CARE ON DEMAND

Improving the coordination between the members of the multidisciplinary team of Endocrine Oncology

MASTER THESIS

Industrial Engineering and Management

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Care on demand

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Management Summary

Introduction

The group of cancer patients in the Netherlands is expected to grow as a consequence of the "double-aging" phenomenon. At the same time the knowledge on cancer care is increasing and thus cancer becomes more and more a chronic disease (Meulepas et al., 2011). These developments ask for a specialized approach of cancer care in a multidisciplinary team. Furthermore, a general development in health care is the shift from inpatient to day care. The UMC Utrecht Cancer Center anticipates on these trends by introducing the Health Care Concept with promises to the patients and making plans for improving the outpatient clinics. Therefore, the coordination between the different disciplines in the multidisciplinary teams must be well organized.

Problem statement

Outpatient clinic Endocrine Oncology, which is part of the UMC Utrecht Cancer Center since the beginning of 2015, experiences some problems with the coordination of multidisciplinary care. We identified four challenges:

1. The procedures of referring a patient to the supporting specialists are unclear, which results in a low walk-in rate to these specialists and thus a low utilization.
2. It is hard to identify the patients who require a consultation of both the Internist and Endocrine Surgeon. Besides that, the scheduling procedures of these patients are not clear, resulting in low utilization of the combination hour (5%) and high internal waiting times for these patients.
3. The agendas of the specialists can be arranged more efficiently, according to our data analysis. The access times to the specialists of Endocrine Oncology are not within the "Treeknormen". Endocrine Surgery does meet the norms (on average 8.7 days) against a price of overbooking the agenda. If the Resident Doctor (who supports the Surgeon) is not available during the consultation session, the overbooked agenda of the Endocrine Surgeon results in high internal waiting times (on average 12.5 minutes with a maximum of 1.5 hours).
4. The comprehensive patient classification with corresponding appointment duration results in scheduled idle time or overbooked timeslots in the Internists' agendas.

Simulation model

By means of a simulation study, we aim to investigate the effect of possible interventions in order to improve upon the performance of the clinics. The input parameters of the discrete-event simulation model consist amongst others of theoretical probability distributions for the arrival rates of patients, the punctuality of patients, consultation durations and referral rates.

The interventions in our experimental design exists of adjustments to the appointment system and changes in the input parameters. Appointment system interventions following from the context analysis are:

- Improvement of the appointment classification of the Internists (adapted IBVI-rule).
- Moving the combination hour to the beginning of the clinic session (CBG-rule).
- Dedicated appointment slots for scheduled patients of supporting specialists (DSNS-rule).

Appointment system interventions following from the literature study are:

- Using sequencing rules (for Endocrine Surgery).
- Using appointment rules (for the Internists).

An overview of the sequencing rules and appointment rules is presented in Table 1.

Table 1: Appointment and sequencing rules mentioned in the literature (Cayirli, Veral, & Rosen, 2006)

Appointment rules	Sequencing rules
Individual-block/fixed-interval rule (IBFI)	New and return patients alternating (ALTER)
OFFSET rule	New patients in beginning (NWBG)
DOME rule	Return patients in beginning (RTBG)
Bailey-Welch rule (2BEG)	New patients in beginning and end (NWBND)
Multiple-block/fixed-interval rule (MBFI)	Return patients in beginning and end (RTBND)

Results

We conclude that the current capacity of Internist A is not sufficient to deal with variations in demand and capacity, since the long term access time is continuously increasing. The average access time can be reduced with up to 85% over a period of 9 years, by changing the appointment rule to Bailey-Welch and Bailey-Welch combined with CBG for Internist A and B respectively. For the Internists, the adapted IBVI rule has the best overall performance, when analyzing the trade-off between waiting time (patient's performance) and idle time and overtime (doctor's performance).

For outpatient clinic Endocrine Surgery there is no sequencing rule that outperforms the base setting: ALTER. The CBG-rule results in the best patient's performance for both Endocrine Surgery and Internist A. However, the doctor's performance of this rule is worse than the base setting.

The analysis showed that the access time to the Internists is highly sensitive to the number of production weeks and the number of appointment requests. The overall performance of outpatient clinic Endocrine Surgery is highly sensitive to the number of appointment requests to the clinic. With an increase of 10% in appointment requests, the waiting time increases with up to 30% and the overtime even with 74%.

For the Nurse Specialist no appointment system outperforms the current system and for the Genetic Counselor no adaptations to the appointment system are investigated.

An overview of the results is presented in Table 2.

Table 2: Overview of performance of the best methods

Specialist	Method	Access time	Patient's performance	Doctor's performance
Internist A	Bailey-Welch	Low (11 days)	Bad (80% worse)	-
	CBG	Low (16 days)	Good (5-10% better)	Bad (50% worse)
	Adapted IBVI	High (70 days)	-	-
Internist B	Bailey-Welch	Low (9 days)	Bad (50% worse)	-
	Adapted IBVI	High (73 days)	Good (30% better)	Good (15% better)
Endocrine Surgery	CBG	-	Good (40% better)	Bad (>100% worse)

- means no significant effect

Conclusions and recommendations

Based on these results, we have the following recommendations:

- We recommend the Internists to take on the adapted patient classification with just two groups (Table 3). This implies that the length of the timeslots of Internist B is changed from 15 minutes to 20 minutes.

Table 3: Adapted duration per patient

Patient type	Duration
New	40 min.
Check-up	20 min.

- We recommend Internist A and Endocrine Surgery to introduce the CBG-rule. This implies that the consultation session of Internist A starts half an hour earlier (8:30h).
- We recommend outpatient clinic Endocrinology to improve the referral procedures of patients to the supporting specialists and referral procedures of the combination patients. With a better identification of the characteristics of referral patients, the forecasts and therefore the appointments systems can be further improved.

Further research can be done to apply this model to a larger outpatient clinic, which provides primary care. In that case, larger patient groups are available with less variation in the disorders, which makes it easier to identify the patient streams through the outpatient clinic and thus to improve the appointment systems of the supporting specialists.

Management Samenvatting

Aanleiding

Het aantal kanker patiënten in Nederland groeit ten gevolge van de "dubbele vergrijzing". Tegelijkertijd is er steeds meer kennis over oncologische zorg tot onze beschikking en dus wordt kanker steeds meer een chronische ziekte (Meulepas et al., 2011). Deze ontwikkelingen vragen om een meer gespecialiseerde aanpak van de zorg in een multidisciplinair team. Een algemene ontwikkeling in de gezondheidszorg is de verschuiving van klinische opname naar dag opvang. Het UMC Utrecht Cancer Center anticipeert op deze trends door het Zorgconcept, met beloften aan de patiënt, te introduceren en door het polikliniekengebouw te vernieuwen. Daarom zal de coördinatie tussen de verschillende disciplines in het multidisciplinaire team goed georganiseerd moeten worden.

Probleem definitie

Polikliniek Endocriene Oncologie, welke sinds het begin van 2015 is aangesloten bij het UMC Utrecht Cancer Center, ervaart enkele problemen met de coördinatie van de multidisciplinaire zorg. We hebben vier uitdagingen geïdentificeerd:

1. De procedures om een patiënt door te verwijzen naar de ondersteunende specialisten zijn niet duidelijk. Dit resulteert in een laag aantal inloop-patiënten en dus lage benutting.
2. Er is veel moeite om patiënten, die een gezamenlijk spreekuur met de Internist en Endocriene Chirurg vereisen, te herkennen. Daarbij zijn de procedures voor het roosteren van deze patiënten niet duidelijk. Dit resulteert in een lage benutting van het combinatie spreekuur (5%) en hoge interne wachttijden voor de ze patiënten.
3. De toegangstijden tot de specialisten van Endocriene Oncologie voldoen niet aan de "Treeknormen". Endocriene Chirurgie voldoet wel aan deze norm (met een gemiddelde van 8,7 dagen), maar betaalt hier de prijs van het overboeken van de agenda voor. Als de Arts in Opleiding (welke de chirurg ondersteund) tijdens het spreekuur niet aanwezig is, zal de overboekte agenda van de Endocriene Chirurg resulteren in hoge interne wachttijden (gemiddeld 12,5 minuten met een maximum van 1,5 uur).
4. De uitgebreide patiëntenclassificatie met bijbehorende afspraakduren resulteert in geroosterde leegloop en overboekte tijdsloten in de agendas van de Internisten.

Simulatie studie

Door middel van een simulatie studie hebben we gepoogd om het effect van verschillende interventies te onderzoeken, om zodoende de prestatie van de klinieken te verbeteren. De parameters van de "Discrete-event" simulatie bestaan onder andere uit theoretische kansverdelingen van het aantal afspraakverzoeken van patiënten, de punctualiteit van patiënten, de duur van de afspraken en het aantal doorverwijzingen.

De interventies in ons experimentele ontwerp bestaan uit aanpassingen aan het afsprakensysteem en wijzigingen in de parameters. Interventies in het afspraaksysteem volgend uit de context analyse zijn:

- Aanpassing van de afspraak classificatie van de internisten (aangepaste IBVI-regel).
- Verplaatsing van het combinatie spreekuur naar het begin van het spreekuur (CBG-regel).
- Toegewijde tijdsloten voor geplande patiënten van de ondersteunende specialisten (DSNS-regel).

Interventies in het afspraaksysteem volgende uit de literatuurstudie zijn:

- Gebruik maken van volgorderegels (voor Endocriene Chirurgie).
- Gebruik maken van afspraakregels (voor de Internisten).

Tabel 1 presenteert een overzicht van deze afspraak en volgorde regels.

