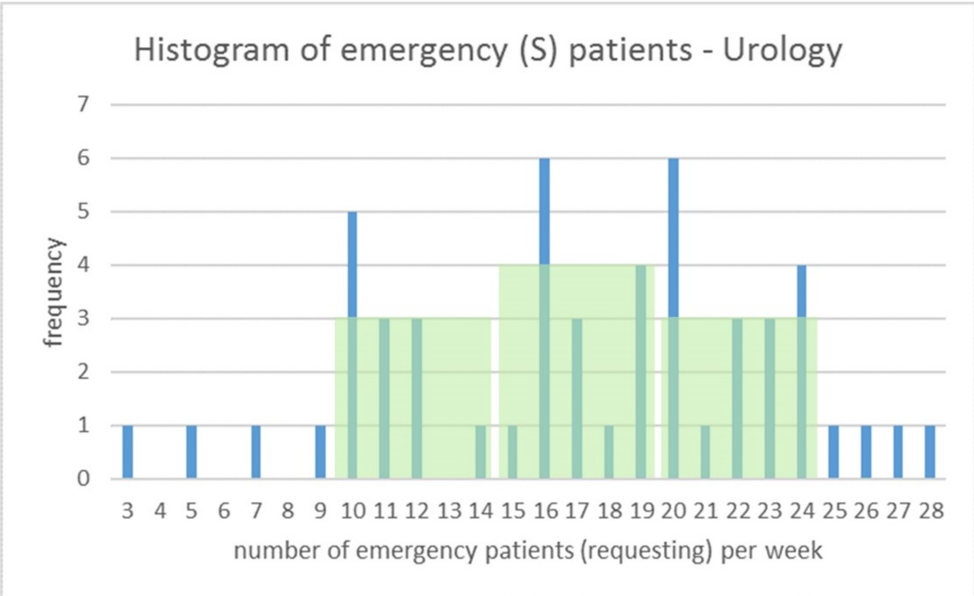

Figure 40: Histogram S - urology

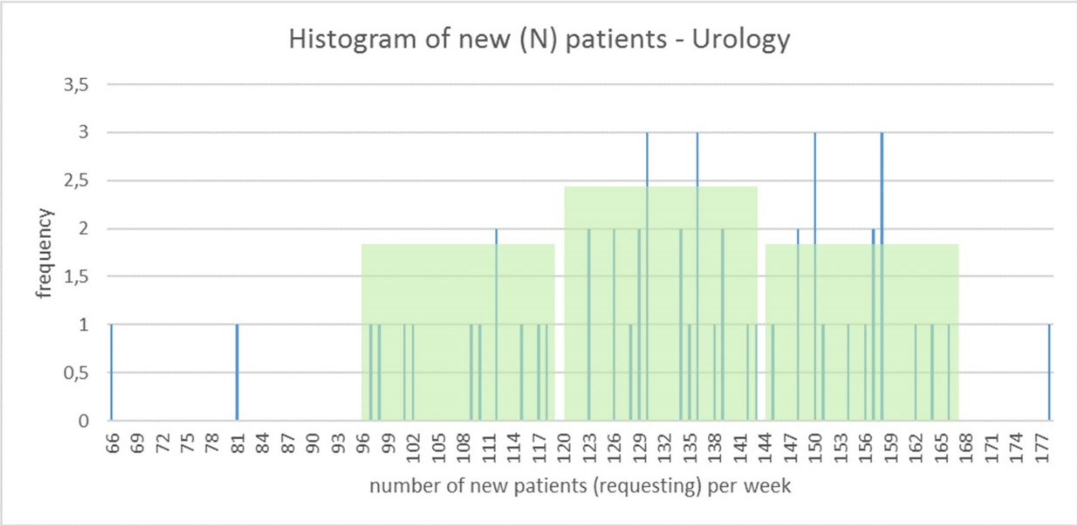

Figure 41: Histogram N - urology

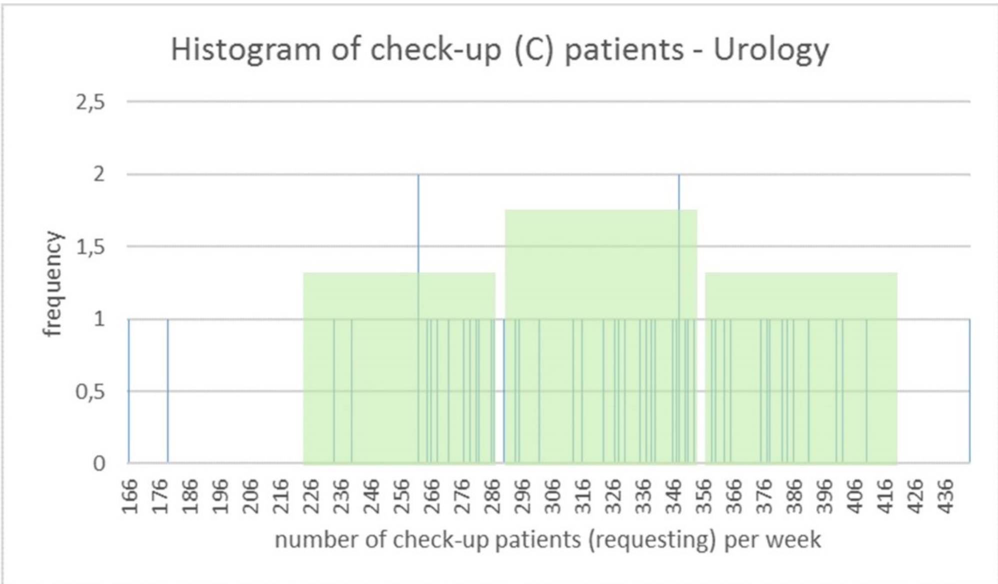

Figure 42: Histogram C - urology