Tabel 1: Afspraak en volgorde regels genoemd in de literatuur (Cayirli et al., 2006)

Afspraakregels	Volgorderegels
Individual-block/fixed-interval (IBFI)	Nieuwe en controle patiënten alternerend (ALTER)
OFFSET	Nieuwe patiënten aan het begin (NWBG)
DOME	Controle patiënten aan het begin (RTBG)
Bailey-Welch (2BEG)	Nieuwe patiënten aan het begin en eind (NWBND)
Multiple-block/fixed-interval (MBFI)	Controle patiënten aan het begin en eind (RTBND)

Resultaten

We concluderen dat de huidige capaciteit van Internist A niet voldoende is om fluctuaties in vraag en aanbod op te vangen, aangezien op de lange termijn de toegangstijden continu stijgen. De gemiddelde toegangstijd kan met wel 85% (over 9 jaar tijd) gereduceerd worden, door de afspraakregel Bailey-Welch en Bailey-Welch gecombineerd met CBG te introduceren voor respectievelijk Internist A en B. Voor de Internisten heeft de aangepaste IBVI regel de beste prestatie, wanneer er een afweging tussen wachttijd (prestatie van de patiënten) en leegloop en overwerk (prestatie van de doktoren) gemaakt wordt.

Voor polikliniek Endocriene Chirurgie is er geen volgorderegel die de huidige setting, ALTER, overtreft. De CBG regel resulteert in de laagste wachttijden voor zowel Endocriene Chirurgie als Internist A. Echter, de prestatie van de doktoren is door deze regel aanzienlijk slechter.

De analyse toont ook aan dat de toegangstijden tot de Internisten zeer afhankelijk is van het aantal productieweken en het aantal afspraakverzoeken. De algehele prestatie van Endocriene Chirurgie is zeer afhankelijk van het aantal afspraakverzoeken voor de kliniek. Met een stijging van het aantal afspraakverzoeken van 10%, stijgt de wachttijd tot maximaal 30% en het overwerk zelfs tot 74%.

Voor de Verpleegkundig Specialist is er geen afsprakensysteem dat het huidige systeem overtreft en voor de Klinisch Geneticus zijn er geen aanpassingen in het afsprakensysteem geanalyseerd. Tabel 2 presenteert een overzicht van de resultaten.

Tabel 2: Overzicht van de prestatie van de beste methodes

Specialist	Methode	Toegangstijden	Prestatie patiënt	Prestatie dokter
Internist A	Bailey-Welch	Laag (11 dagen)	Slecht (80% slechter)	-
	CBG	Laag (16 dagen)	Goed (5-10% beter)	Slecht (50% slechter)
	Aangepaste IBVI	Hoog (70 dagen)	-	-
Internist B	Bailey-Welch	Laag (9 dagen)	Slecht (50% slechter)	-
	Aangepaste IBVI	Hoog (73 dagen)	Goed (30% beter)	Goed (15% beter)
Endocriene Chirurgie	CBG	-	Goed (40% beter)	Slecht (>100% slechter)

\- betekent dat er geen significant effect is waargenomen

Conclusies en aanbevelingen

Gebaseerd op deze resultaten, doen we de volgende aanbevelingen:

- We adviseren de Internisten om de aangepaste patiënt classificatie aan te nemen, waarbij er slechts twee patiëntengroepen zijn. Dit impliceert dat de tijdsloten van Internist B wijzigen van 15 minuten naar 20 minuten.
- We adviseren Internist A en Endocriene Chirurgie om de CBG regel te introduceren. Dit impliceert dat het spreekuur van Internist A een half uur eerder begint (8:30u).
- We adviseren polikliniek Endocrinologie om de procedures te verbeteren voor het doorverwijzen van patiënten naar de ondersteunde specialisten en het doorverwijzen van Combinatie patiënten. Met een betere herkenning van de karakteristieken van deze doorverwijs-patiënten, zullen de voorspellingen en dus de afspraaksystemen verder kunnen worden verbeterd.

Verder onderzoek zal gedaan moeten worden om dit onderzoek toepasbaar te maken op andere poliklinieken. Door dit onderzoek uit te voeren in een grotere kliniek, waar primaire zorg verleend wordt, zullen er grotere patiëntengroepen met minder variaties in aandoening beschikbaar zijn. Hierdoor is het makkelijker om de patiëntenstromen door de polikliniek te identificeren en dus de afspraaksystemen van de betrokken specialisten te verbeteren.

List of abbreviations

2BEG	Bailey-Welch rule, two patients on first timeslot (Appointment Rule)
Adapted IBFI	IBFI rule (see below) with appointment durations adapted according to data analysis of the service times
ALTER	New and return patients alternating (Sequencing Rule)
AVL	Antoni van Leeuwenhoek
CBG	Combination patients at beginning (Appointment System)
CGO	Surgical Gastroenterological Oncology (in Dutch: “Chirurgische Gastro-enterologie & Oncologie”)
DOME	Appointment rule, where the intervals slightly increase towards the middle and decrease towards the end of the session
DSNS	Dedicated appointment slots for scheduled patients of Nurse Specialist (Appointment System)
EZIS	Electronic hospital information system (in Dutch: “Elektronisch Ziekenhuisinformatiesystem”)
HOD	Oncologic diseases treated by surgery (in Dutch: “Heelkundige Oncologische Disciplines”)
IBFI	Individual-block/fixed-interval rule (Appointment Rule)
MBFI	Multiple-block/fixed-interval rule (Appointment Rule)
MDO	Multidisciplinary meeting (in Dutch: “Multidisciplinair Overleg”)
MEN-1	Multiple Endocrine Neoplasia type 1
MEN-2	Multiple Endocrine Neoplasia type 2
MOD	Oncologic diseases treated with medication (in Dutch: “Medische Oncologische Disciplines”)
NEC	Neuro-Endocrine Carcinoma
NET	Neuro-Endocrine Tumor
NWBG	New patients in beginning (Sequencing Rule)
NWBND	New patients in beginning and end (Sequencing Rule)
OFFSET	Appointment rule, where earlier slots are shorter than average service time and later slots are longer than average service time
RTBG	Return patient in beginning (Sequencing Rule)
RTBND	Return patients in beginning and end (Sequencing Rule)
TWG	Tumor Workgroups
UMC Utrecht	University Medical Center Utrecht

Preface

More than six years ago, I started with a Bachelor in Mathematics at the University of Twente. The main motivation behind this choice was my love for solving mathematical puzzles. During my study path I have taken many opportunities to develop myself and to gain more self-knowledge. For example, the experience as a mathematics teacher, board member of the study association and study period abroad has shown me that I like to establish and maintain social contacts and that I have a great sense of responsibility in the organization of projects. This self-knowledge has led me to the Master Industrial Engineering and Management, where both the social- and the analytic aspects come together. After I heard the enthusiastic stories of Erwin Hans about using mathematics to improve the health care sector, I was convinced: A graduation assignment in UMC Utrecht is really something for me.

During my search to improve the organization of multidisciplinary care in the Outpatient Clinic Endocrinology, I did not regret this choice for a moment. Both in Outpatient Clinic Endocrinology and Endocrine Surgery I was warmly welcomed. Especially, Gerlof Valk, Nick van der Meij, Menno Vriens and José Smit took the time to learn me all about the health care processes. With Gerlof and Nick I have also had many fruitful discussions about the content of the Master Thesis project. By questions like: “Are you still happy in the project?”, I also felt a lot of support on a personal level. Next to the support of the health care professionals, the interesting conversations with Arjan van Hoorn made my internship to what it was. Accompanied by Arjan I have been to several meetings in my field of study and participated in non-work activities like the relay race. Hereby I learned more about the organization of the UMC Utrecht and about the next step in my career in general.

The support from the supervisors of the University of Twente, I have experienced as very pleasant. Especially I would like to thank Gréanne Leeftink for her involvement in the execution of my Master Thesis. Not only professionally, but especially the personal conversations, have motivated me to get the best out of myself. From Erwin Hans I received great support on distance. My confidence in the project and myself was strongly enhanced by him.

Last but not least, I would like to thank my parents and Lisette for their support and ongoing believe in me.

Elieke van Sark
Utrecht, February 2016

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1 Introduction

The knowledge about the origin and treatment of cancer is rapidly growing. These developments ask for personalized cancer care in multidisciplinary teams. At the same time, the outpatient clinics of University Medical Center Utrecht (UMC Utrecht) no longer meet the functional needs. With a new design of the outpatient clinics, called “Outpatient clinic 3.0”, UMC Utrecht provides a framework to organize the multidisciplinary care more efficient.

In this report (multidisciplinary) capacity planning models are analyzed and the most appropriate planning tool is selected and developed. In Section 1.1 UMC Utrecht is introduced and the context of the project is made clear. Section 1.2 presents the motivation of the research. Section 1.3 presents the overall objective of the research, and Section 1.4 presents the selected case study. Section 1.5 describes the research questions tailored to the case study and ends with the project approach.

1.1 Context description

The UMC Utrecht is a leading national and international academic medical center, where “knowledge of health, illness and care is generated, evaluated, shared and applied for the benefit of patients and society” (UMC Utrecht, 2014c). With the merger in 2000 of Academic Hospital Utrecht (AHU), Wilhelmina Children’s Hospital (WCH) and Medical Faculty of Utrecht University (MFU), UMC Utrecht was founded. UMC Utrecht has grown to one of the largest health care organizations in the Netherlands, with 1,042 hospital beds, 11,169 employees and 4,720 students (UMC Utrecht, 2014a).

Over the last century, technological improvements as well as the costs of care and cultural and politic changes, have moved hospitals to have a more patient-empowered approach (Leonard, 2014). UMC Utrecht anticipated to this by developing a ‘Clinical need loop’; a dynamic process of innovation to develop new types of adequate care. Hereby the needs of the patient and society are central and leading in the choices made. The goal is innovation, whereby ‘state of the art’ patient care, extraordinary expertise and outstanding education are required to reach this goal (UMC Utrecht, 2014a). This is visualized in Figure 1.

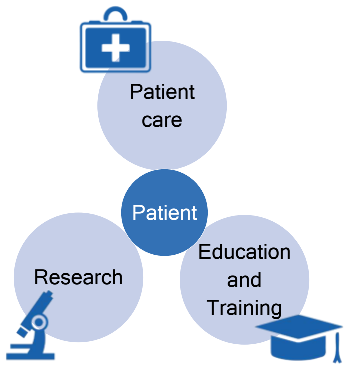


Figure 1: Core business of UMC Utrecht

1.1.1 UMC Utrecht Cancer Center

Since 2008 cancer is the leading cause of death in the Netherlands. The estimation is that 2.5% of the Dutch population deals with this disease, while this group is still growing (Wessels-Wynia, 2010) (Meulepas et al., 2011). Reason for this growth is the fact that the Dutch population is "double-aging": elderly people are increasing in number and are living longer. Besides this, the knowledge on cancer care has increased, which leads to a lower mortality rate (Meulepas et al., 2011). It has been discovered that cancer is a consequence of mutations in the DNA. These mutations, and thus the tumors as a result of these mutations, can vary a lot between two patients with the same type of cancer, which requires a personalized treatment for this disease (MEDIAPLANET, 2013). Both the growing group of cancer patients as well as the rapid-changing developments in the treatment of cancer asks for a specialized approach of cancer care. In other words, where first the Gastroenterologist (gastrointestinal tract and liver doctor) both treated gallstones and (malignant) tumors, today's trends requires a Gastroenterologist who provides specialized care to the oncologic gastroenterological disorders only.

UMC Utrecht meets this requirement by establishing the UMC Utrecht Cancer Center. This center is instituted in 2013 and is responsible for all oncologic care. With the introduction of the UMC Utrecht Cancer Center, the structure of oncologic care at UMC Utrecht has changed. Traditionally, the clusters where formed per specialty (the so-called mother specialty), where today most clusters are formed per disease or organ. In other words, formerly cancer care was organized by project groups including professionals from different functional divisions. Today, the cancer care is detached from the mother specialty and combined in an own division. This organizational change is visualized in Figure 2.

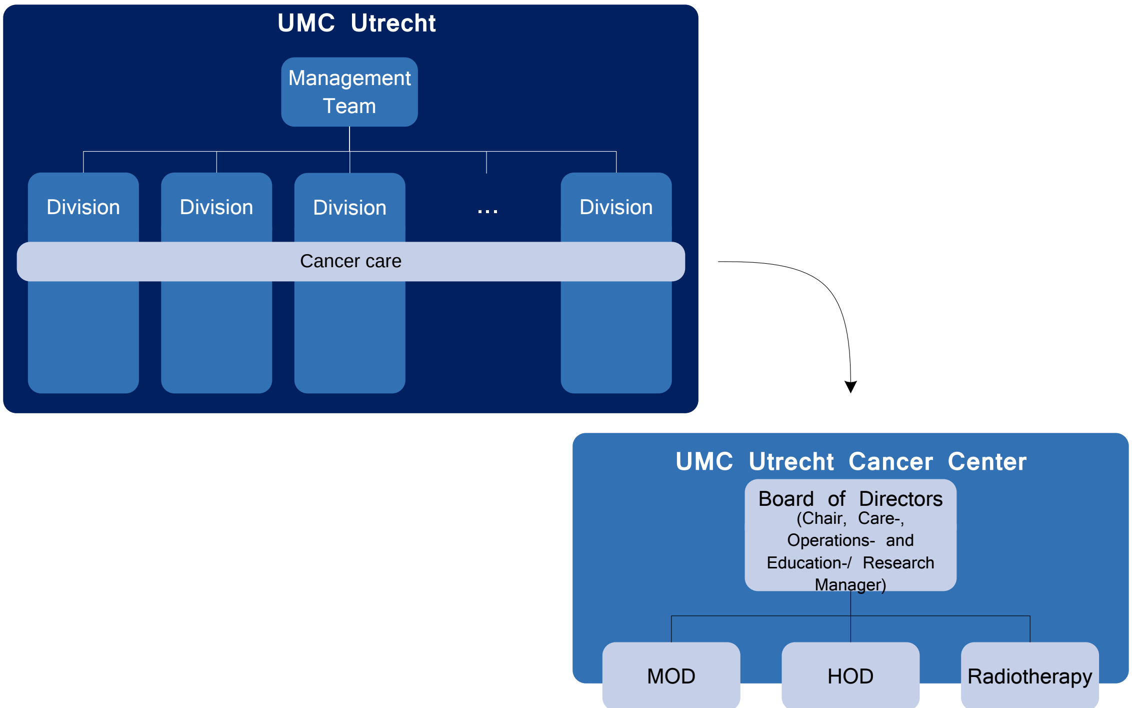


Figure 2: Organizational change to UMC Utrecht Cancer Center

In practice this means that the divisions of UMC Utrecht are divided into oncologic and non-oncologic care. In some cases this includes the division of staff into separate teams, where in other cases the staff provides both oncologic and non-oncologic care. MOD, HOD and radiotherapy form the disciplines of UMC Utrecht Cancer Center, where the abbreviation MOD (in Dutch: “Medische Oncologische Disciplines”) stands for the oncologic diseases treated with medication, while HOD (in Dutch: “Heelkundige Oncologische Disciplines”) includes surgical treatment of oncologic diseases.

The mission of the UMC Utrecht Cancer Center is “to cure people with cancer and improve the quality of life if this does not belong to the possibilities anymore”. To ensure that the patient is central in the decision-making regarding the treatment, UMC Utrecht Cancer Center has developed the Health Care Concept with promises to the patient. One of these focus points is Personalized Cancer Care (UMC Utrecht, 2014a). This implies that all potential treatments are careful considered by a multidisciplinary team. The multidisciplinary team exists of diagnostic and therapy specialists, e.g. the pathologist, radiologist, nuclear physician and the surgeon, oncologist, radiotherapist etc. In order to “monitor, promote and assure the quality of cancer care and research within a subspecialty of oncologic care” the UMC Utrecht Cancer Center started with setting up “Tumor Workgroup” (TWG). These groups support the multidisciplinary teams by coordinating the medical, nursing and organizational policies between the different disciplines. The organizational chart will look as follows (Figure 3):

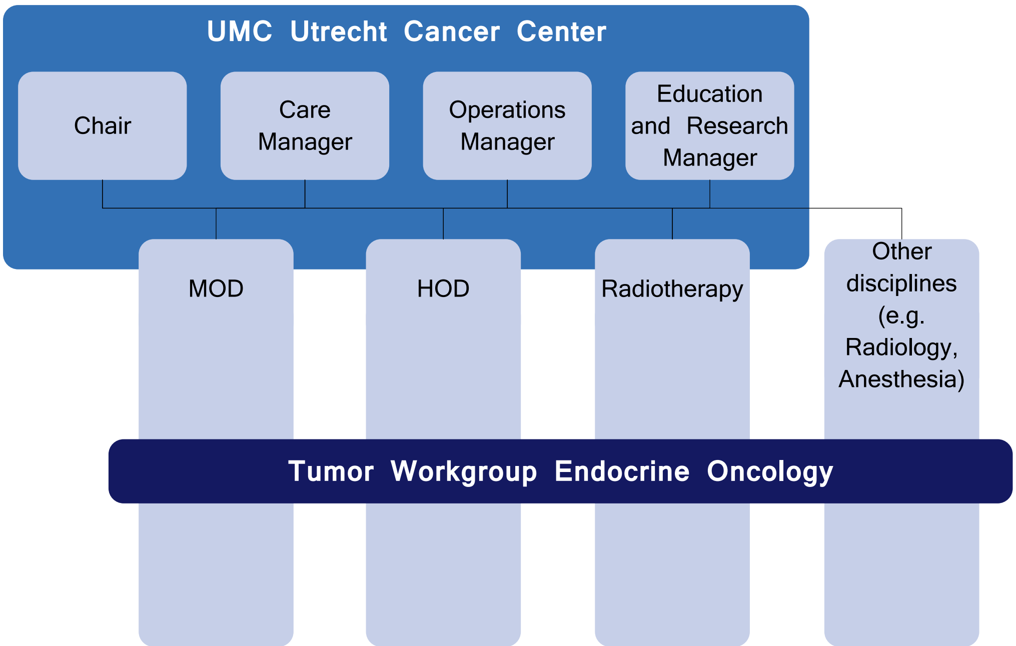


Figure 3: Tumor Workgroups in relation with UMC Utrecht Cancer Center

With the assistance of the Tumor Workgroups, the professionals are continuously stimulated to adapt studies and improve the treatments.

Next to the implementation of Tumor Workgroups, UMC Utrecht Cancer Center continues to develop and improve care pathways. With the development of care pathways, the steps in the treatment plan can be coordinated and the care can be unified. For the patient this will result in a more efficient route through the hospital.

1.1.2 "Outpatient clinic 3.0 - the human, the meeting, flexible and sustainable"

The aging of the population and the growing amount of medical treatments through innovation does not only stimulate the growth of the cancer population: the entire Dutch population is using more hospital care. From 1995 to 2005 the percentage of hospitalized Dutch people has increased from 9.8% to 11.5% (Eysink & Poos, 2011). Yet the amount of hospital beds in the Netherlands has decreased with circa 5% in the period from 2005 to 2008 (Deuning, 2009). This seems contradictory, however with a decrease in length of stay and shift from inpatients to outpatients and day patients, the use of beds can be compensated. Between 1993 and 2012, the length of stay for a patient has decreased with 50%. As shown in Figure 4, the number of outpatients and day patients increased respectively 10% and 250% (Centraal Bureau voor de Statistiek, 2014).