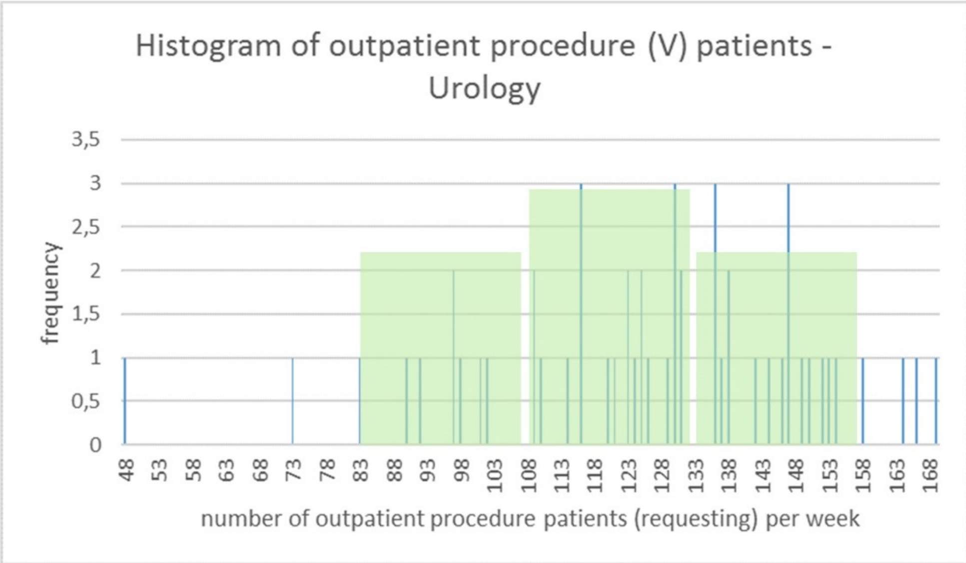

Figure 43: Histogram V – urology

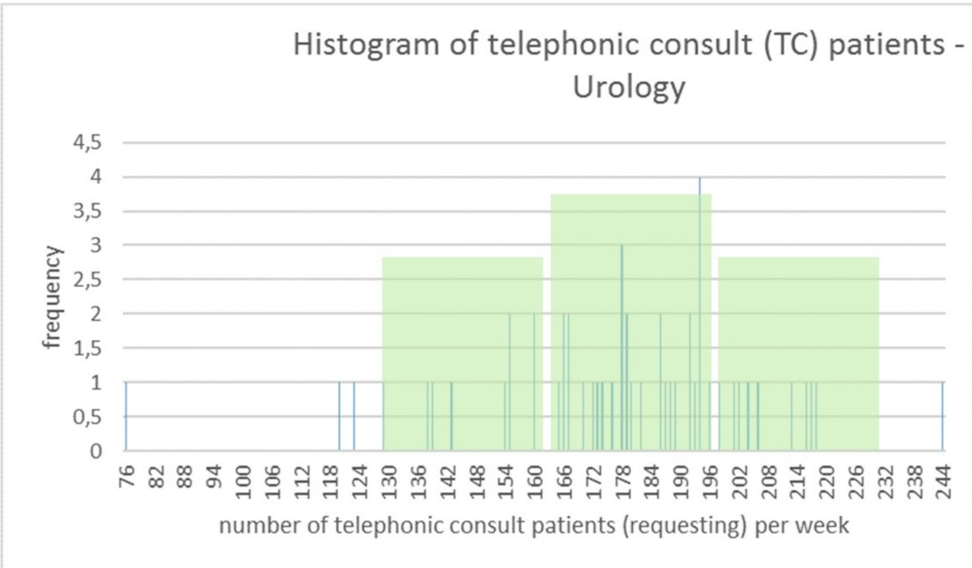

Figure 44: Histogram TC - urology

VI. Simulation output

Blue lines indicate a holiday week.

Data from 2015.