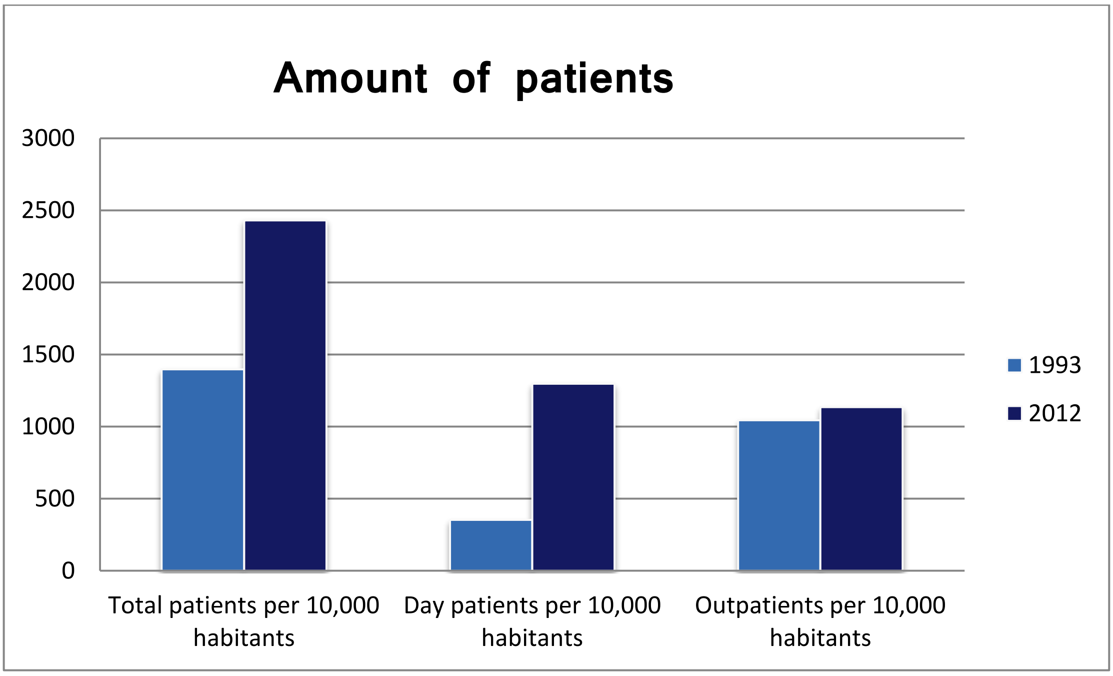


Figure 4: Amount of patients in the Netherlands between 1993 and 2012 (CBS, 2014)

In order to cope with the increasing number of outpatients and at the same time increase the comfort level for the patients, the clinical departments have to improve continuously. Consequently, UMC Utrecht will redesign and improve the outpatient clinics by realizing "Outpatient clinic 3.0". With the current design of the outpatient clinics, the number of health professionals has to increase in order to cope with the growing demand for health care. This results in higher costs for the hospital, which makes it not profitable to take on more patients. The new design of the outpatient clinic encourages the care processes to be organized more efficiently where at the same time the patient shall get a more participating role (UMC Utrecht, 2014b). The design of Outpatient Clinic 3.0 includes a circle of consulting rooms surrounding a workplace/meeting room for the medical staff of which Figure 5 is an abstract representation.

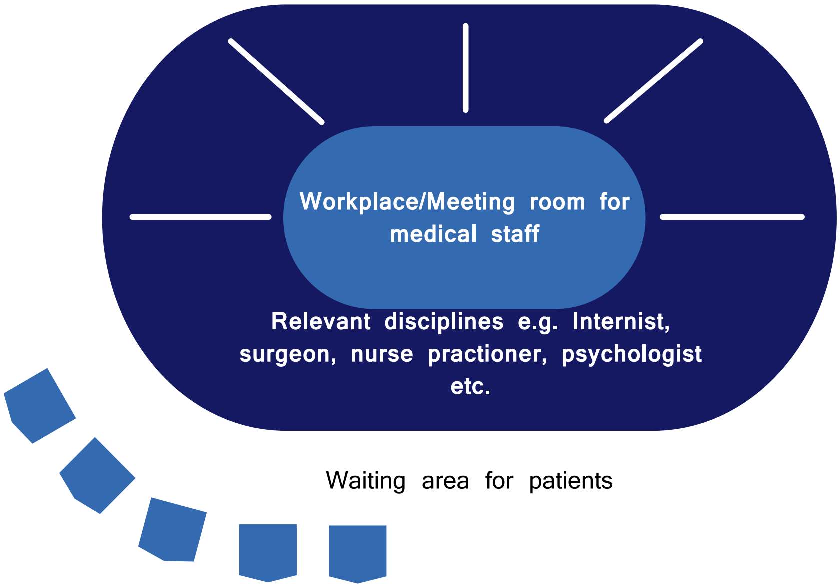


Figure 5: Representation of Outpatient clinic 3.0

The new design of the outpatient clinics facilitates meetings between staff of different disciplines and has the advantage that less space is needed. Although the amount of patients increases (to 350,000 patients a year over all outpatient clinics), with the new outpatient clinics, “UMC Utrecht expects the building volume to decrease with one third” (UMC Utrecht, 2014b).

1.2 Research motivation

From the Context Description we can conclude that there are several ongoing developments in health care. UMC Utrecht, as a leading Academic Medical Center, strives to continuously anticipate to these developments in order to stay ahead of fellow hospitals. A summary of the evolvements in health care and anticipations of UMC Utrecht to these are presented below to emphasize the need for this research.

According to Meulepas et al. (2011) the population in general is changing as a consequence of the “double-aging” phenomenon. This results in more hospitalized people in general, in specific in more cancer patients.

The evolvements in knowledge and treatment possibilities of (cancer) care are going incredibly fast. We now know that cancer needs a more personalized approach, where UMC Utrecht Cancer Center takes the lead. In the Health Care Concept of UMC Utrecht Cancer Center promises are made to the patient to: (amongst other) provide personalized care by a specialized multidisciplinary team.

On the other hand there is a shift from inpatients to day- and outpatients in hospitals. In order to be able to provide efficient care pathways to the growing group of patients, UMC Utrecht is building Outpatient Clinic 3.0. Prerequisites for an efficient organization of care in this clinic are well-working care pathways and good coordination between the different disciplines in the multidisciplinary teams.

These findings are summarized in Figure 6.

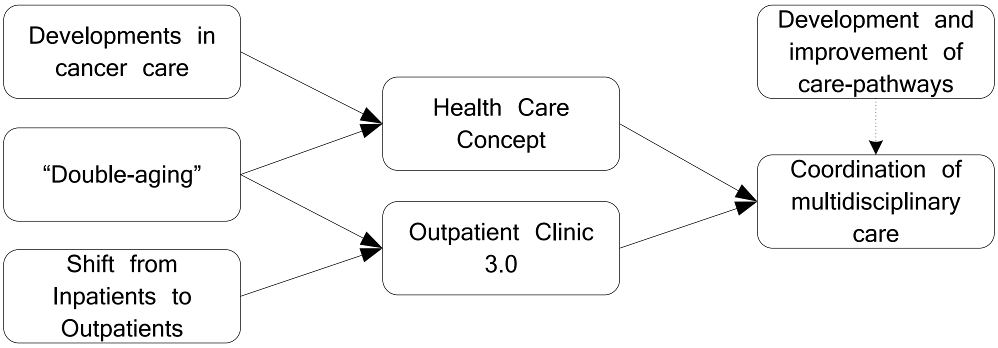


Figure 6: Problem cluster

So, to keep the promises to the patient (in the Health Care Concept) and to efficiently organize the care in Outpatient Clinic 3.0, the multidisciplinary teams should be well-coordinated. Currently the planning (on tactical as well as operational level) of the various disciplines of the team is based on empirical data. In other words, the agendas are individually designed by logical reasoning. The lack of coordination between the disciplines results in inconvenience for both the patients and the professionals. So there is a wish to design a capacity planning instrument, to support the tactical decisions of the multidisciplinary care.

1.3 Research objective

The findings in the previous section lead us to the research objective:

*Develop a prototype **flexible resource capacity planning** instrument that supports the decision-making of the capacity plans of the **multidisciplinary team** in the **outpatient clinics**, where the objective is to **maximize the quality of care**, while **maximizing the utilization of professionals and consulting rooms**.*

The highlighted words in the research objective need extra attention as these influence the success of the instrument the most. First the instrument needs to be **flexible**, i.e. the model is dependent on several parameters which must be able to be adjusted. For instance the input of the model, the number of patients, is variable. This number depends on the growth of the number of cancer patients as well as on the exchange of patients with other hospitals. Flexibility of the model is a prerequisite to be able to generalize the model and adapt it to the specific specialties.

We are looking for a **resource capacity planning** instrument as UMC Utrecht needs support on the tactical planning level. Questions like: “How much consulting rooms do we need?”, “How many time-slots in the agenda of the professional are required?” etc. need to be answered. Hereby, we emphasize that the planning instrument is a **prototype**. To build a complete end product, which is user-friendly and easy to modify, specialized programming skill are required, which is not part of this research.

The object of the instrument is the **multidisciplinary team**, which should be efficiently coordinated. In the future, **Outpatient Clinic 3.0** is the environment in which the instrument has to operate. Therefore, the instrument has to cope with the building and planning restrictions of this environment. For instance, not all disciplines can be moved to the carousel, because of the required medical instruments or coordination with the rest of the department.