	period	cap_tot	cap_b	cap_fut	demand booked						expected demand future						protect		max fill up	fill-up now	on track?
					S	N	C	V	TC	*total*	S	N	C	V	TC	*total*	hours	%			
now: wk 8	**wk 9**	61,50	48,24	13,26	0,00	25,50	17,83	1,83	3,08	*48,24*	1,32	5,10	15,23	13,89	3,22	*38,76*	13,26	22%	78%	78%	0%
	wk 10	158,42	95,25	63,17	0,00	28,00	45,92	17,83	3,50	*95,25*	2,20	23,00	9,18	8,37	7,00	*49,75*	63,05	40%	60%	60%	0%
	wk 11	117,75	58,42	59,33	0,00	3,58	33,00	21,67	0,17	*58,42*	2,20	47,42	22,10	4,53	10,33	*86,58*	59,33	50%	50%	50%	0%
	wk 12	152,25	53,08	99,17	0,00	4,25	31,50	16,50	0,83	*53,08*	2,20	46,75	23,60	9,70	9,67	*91,92*	97,8	64%	36%	35%	1%
	wk 13	169,33	42,76	126,58	0,00	0,67	25,67	16,00	0,42	*42,76*	2,20	50,33	29,43	10,20	10,08	*102,24*	116,82	69%	31%	25%	6%
	wk 14	174,25	18,50	155,75	0,00	0,00	17,83	0,67	0,00	*18,50*	2,20	51,00	37,27	25,53	10,50	*126,50*	138,42	79%	21%	11%	10%
	wk 15	106,25	1,41	104,84	0,00	0,00	0,00	1,33	0,08	*1,41*	2,20	51,00	55,10	24,87	10,42	*143,59*	117,85	111%	-11%	1%	-12%
	wk 16	139,50	7,83	131,67	0,00	0,00	6,83	1,00	0,00	*7,83*	2,20	51,00	48,27	25,20	10,50	*137,17*	169,35	121%	-21%	6%	-27%
now: wk 9	**wk 10**	158,42	117,58	40,84	0,33	41,25	49,75	19,83	6,42	*117,58*	1,87	9,75	5,35	6,37	4,08	*27,42*	27,42	17%	83%	74%	8%
	wk 11	117,75	76,25	41,50	0,00	18,83	36,17	20,67	0,58	*76,25*	2,20	32,17	18,93	5,53	9,92	*68,75*	41,5	35%	65%	65%	0%
	wk 12	152,25	74,17	78,08	0,00	8,58	47,67	17,50	0,42	*74,17*	2,20	42,42	7,43	8,70	10,08	*70,83*	76,51	50%	50%	49%	1%
	wk 13	169,33	57,01	112,33	0,00	3,75	31,67	21,17	0,42	*57,01*	2,20	47,25	23,43	5,03	10,08	*87,99*	100,14	59%	41%	34%	7%
	wk 14	174,25	23,51	150,74	0,00	0,50	22,17	0,67	0,17	*23,51*	2,20	50,50	32,93	25,53	10,33	*121,49*	126,79	73%	27%	13%	14%
	wk 15	106,25	5,08	101,17	0,00	0,00	1,67	3,33	0,08	*5,08*	2,20	51,00	53,43	22,87	10,42	*139,92*	100,34	94%	6%	5%	1%
	wk 16	139,50	11,50	128,00	0,00	0,50	10,00	1,00	0,00	*11,50*	2,20	50,50	45,10	25,20	10,50	*133,50*	130,06	93%	7%	8%	-1%