This objective of the instrument is based on the general objective of health care organizations “to provide high-quality care using the limited resources that are available” (Hulshof, Kortbeek, Boucherie, Hans, & Bakker, 2012). The **quality of care** for individual patients can be rated by dividing it into access and effectiveness. Thus, “are services available according to need and are these services effective?” (Campbell, Roland, & Buetow, 2000). **Maximizing utilization** and minimizing resources are closely related. When every professional and consulting room is fully planned, less professionals and rooms are necessary.

1.4 Case study

To narrow down the scope of this research one oncologic specialty will be chosen as research area. Endocrinology will be the specialty of our interest. This specialty focuses on providing care to patients with deviations in organs that regulate the endocrine system. Organs that produce hormones include: adrenals, the genitals, pancreas, pituitary, thyroid and parathyroid (UMC Utrecht, 2015). Hereby the diseases can be divided into oncologic and non-oncologic diseases.

Since the beginning of 2015, Endocrine Oncology is part of the UMC Utrecht Cancer Center as well. Although the oncology and non-oncology department of Endocrinology are organizationally separated, the care for both types is still provided at the same outpatient clinic. With the building of Outpatient Clinic 3.0, the UMC Utrecht Cancer Center will get its own clinic, which means that the consults of Endocrine Oncology will also be physically separated from the consults of non-oncologic Endocrinology.

The goal is to organize the multidisciplinary care for Endocrine Oncology in the format of Outpatient Clinic 3.0. Most disciplines involved can be specified based on the care pathway of an Endocrine Oncology patient (Figure 7).

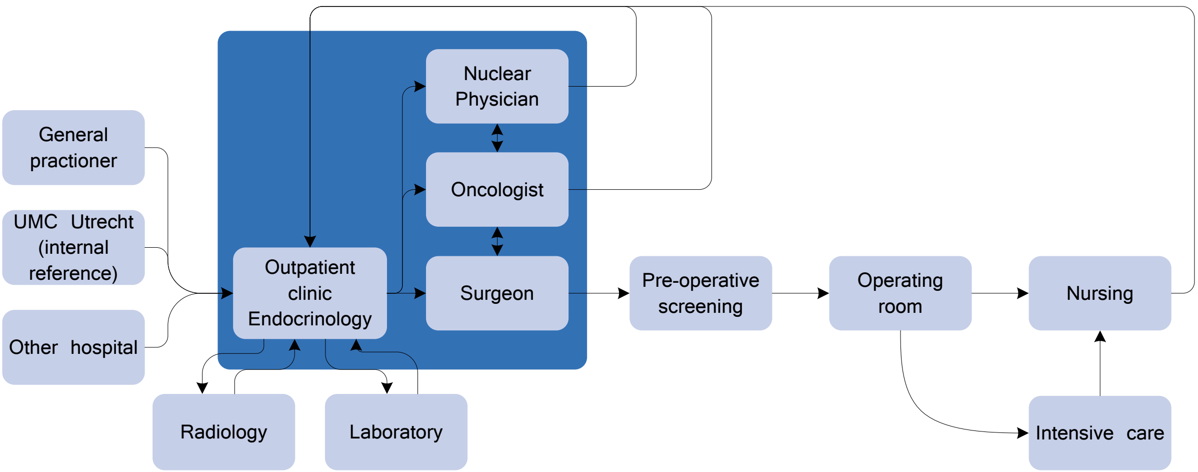


Figure 7: General overview the care pathway of a patient of outpatient clinic Endocrinology adapted from (van Stek, 2015)

Figure 7 shows the journey of an Endocrinology-patient through UMC Utrecht; starting with the referral by the general practitioner or specialist to the outpatient clinic, here the patient meets the Endocrinology specialists (internist, nurse specialist and/or genetic counselor) who may request the patient to visit the radiologist and/or laboratory. If treatment is necessary, a consult with the surgeon and/or radiotherapist will be scheduled, followed by the rest of the care pathway. The highlighted area indicates the scope of our research; the planning of the specialists in the outpatient clinics of Endocrinology, CGO (the Surgical Gastroenterological Oncology) and Radiotherapy should be multidisciplinary coordinated to let Outpatient Clinic 3.0 be successful. Hereby the influence of the planning on the mother specialty should be taken into account. Figure 8 gives an organizational overview of the research scope.

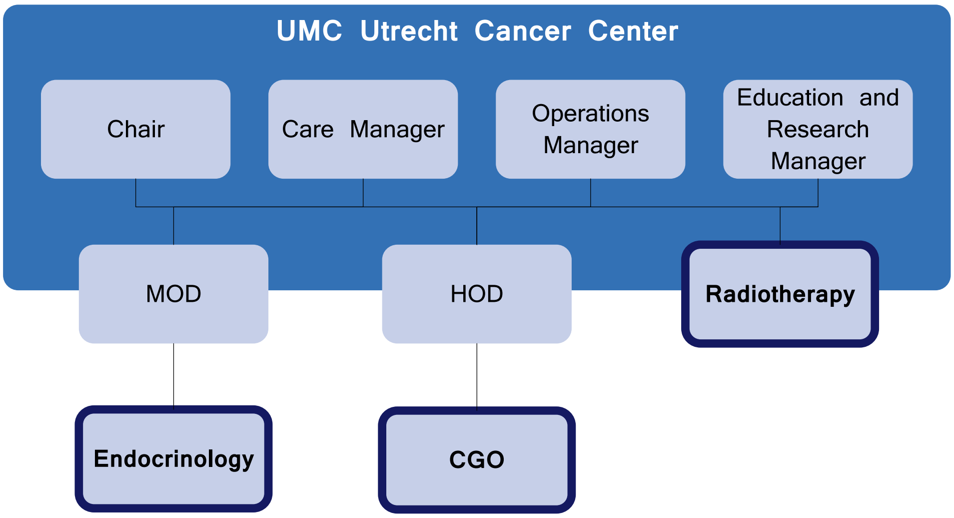


Figure 8: Organizational overview of the research

The outpatient clinic of Endocrine Oncology is chosen as case study, because the care in this department is already multidisciplinary organized. The care is standardized and the professionals meet each other's needs. Moreover, this specialty is ahead of other specialties in documenting the care pathways of specific diseases.

1.5 Research questions

In order to realize the research objective the following research questions have to be answered:

1. What is the current situation concerning Endocrine Oncologic care in terms of consultation and scheduling processes and what is the performance of these processes? [Chapter 2]
    - 1.1. What are the consultation processes at outpatient clinic Endocrinology and CGO?
        - 1.1.1. What are the characteristics of Oncologic Endocrine patients?
        - 1.1.2. What does the care pathway of Oncologic Endocrine patients look like?
        - 1.1.3. How are the appointment scheduling processes at outpatient clinic Endocrinology and CGO organized?
    - 1.2. Do the outpatient clinics use flexibility to accommodate variations in supply and demand?
        - 1.2.1. What does the planning and control on strategic level look like?
        - 1.2.2. What does the planning and control on tactical level look like?
        - 1.2.3. What does the planning and control on operational level look like?
    - 1.3. What is the performance of the scheduling processes?
        - 1.3.1. What performance indicators can we use to quantify the scheduling processes?
        - 1.3.2. What is the actual performance of the current scheduling processes?
    - 1.4. Which (scheduling) processes of outpatient clinic Endocrinology and CGO are underperforming and can be designed more efficiently?

Question 1.1 gives an overview of the processes at outpatient clinic Endocrinology and CGO. Question 1.2 focuses on the planning and control of the appointments at the outpatient clinics, e.g. what appointment rules are currently used? The required information for question 1.1 and 1.2 is obtained by means of interviews with: the professionals of both departments and policy makers and available documents about these departments. By answering question 1.3 the performance indicators are defined and used to determine the performance of the current processes. Hereby the choice of performance indicators is inspired by literature and interviews. The performance of the current processes is determined by analyzing data from the Electronic hospital information system (EZIS) and collected data about the appointment times. Question 1.4 summarizes the inefficiencies in the processes of outpatient clinic Endocrinology and CGO and presents a demarcation of the core problem.

2. How can multidisciplinary appointments be coordinated? [Chapter 3]

2.1. What are the characteristics of multidisciplinary care?

2.2. How can multidisciplinary appointments be arranged in a carousel?

2.3. What should be focused on to improve efficiency in health care?

2.4. How can the processes be designed and organized?

2.5. What approaches are presented in the literature to develop a planning model?

2.6. What appointment systems are presented in the literature?

Question 2 is answered by means of a literature study. This study investigates the main points of improvements in the organization of health care processes and presents models to overcome these problems.

3. How can the consultation and scheduling processes be modeled? [Chapter 4]

   3.1. What does the *Analytic* model of the current situation look like?

4. How can the consultation and scheduling processes be modeled using a *Simulation* model? [Chapter 5]

   4.1. What does the conceptual model of the processes look like?

   4.2. What are the input parameters for the model?

   4.3. How is the conceptual model translated in a computer model?

   4.4. Is the programmed model valid?

Question 3 and Question 4 apply the theoretical models, which are presented in Chapter 3, to the current system. Respectively Question 3 presents the *Analytic* model, while Question 4 presents the *Simulation* model. The seven-step approach of Law and Kelton (2003) is used as guidance for the Simulation model. The required input parameters for the model are extracted from available hospital data (EZIS). Input data which cannot be obtained from EZIS, will be determined from real life measurements. Model verification is achieved by comparing the computer model with the conceptual model. Model validation is achieved by comparing output from the programmed Simulation model with the real life performance.

5. What does the experimental design look like? [Chapter 6]

   5.1. What improvements to the Appointment System are suggested?

   5.2. What parameters may be of influence to the performance of the model?

Question 5 presents the interventions from the literatures, which are expected to have a (positive) effect on the performance indicators. By answering Question 5.2 the influence of parameters on the output is tested; in other words a sensitivity analysis is performed.