	wk 17	185,17	8,08	177,08	0,00	0,00	5,33	2,67	0,08	*8,08*	2,20	51,00	49,77	23,53	10,42	*136,92*	183,55	99%	1%	4%	-3%
now: wk 10	**wk 11**	117,75	93,25	24,50	0,83	27,75	39,17	21,17	4,33	*93,25*	1,37	23,25	15,93	5,03	6,17	*51,75*	24,5	21%	79%	79%	0%
	wk 12	152,25	102,42	49,83	0,00	34,08	43,67	22,67	2,00	*102,42*	2,20	16,92	11,43	3,53	8,50	*42,58*	49,83	33%	67%	67%	0%
	wk 13	169,33	76,91	92,42	0,00	9,33	41,83	25,67	0,08	*76,91*	2,20	41,67	13,27	0,53	10,42	*68,09*	83,01	49%	51%	45%	6%
	wk 14	174,25	40,74	133,51	0,00	3,33	34,83	2,00	0,58	*40,74*	2,20	47,67	20,27	24,20	9,92	*104,26*	109,08	63%	37%	23%	14%
	wk 15	106,25	12,91	93,34	0,00	0,42	3,83	8,33	0,33	*12,91*	2,20	50,58	51,27	17,87	10,17	*132,09*	92,56	87%	13%	12%	1%
	wk 16	139,50	20,92	118,58	0,00	0,67	17,50	2,50	0,25	*20,92*	2,20	50,33	37,60	23,70	10,25	*124,08*	115,02	82%	18%	15%	3%
	wk 17	185,17	23,50	161,67	0,00	0,00	14,33	9,00	0,17	*23,50*	2,20	51,00	40,77	17,20	10,33	*121,50*	154,47	83%	17%	13%	4%
	wk 18	140,58	3,66	136,92	0,00	0,67	1,83	1,00	0,17	*3,66*	2,20	50,33	53,27	25,20	10,33	*141,34*	156,14	111%	-11%	3%	-14%
now: wk 11	**wk 12**	152,25	118,16	34,09	0,83	38,00	46,83	25,67	6,83	*118,16*	1,37	13,00	8,27	0,53	3,67	*26,84*	6,66	4%	96%	78%	18%
	wk 13	169,33	104,58	64,75	0,00	35,33	43,17	25,33	0,75	*104,58*	2,20	15,67	11,93	0,87	9,75	*40,42*	58,27	34%	66%	62%	4%
	wk 14	174,25	75,41	98,84	0,00	18,83	46,50	9,83	0,25	*75,41*	2,20	32,17	8,60	16,37	10,25	*69,59*	72,74	42%	58%	43%	15%
	wk 15	106,25	24,09	82,16	0,00	0,83	12,17	10,67	0,42	*24,09*	2,20	50,17	42,93	15,53	10,08	*120,91*	81,8	77%	23%	23%	0%
	wk 16	139,50	29,00	110,50	0,00	1,17	23,00	4,50	0,33	*29,00*	2,20	49,83	32,10	21,70	10,17	*116,00*	107,26	77%	23%	21%	2%
	wk 17	185,17	33,49	151,67	0,00	0,17	22,33	10,83	0,17	*33,49*	2,20	50,83	32,77	15,37	10,33	*111,51*	143,69	78%	22%	18%	4%
	wk 18	140,58	8,59	131,99	0,00	1,00	5,67	1,67	0,25	*8,59*	2,20	50,00	49,43	24,53	10,25	*136,41*	135,37	96%	4%	6%	-2%