6. What is the impact of different scenarios on the performance of the outpatient clinics? [Chapter 7]

To answer Question 6, several statistical analyses are performed on the output of the model. The efficient frontier presents the trade-off between the patient's and doctor's performance.

7. What are the recommendations concerning the implementation of the scenarios with the best performance? [Chapter 8]

2 Context analysis

The context analysis can be divided into three stages: *process* (Section 2.1), *planning and control* (Section 2.2) and *performance* (Section 2.3). With the knowledge gathered during the context analysis, Section 2.4 presents a demarcation of the core problem.

2.1 Process description

This section elaborates the organization of the processes at outpatient clinic Endocrinology and CGO. Section 2.1.1 describes the characteristics of Endocrine patients, because these influence the process steps. Section 2.1.2 presents the care pathway of an Endocrine patient. Section 2.1.3 presents the appointment scheduling processes.

2.1.1 Patient group

The specialty Endocrinology focuses on deviations in hormone producing organs (section 1.4 Case study). The specialists of Endocrine Oncology treat patients with tumors in the (Neuro-)Endocrine system: Endocrine and Neuro-Endocrine Tumors (NET), or patients with a high risk of developing these tumors. The diagnosis and treatment of Neuro-Endocrine tumors is difficult, mostly because these tumors are rare (approximately 700 newly diagnosed patients per year in the Netherlands) and vary between patients (UMC Utrecht, 2015). For some of these patients, the tumor is caused by a genetic disorder. Examples are the MEN-1, MEN-2a, MEN-2b and the Von Hippel-Lindau (VHL) syndrome. For more information on Neuro-Endocrine Tumors and the syndromes causing these tumors, see Appendix A.

Growth of patient volume

The chronic nature of patients with a syndrome, together with the exchange of palliative patients for curative patients with Antoni van Leeuwenhoek hospital (AVL), makes that the department Endocrine Oncology faces a high return rate of patients. The return rate of patients can be calculated as follows (CBO, 2007):

$$Return\,rate = \frac{All\ consultations}{Number\ of\ intakes}$$

Based on data from January 2015 to November 2015, the return rate at Endocrine Oncology is 4.87. So on average patients visit the clinic 4.87 times.

UMC Utrecht experiences a growth in the amount of newly diagnosed patients (Table 4). The high return rate and growth of new patients results in an increasing amount of appointments for the specialists at Endocrine Oncology.

Table 4: Amount of newly diagnosed patients between 2013 and November 2015 at UMCU (from EZIS)

	MEN-1	MEN-2	Carcinoïd syndrome (gastrointestinal, lungs)	Pheochromocytoma (adrenal glands)	Paraganglioma (head, neck, thorax)	Von Hippel-Lindau (brain, pancreas)	Thyroid Carcinoma	Total
2013	10	4	0	3	0	0	34	51
2014	8	4	2	8	4	2	56	84
2015 (up to November)	15	4	31	19	19	15	85	188

2.1.2 Care pathway of Endocrinology patients

The first visit of a patient to outpatient clinic Endocrinology is the result of a referral of: 1) the General practitioner, 2) an other hospital or 3) an internal reference. New patients can be divided into four groups: 1) founded suspicion of malignancy, 2) proven malignancy, 3) suspicion on genetic disorders and 4) genetic disorder with an increased risk of malignity.

Patients of all types receive an appointment with the Internist Endocrinologist; the primary practitioner. During this consultation, the Internist performs anamneses, where after he decides on the additional diagnostics and consultations needed. The diagnostics exist mostly of a blood investigation and imaging tests, so the patient has to visit the Laboratory and the Radiology department. In case the Internist Endocrinologist has clinically diagnosed the type 3 patient with a genetic disorder, this patient may receive a DNA-investigation. When the patient is advised to have additional consultations, the patient receives an appointment for the Nurse Specialist or Genetic Counselor who are located at the outpatient clinic. See Figure 9 for the route of the patient through the hospital.

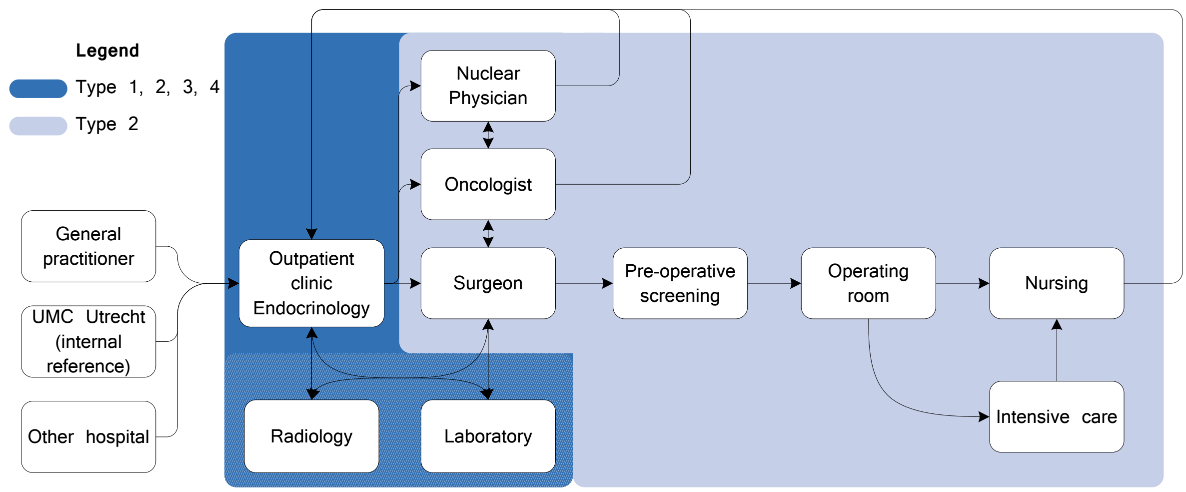


Figure 9: General overview the care pathway of a patient of outpatient clinic Endocrinology adapted from van Stek (2015)

In case the diagnostic tests show a deviation in a hormone producing organ of the patient, a treatment plan shall be created. As one of the focus points of UMC Utrecht Cancer Center is “Personalized Cancer Care”, weekly a multidisciplinary meeting (MDO) is planned where the treatment policy for an individual patient is determined by all the disciplines involved in the care of Endocrine patients (Figure 10).

The specialists involved can be divided into diagnostic (Radiologist and Pathologist) and therapy specialists (Genetic counselor, Nurse Specialist, Internist Endocrinologist, Surgeon, Internist Oncologist and Nuclear Physician). The Genetic counselor, Internist Oncologist and Nuclear Physician are only in some cases involved in the care process; respectively in case of genetic disorders (type 3 and 4), radio-/ or chemotherapy is required or nuclear medicine is required (in some cases of type 2).

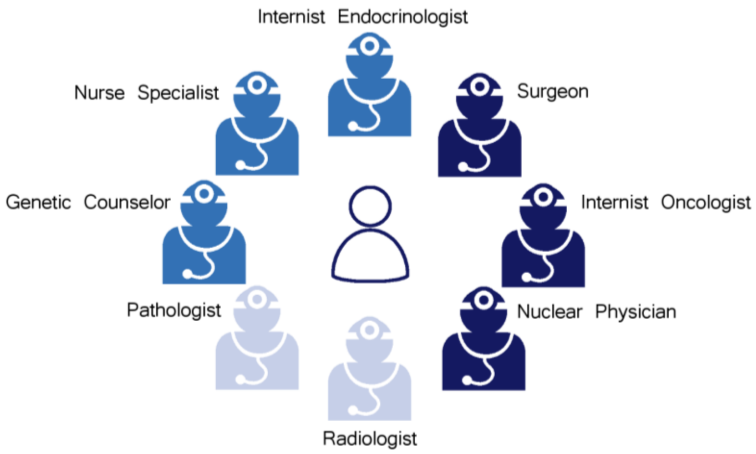


Figure 10: Visualization of the multidisciplinary meeting

In case the tumor is graded as a slow-growing (benignant) tumor the advice can be to postpone the treatment. This means that the patients should regularly be reassessed by the Internist Endocrinologist (and other specialists), until surgery is necessary. In case of a malignant tumor the patient will receive a treatment indication and becomes a type 2 patient. For most Endocrinology patients this treatment exists of surgery, thus the patient is referred to the outpatient clinic Endocrine Surgery to have an appointment with the Surgeon.

The patients with a surgery-indication arrive at the outpatient clinic Endocrine Surgery. Patients with rare tumors (type 2) are assigned to the Surgeon and patients with benignant tumors receive a consultation by either the Surgeon or the Resident Doctor. In case the tumor of the patient is a consequence of a genetic disorder (e.g. MEN1 or MEN2) the patient may receive a *combination consultation* with both the Surgeon and the Internist Endocrinologist.

During the consultation of a new patient, the Surgeon (or Resident Doctor) performs anamneses and/or physical examination. If additional information is needed, the patient is requested to visit the Laboratory and/or Radiology department to give blood or do imaging tests. In some cases a biopsy is needed to grade the tumor of the patient. In this case, the patient is referred to day care. When the results of the tests are available a definitive decide is taken on the progress of the treatment plan. This decision is communicated to the patient in a telephone or physical consultation. If the patient will receive surgery an operating room is scheduled and the patient is sent to Pre-Operative Screening (POS).

After surgery the patient returns back at the outpatient clinic Endocrine Surgery for a check-up and removal of the stitches. In most cases the contact with the Surgeon ends here and the patient is referred back to the Internist Endocrinologist for the (semi-) annual check-ups.

2.1.3 Appointment scheduling processes

The patient requests an appointment by phone, e-mail or at the counter in the outpatient clinic. Upon appointment request the scheduler has to perform several tasks: 1) decide if the patient needs a combination appointment, 2) decide on the consultation type of the patient, 3) decide on the doctor for the patient, 4) decide on the appropriate time slot for the appointment and 5) schedule the appointment.