	wk 19	72,08	1,41	70,67	0,00	0,50	0,83	0,00	0,08	*1,41*	1,32	30,10	32,23	15,72	6,22	*85,59*	100,4	139%	-39%	2%	-41%
now: wk 12	**wk 13**	169,33	117,92	51,41	0,00	38,67	47,00	26,17	6,08	*117,92*	2,20	12,33	8,10	0,03	4,42	*27,08*	14,72	9%	91%	70%	22%
	wk 14	174,25	116,25	58,00	0,00	48,58	53,50	12,67	1,50	*116,25*	2,20	2,42	1,60	13,53	9,00	*28,75*	41,67	24%	76%	67%	9%
	wk 15	106,25	39,09	67,16	0,00	5,42	17,33	15,67	0,67	*39,09*	2,20	45,58	37,77	10,53	9,83	*105,91*	67,16	63%	37%	37%	0%
	wk 16	139,50	43,44	96,06	0,00	7,00	30,67	5,17	0,60	*43,44*	2,20	44,00	24,43	21,03	9,90	*101,56*	94,3	68%	32%	31%	1%
	wk 17	185,17	47,33	137,84	0,00	0,17	33,83	12,83	0,50	*47,33*	2,20	50,83	21,27	13,37	10,00	*97,67*	129,9	70%	30%	26%	4%
	wk 18	140,58	15,24	125,34	0,00	0,08	11,83	3,00	0,33	*15,24*	2,20	50,92	43,27	23,20	10,17	*129,76*	136,82	97%	3%	11%	-8%
	wk 19	72,08	2,08	70,00	0,00	0,00	2,00	0,00	0,08	*2,08*	1,32	30,60	31,06	15,72	6,22	*84,92*	88,75	123%	-23%	3%	-26%
	wk 20	71,00	1,58	69,42	0,00	0,00	1,50	0,08	0,00	*1,58*	2,20	51,00	53,60	26,12	10,50	*143,42*	145,01	204%	-104%	2%	-106%
now: wk 13	**wk 14**	174,25	128,41	45,84	0,00	50,83	54,83	17,33	5,42	*128,41*	2,20	0,17	0,27	8,87	5,08	*16,59*	16,59	10%	90%	74%	17%
	wk 15	106,25	65,59	40,66	0,00	26,50	21,00	17,67	0,42	*65,59*	2,20	24,50	34,10	8,53	10,08	*79,41*	40,66	38%	62%	62%	0%
	wk 16	139,50	70,25	69,25	0,00	20,50	39,17	10,50	0,08	*70,25*	2,20	30,50	15,93	15,70	10,42	*74,75*	69,25	50%	50%	50%	0%
	wk 17	185,17	66,63	118,54	0,00	6,58	43,67	16,33	0,05	*66,63*	2,20	44,42	11,43	9,87	10,45	*78,37*	111,77	60%	40%	36%	4%
	wk 18	140,58	30,74	109,84	0,00	1,33	21,83	7,00	0,58	*30,74*	2,20	49,67	33,27	19,20	9,92	*114,26*	104,38	74%	26%	22%	4%
	wk 19	72,08	6,33	65,75	0,00	0,75	5,00	0,50	0,08	*6,33*	1,32	29,85	28,06	15,22	6,22	*80,67*	66,77	93%	7%	9%	-1%
	wk 20	71,00	3,34	67,66	0,00	0,00	3,17	0,17	0,00	*3,34*	2,20	51,00	51,93	26,03	10,50	*141,66*	74,11	104%	-4%	5%	-9%
	wk 21	174,42	13,58	160,83	0,00	0,50	10,17	2,83	0,08	*13,58*	2,20	50,50	44,93	23,37	10,42	*131,42*	175,63	101%	-1%	8%	-8%

Figure 45: Simulation 2015 dermatology

	period	cap_tot	cap_b	cap_fut	demand booked						expected deman future						protect		max fill up	fill-up now	on track?
					S	N	C	V	TC	*total*	S	N	C	V	TC	*total*					
now: wk 8	wk 9	81,58	74,83	6,75	0,00	16,50	36,17	13,58	8,58	*74,83*	2,58	2,10	2,59	9,10	0,24	*16,61*	4,92	6%	94%	92%	2%
	wk 10	172,67	109,25	63,42	0,00	14,75	50,00	37,67	6,83	*109,25*	4,30	16,25	14,60	0,13	7,87	*43,15*	55,68	32%	68%	63%	4%
	wk 11	129,42	81,59	47,83	0,00	5,67	41,92	31,33	2,67	*81,59*	4,30	25,33	22,68	6,47	12,03	*70,81*	48,22	37%	63%	63%	0%
	wk 12	135,42	61,25	74,17	0,00	6,33	35,00	19,00	0,92	*61,25*	4,30	24,67	29,60	18,80	13,78	*91,15*	76,2	56%	44%	45%	-2%
	wk 13	164,33	42,91	121,42	0,00	3,67	24,58	13,92	0,75	*42,91*	4,30	27,33	40,02	23,88	13,95	*109,49*	117,79	72%	28%	26%	2%
	wk 14	166,42	32,83	133,58	0,00	2,00	17,75	12,42	0,67	*32,83*	4,30	29,00	46,85	25,38	14,03	*119,57*	129,76	78%	22%	20%	2%
	wk 15	112,92	2,50	110,42	0,00	0,00	1,33	1,00	0,17	*2,50*	4,30	31,00	63,27	36,80	14,53	*149,90*	128,22	114%	-14%	2%	-16%
	wk 16	155,17	0,50	154,67	0,00	0,00	0,50	0,00	0,00	*0,50*	4,30	31,00	64,10	37,80	14,70	*151,90*	190,93	123%	-23%	0%	-23%
now: wk 9	wk 10	172,67	134,48	38,18	0,75	18,83	64,50	37,65	12,75	*134,48*	3,55	12,17	0,10	0,15	1,95	*17,92*	17,92	10%	90%	78%	12%
	wk 11	129,42	104,58	24,83	0,00	11,25	53,00	34,25	6,08	*104,58*	4,30	19,75	11,60	3,55	8,62	*47,82*	33,41	26%	74%	81%	-7%
	wk 12	135,42	72,83	62,58	0,00	7,00	41,00	21,50	3,33	*72,83*	4,30	24,00	23,60	16,30	11,37	*79,57*	62,98	47%	53%	54%	0%
	wk 13	164,33	53,58	110,75	0,00	6,08	29,25	15,25	3,00	*53,58*	4,30	24,92	35,35	22,55	11,70	*98,82*	108,16	66%	34%	33%	2%
	wk 14	166,42	43,58	122,83	0,00	3,42	23,75	14,17	2,25	*43,58*	4,30	27,58	40,85	23,63	12,45	*108,82*	114,18	69%	31%	26%	5%
	wk 15	112,92	18,67	94,25	0,00	0,92	11,50	3,33	2,92	*18,67*	4,30	30,08	53,10	34,47	11,78	*133,73*	96,3	85%	15%	17%	-2%
	wk 16	155,17	10,67	144,50	0,00	1,50	5,00	1,83	2,33	*10,67*	4,30	29,50	59,60	35,97	12,37	*141,73*	153,79	99%	1%	7%	-6%