1) A combination appointment (indicated with ENDCHI or CHIEND) is often requested by the Internist Endocrinologist. If the right code is used for the booking, the combination appointment is booked in both the agenda of the Surgeon and the agenda of the Internist. Subsequently the patient receives a confirmation with both doctors on it, but only *one* location on it. Because the amount of combination patients is currently low and the amount of appointment schedulers is high, not all schedulers are aware of the scheduling policies. This results in "wrongly" booked patients, i.e. patients who are booked in the agenda of just one specialist (occurred 7 times of the in total 14 patients from January until August 2015), or patients who are separately booked for both specialists and consequently receive two locations to check-in (occurred 3 times of the in total 14 patients from January until August 2015). These observations ask for an improvement of the combination appointment scheduling. When decided whether the patient is a combination patient, the scheduler has to decide on the consultation type.

2) Physical appointments can be divided into two groups: *new* and *check-up* appointments.

At Endocrinology, check-up appointments can subsequently be divided into four larger groups depending on the diagnose of the patients: *check-up MEN-1 (CM1), check-up MEN-2 (CM2), check-up Von Hippel Lindau (CVHL)* and (the remaining) *check-up* patients (C). The length of the appointment depends on the consultation type. For example, for a new patient 45 minutes are reserved, for a general check-up 15 minutes and for a check-up MEN-1 or MEN-2 20 minutes. It is often hard for the receptionist to categorize the patients based on the diagnosis, because the receptionist has no medical background.

Endocrine Surgery's check-up appointments can be divided into: *check-up (C)* and *check-up after surgery (CNO)*, respectively with a duration of 20, 15 and 15 minutes. See Appendix A for the complete overview of patient types and appointment slots.

Patients that have (a suspicion on) a (malignant) deviation need to be scheduled as quickly as possible. In Endocrine Surgery this goes for almost all patients, which means all patients are categorized as urgent. This means the scheduling of patients is not flexible and depends highly on the inflow of patients. Patients that have no suspicion on deviations yet, but do have a high risk on deviations (as a consequence of a genetic disorder) can be categorized as non-urgent. These patients are scheduled after a fixed time period of half a year, or year (within the planning horizon). Additionally, both appointment clinics have telephone consults. When the consultation type is selected, the doctor needs to be selected.

3) Internist A of Outpatient Clinic Endocrinology is mostly dedicated to patients with the MEN-syndrome. This results in mostly check-up patients for Internist A. Internist B receives new patients and the remaining check-up patients. Outpatient Clinic Endocrine Surgery has no personalized agenda, just one general agenda: "Consultation hour Endocrine Surgery". So the scheduler does not need to decide whether a patient is seen by the Resident Doctor or the Surgeon.

4) Outpatient clinic Endocrine Oncology and Endocrine Surgery both use dedicated time slots to schedule the appointments of patients. This means that for a certain consultation type a specific appointment interval with a pre-defined length is reserved.

Endocrine Oncology categorizes the timeslots as:

- Regular timeslots for *new* and *check-up* patients (20 min),
- Combination timeslots for combination patients for *new* or *check-up* patients (15 min),
- Telephone timeslots for *check-up* patients (5 min),
- Supervision timeslots (20 min).

Endocrine Surgery categorizes the timeslots as:

- Regular time slots for *new* (20 min),
- Regular time slots for *check-up* patients (15 min),
- Combination time slots for combination patients for *new* or *check-up* patients (15 min),
- Telephone time slots for *check-up* patients (5 min).

Remarkable is that Endocrinology's appointment-lengths (according to patient type) do not correspond with the timeslots they are dedicated to. Thus, a general check-up patient will be assigned to a regular timeslot causing a gap of 5 unplanned minutes.

5) When an empty timeslot is found (taking the consultation type into account), the scheduler can schedule the appointment. When no empty timeslot can be found, but the patient is urgent (needs a consultation within a week), the scheduler can decide to double book a timeslot in the agenda of the Endocrine Surgeon. For Endocrinology patients appointments can be scheduled up to 12 months in the future, i.e. the rolling planning horizon is 12 months for Endocrinology. For Endocrine Surgery this is 3 months. When the appointment is scheduled, the patient receives a confirmation. On this confirmation the appointment date, time, specialist and location is specified.

See Figure B-1 and Figure B-2 (in Appendix B) for the flowchart of the scheduling processes and Appendix C for additional information about the doctor's processes of Endocrine Surgery and Endocrine Oncology.

2.2 Planning and control

In this section the planning and control of the processes of Outpatient Clinic Endocrinology and Endocrine Surgery shall be described following the hierarchical levels of the Health care planning and control Framework (Hans, Van Houdenhoven, & Hulshof, 2012): the strategic, tactical, offline and online operational level. The main area of interest for this research is the resource capacity planning. The theory behind the model of Hans et al. (2012) is elaborated in Section 3.4.

2.2.1 Strategic level

The strategic level concerns the organization's long term goals. One of these goals is to keep the access times of the patients to the outpatient clinics within norms (see Section 2.3 for these norms). To make sure these objectives are achieved, the (long-term) supply should meet the demand. As mentioned in Section 2.1.1 the volume of the patient group has increased and therefore the prediction is that the demand shall further increase in the upcoming years. Possibilities for Endocrinology to response to this growth are: to reallocate the patients between the specialists, to change the responsibilities of the Nurse Specialist from a supporting specialist to a care manager who has own patients, etc.

2.2.2 Tactical level

The tactical level concerns the midterm planning decisions like staffing and working in overtime.

Staffing

Since 2015, the department of Endocrine Oncology is part of UMC Utrecht Cancer Center. This means that part of the staff of outpatient clinic Endocrinology is assigned to oncologic care. The staff of Endocrine Oncology consists of 2 Internist Endocrinologists and 1 Nurse

Specialists. The staff of Endocrine Surgery consists of 1 Surgeon and 1 dedicated Nurse. In addition, some of the clinic sessions of the Specialists or Resident Doctors are attended by medical students (Dutch: “co-assistenten”). These students are not authorized to independently treat a patient.

The staffing of Endocrine Surgery is highly flexible: the main Surgeon is supported by another Surgeon in case of absence and most of the time a Resident Doctor, that can (independently) treat patients, is available. The staffing of Endocrinology is inflexible. When an Internist is unable to attend the clinic session, the clinic session is canceled. Data from EZIS about the production weeks shows the effect of the flexibility of the outpatient clinics on the capacity.

Capacity

The number of production weeks per year of Outpatient Clinic Endocrinology is on average 42, based on data from January 2014 to December 2015 from EZIS. The clinic sessions of Internist A and the Nurse Specialist are on Monday and every other week on Wednesday, so on average 63 sessions per year. Internist B provides clinic sessions on Monday and Thursday; 84 sessions per year and the Genetic Counselor provide clinic sessions on Monday 42 per year. The number of production weeks per year in Outpatient Clinic Endocrine Surgery is on average 47.

The average duration of a clinic session is 180 minutes for Endocrinology, 240 minutes for Endocrine Surgery and 60 minutes for Genetic Counseling. An overview of the clinic session days and the number of slots available per clinic session is given in Appendix E.

2.2.3 Offline operational

When all appointment decisions are made prior to the start of the clinic session, the system is called offline operational, i.e. static. Figure C-1 shows that the appointments for the Internists are made during the scheduling processes so prior to the clinic session. Thus the schedule of the Internists is static. The same goes for the Surgeon (Figure C-2).

Appointment rules

According to the appointment rules described by Cayirli & Veral (2003) the Internist and Surgeon both use the *individual-block/variable-interval* appointment rule. The mathematical representation is given in Figure 11.

$n_i = 1 \; \forall \; i = 1, 2, 3, \dots, N$

$a_i \; variable$

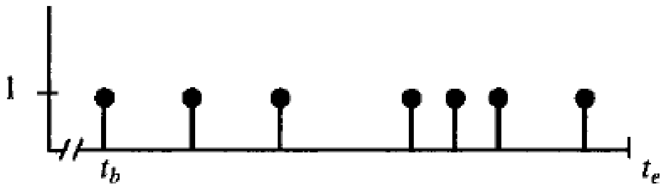


Figure 11: Individual-block/variable-interval rule (Cayirli & Veral, 2003)

With a_i = appointment interval, t_b = time begin session, t_e = time end session, n_i = block size for i[th] block, n_1 = initial block. This appointment rule implies that patients are individually scheduled, in contrast to *multiple-block* or *variable-block* where a (variable) group of patients is assigned to an appointment slot. The appointment intervals vary depending on the patient classification.

Sequencing rules

Endocrine Oncology does not make use of any sequencing rules. During the general timeslots, patients of all consultation types (N, C, CM1, CM2 etc.) are randomly booked. Endocrine Surgery makes use of the alternating sequencing rule (ALTER), so *new* and *check-up* patients alternate with each other.

Overbooking

As mentioned in Section 2.1.3 Appointment scheduling processes all Endocrine Surgery's patients are categorized as urgent. The outpatient clinic therefore strives to give all new patients an appointment within a week. The patients who received surgery also need to receive a check-up appointment in the first possible clinic session. In reality, this results in the overbooking of clinic sessions. The *individual-block* appointment rule is changed into a *variable-block* appointment rule where multiple patients are booked on the same appointment slot. For example patient 1 is scheduled at 9:00 o'clock and patient 2 at 9:10, although the timeslot of patient 1 originally was 20 minutes. The scheduler tries to comply with the scheduling rules. For example, the roster will change from CNCNCNCNC to CCNNCCNNCCNNCC.