	wk 17	169,50	0,00	169,50	0,00	0,00	0,00	0,00	0,00	*0,00*	4,30	31,00	64,60	37,80	14,70	*152,40*	193,34	114%	-14%	0%	-14%
now: wk 10	wk 11	129,42	130,83	-1,41	0,83	16,92	63,67	37,08	12,33	*130,83*	3,47	14,08	0,93	0,72	2,37	*21,57*	17,55	14%	86%	101%	-15%
	wk 12	135,42	90,83	44,58	0,00	9,42	49,33	25,00	7,08	*90,83*	4,30	21,58	15,27	12,80	7,62	*61,57*	44,59	33%	67%	67%	0%
	wk 13	164,33	76,33	88,00	0,00	9,58	40,42	18,83	7,50	*76,33*	4,30	21,42	24,18	18,97	7,20	*76,07*	85,26	52%	48%	46%	2%
	wk 14	166,42	60,92	105,50	0,00	4,50	32,92	17,50	6,00	*60,92*	4,30	26,50	31,68	20,30	8,70	*91,48*	95,87	58%	42%	37%	6%
	wk 15	112,92	31,25	81,67	0,00	2,83	17,92	5,33	5,17	*31,25*	4,30	28,17	46,68	32,47	9,53	*121,15*	82,61	73%	27%	28%	-1%
	wk 16	155,17	33,08	122,08	0,00	4,58	16,92	4,17	7,42	*33,08*	4,30	26,42	47,68	33,63	7,28	*119,32*	130,12	84%	16%	21%	-5%
	wk 17	169,50	14,25	155,25	0,00	2,00	8,00	1,25	3,00	*14,25*	4,30	29,00	56,60	36,55	11,70	*138,15*	165,64	98%	2%	8%	-6%
	wk 18	93,75	6,75	87,00	0,00	0,42	3,83	0,83	1,67	*6,75*	4,30	30,58	60,77	36,97	13,03	*145,65*	152,72	163%	-63%	7%	-70%
now: wk 11	wk 12	135,42	125,90	9,52	0,67	17,25	64,23	29,33	14,42	*125,90*	3,63	13,75	0,37	8,47	0,28	*26,50*	17,38	13%	87%	93%	-6%
	wk 13	164,33	99,42	64,92	0,00	13,25	50,17	23,92	12,08	*99,42*	4,30	17,75	14,43	13,88	2,62	*52,98*	59,09	36%	64%	60%	4%
	wk 14	166,42	81,17	85,25	0,00	7,83	43,00	20,83	9,50	*81,17*	4,30	23,17	21,60	16,97	5,20	*71,23*	74,47	45%	55%	49%	6%
	wk 15	112,92	44,17	68,75	0,00	5,50	24,50	6,17	8,00	*44,17*	4,30	25,50	40,10	31,63	6,70	*108,23*	69,35	61%	39%	39%	-1%
	wk 16	155,17	46,25	108,92	0,00	5,75	24,17	5,75	10,58	*46,25*	4,30	25,25	40,43	32,05	4,12	*106,15*	113,54	73%	27%	30%	-3%
	wk 17	169,50	35,00	134,50	0,00	6,25	19,92	2,75	6,08	*35,00*	4,30	24,75	44,68	35,05	8,62	*117,40*	143,93	85%	15%	21%	-6%
	wk 18	93,75	16,92	76,83	0,00	1,58	9,50	1,75	4,08	*16,92*	4,30	29,42	55,10	36,05	10,62	*135,48*	106,21	113%	-13%	18%	-31%
	wk 19	93,75	4,92	88,83	0,00	1,33	2,83	0,42	0,33	*4,92*	2,58	17,27	35,93	22,26	8,49	*86,52*	119,85	128%	-28%	5%	-33%
now: wk 12	wk 13	164,33	131,51	32,82	1,08	22,00	63,67	30,33	14,43	*131,51*	3,22	9,00	0,93	7,47	0,27	*20,89*	15,12	9%	91%	80%	11%
	wk 14	166,42	106,15	60,27	0,00	13,33	53,25	24,92	14,65	*106,15*	4,30	17,67	11,35	12,88	0,05	*46,25*	52,91	32%	68%	64%	4%
	wk 15	112,92	59,75	53,17	0,00	8,08	30,58	8,92	12,17	*59,75*	4,30	22,92	34,02	28,88	2,53	*92,65*	53,17	47%	53%	53%	0%
	wk 16	155,17	68,75	86,42	0,00	9,08	35,75	10,00	13,92	*68,75*	4,30	21,92	28,85	27,80	0,78	*83,65*	90,64	58%	42%	44%	-3%
	wk 17	169,50	51,25	118,25	0,00	9,42	28,50	4,42	8,92	*51,25*	4,30	21,58	36,10	33,38	5,78	*101,15*	129,86	77%	23%	30%	-7%
	wk 18	93,75	30,92	62,83	0,00	3,83	17,17	3,75	6,17	*30,92*	4,30	27,17	47,43	34,05	8,53	*121,48*	100,88	108%	-8%	33%	-41%
	wk 19	93,75	13,50	80,25	0,00	3,67	7,17	1,17	1,50	*13,50*	2,58	14,93	31,59	21,51	7,32	*77,94*	99,81	106%	-6%	14%	-21%
	wk 20	93,58	9,92	83,67	0,00	1,50	5,50	2,08	0,83	*9,92*	4,30	29,50	59,10	35,72	13,87	*142,48*	143,65	153%	-53%	11%	-64%
now: wk 13	wk 14	166,42	133,84	32,58	0,50	22,42	64,33	32,42	14,17	*133,84*	3,80	8,58	0,27	5,38	0,53	*18,56*	18,56	11%	89%	80%	8%
	wk 15	112,92	81,75	31,17	0,00	12,42	42,42	12,58	14,33	*81,75*	4,30	18,58	22,18	25,22	0,37	*70,65*	31,17	28%	72%	72%	0%
	wk 16	155,17	83,25	71,92	0,00	12,00	43,67	13,08	14,50	*83,25*	4,30	19,00	20,93	24,72	0,20	*69,15*	74,13	48%	52%	54%	-1%
	wk 17	169,50	69,58	99,92	0,00	12,50	37,42	7,67	12,00	*69,58*	4,30	18,50	27,18	30,13	2,70	*82,82*	111,97	66%	34%	41%	-7%
	wk 18	93,75	40,50	53,25	0,00	5,08	21,75	6,50	7,17	*40,50*	4,30	25,92	42,85	31,30	7,53	*111,90*	81,19	87%	13%	43%	-30%
	wk 19	93,75	21,42	72,33	0,00	4,67	11,25	3,25	2,25	*21,42*	2,58	13,93	27,51	19,43	6,57	*70,02*	91,46	98%	2%	23%	-20%
	wk 20	93,58	21,67	71,92	0,00	4,00	11,42	3,25	3,00	*21,67*	4,30	27,00	53,18	34,55	11,70	*130,73*	103,27	110%	-10%	23%	-34%
	wk 21	156,50	27,75	128,75	0,00	4,33	12,67	5,17	5,58	*27,75*	4,30	26,67	51,93	32,63	9,12	*124,65*	166,44	106%	-6%	18%	-24%

Figure 46: Simulation 2015 urology