The scheduler of Endocrine Surgery mentions that in case it is known that the Resident Doctor will be present at a consultation session, extra patients are scheduled. In this way, Endocrine Surgery makes use of the flexibility in capacity. Endocrinology only overbooks telephone consultations. This means that at the offline operational level, Endocrinology has a low flexibility.

2.2.4 Online operational

A online operational (dynamic) system schedules patients as they arrive, which means that the schedule is continuously revised (Cayirli & Veral, 2003).

The appointments of the Nurse Specialist and Genetic Counselor are partially planned during the doctor's processes (Figure C-1). This means these schedules are partially dynamic and partially static. When a patient is referred to the Nurse Specialist or Genetic Counselor by the Internist, it is important that these specialists are (almost) instantly available for the patient. For example after a patient received bad news from the Internist, he needs to receive psychological support by the Nurse Specialist. If the Nurse Specialist is occupied with scheduled patients at that moment, the referred patient may decide to cancel the appointment. This is not desirable and not patient-friendly.

Staff can flexibly be assigned to the patients in Outpatient Clinic Endocrine Surgery (in case the Resident Doctor is present and the patient is not diagnosed with a malignant tumor). In Outpatient Clinic Endocrinology, patients can only be treated by their own specialist, which results in a low flexibility.

2.3 Performance

As mentioned in the introduction, the objective in health care to: "to provide high-quality care using the limited resources that are available" (Hulshof et al., 2012). In order to develop an appropriate planning system which meets this objective, first the performance measures should be defined.

Waiting time (W_i) of patients, flow time (F_i) of patients, idle time (I_i) of doctors and overtime (O) of doctors are the most common performance criteria presented in the literature (Cayirli & Veral, 2003). Waiting time is the time a patient needs to wait for the appointment. Hereby the waiting time in outpatient clinics can be divided into 'micro' and 'macro' waiting; 'micro' waiting time refers to the time between the scheduled start of the appointment and the actual start of the appointment and 'macro' to "the delay between patients' need for specialist treatment (referral date) and actual date of treatment (outpatient clinic date)" (Günal & Pidd, 2010). Günal & Pidd (2010) state that although most studies focus on 'micro' waiting, 'macro' waiting is more significant for patients. In this research 'macro' waiting time will be referred to as access time and 'micro' waiting time as waiting time (Zonderland, 2014). The flow time is the total time a patient spends in the clinic, i.e. the service time added to the waiting time. These computations are visualized in Figure 12.

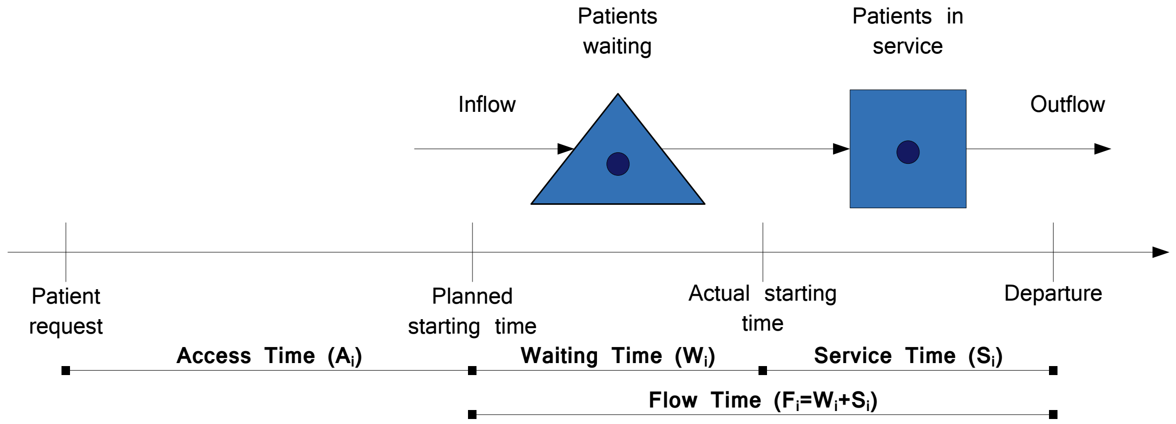


Figure 12: Computation expected Waiting, Service and Flow Time

The total time there is no patient in service with the doctor, while at the same time no patient is waiting to be seen, is called idle time. Overtime is the (nonnegative) difference between the desired and actual completion time of the clinic session (Cayirli & Veral, 2003).

2.3.1 Performance indicators of interest

In agreement with the decision-makers we decided on the following performance indicators:

1. Access time;
2. Waiting time;
3. Utilization;
4. Overtime.

There is a strong focus on access time, because in the Netherlands there is a norm for the maximal acceptable access time, the “Treeknormen”. The “Treeknormen” state that the access time to an outpatient clinic should be maximal 4 weeks, where 80% of the patients should be consulted within 3 weeks. The same norm for access times goes for diagnostics/treatment indication.

Waiting time and overtime are chosen, because these are recommended by literature. We decide to leave idle time (and flow time) outside of consideration and analyze the utilization of the specialists instead, because it is hard to record the actions of the specialists in between the consultations and to assign this spare time to a specific reason. To indicate whether the current Appointment System is appropriate, also the service time (consultation time) shall be investigated.

To formulate the performance indicators formally, the following parameters and indices are used:

A =	Access time	p =	Patient ∈ {1,…,n}
W =	(Internal) waiting time	d =	Doctor ∈ {1,…,m}
O =	Overtime		

Access time

The access time of a patient in the clinic is calculated as the actual appointment date minus the date of the appointment request. In formula, the average access time (for doctor d) is:

$$A = \frac{\sum_{p=1}^{n} D'_{p,d} - D_{p,d}}{n}$$

$D_{p,d}$ = Date of appointment request

$D'_{p,d}$ = Actual date of treatment

Data from EZIS in the period of January 2015 to November 2015 has been analyzed to determine the current access time for the specialists. It is hereby important to only take the first consults into account. Taking check-up consults into account can give an unreliable picture of the situation, because chronic patients may directly after their visit request a next appointment for over a year. According to the calculation above, this will lead to an access time of 365 days, which is not representative. Because the Nurse Specialist and Genetic Counselor do not distinct between new and check-up patients, their access times are disregarded. The calculated access times are presented in Table 5.

Table 5: Average access time to the Internists and Surgeon (in days)

Patient type	Internist A	Internist B	Surgeon
New (N)	35.5 (N=19)	25.1 (N=89)	10.1 (N=206)
New (without displacements)	18.1 (N=13)	15.7 (N=71)	8.7 (N=184)
Check-up (C)	84.3 (N=48)	65.6 (N=148)	36.8 (N=150)
Check-up MEN-1 (CM1)	155.2 (N=125)	100.3 (N=28)	
Check-up MEN-2 (CM2)	133.1 (N=78)	162.9 (N=13)	
Check-up after surgery (CNO)			10.8 (N=173)

If we do not take patients into account whose appointment has been rescheduled between the date of appointment request and actual date of appointment, the average access time is considerably lower. For data about the replacements, see Section 5.2 Data and information collection. The high calculated access time for chronic patients (CM1 and CM2) is consistent with our expectations. Also, the calculated access time for new patients at Endocrine Surgery matches the reality, as the Surgeon strives to see all new patients within a week. Check-up after surgery patients need to be seen within a week after surgery, so this calculated access time is low too.

If we compare the access times at Endocrine Oncology and Endocrine Surgery with the “Treeknormen” (Table 6), we notice that the access times for an appointment with the Internists are too high.

Table 6: Access times in line with "Treeknormen"

	Internist A (N=17)	Internist B (N=75)	Surgeon (N=199)
$P(A = 0)$	6%	4%	3%
$P(A \leq 7)$	47%	32%	60%
$P(A \leq 14)$	59%	56%	89%
$P(A \leq 21)$	65%	72%	94%
$P(A \leq 28)$	82%	84%	98%

Of the malignant patients requesting an appointment at Endocrinology (N=16 in 2015), 75% had a consultation within 2 weeks, 88% of the patients within 3 weeks. This is in line with the "Treeknormen".

Waiting time

The waiting time of a patient in the clinic is calculated "by subtracting the greater of (appointment time, arrival time) from the consultation start time" (Cayirli & Veral, 2003):

$$W = \sum_{p=1}^{n} \frac{C'_p - \max(A'_p, C_{start}'_p)}{p}$$

C_p	=	Scheduled appointment time
$C_{start}'_p$	=	Actual consultation start time
A'_p	=	Actual arrival time

Because waiting due early arrival is voluntary, this waiting time is not included. It can occur that the waiting time is negative. In this case the patient is served before the appointment time (Cayirli & Veral, 2003).

During the period of 21 September 2015 to 9 November 2015 data about the actual consultation start time and arrival time of the patient is collected at Outpatient Clinic Endocrinology and Endocrine Surgery.

At Outpatient Clinic Endocrinology, the waiting times for patients of Internist A (on average 9 minutes and 35 seconds for N=44) did not differ significantly of those of Internist B (on average 8 minutes and 3 seconds for N=38). As well the waiting times did not differ significantly between the different patient types. The same goes for Endocrine Surgery, where no significant difference in doctors or patient types is noticed. Table 7, Figure 13 and Figure 14 present the statistical analysis of the measured waiting time of patients.

Table 7: Descriptive Statistics of patient's waiting time

Endocrinology		*Endocrine Surgery*	
N	91	N	71
Mean	00:08:11	Mean	00:12:24
Standard Deviation	00:11:02	Standard Deviation	00:20:47
Coefficient of variation	1.3	Coefficient of variation	1.7
$P(W \leq 0)$	17.6%	$P(W \leq 0)$	25.4%
$P(W \leq 15)$	74.7%	$P(W \leq 15)$	63.4%
$P(W \leq 30)$	93.4%	$P(W \leq 30)$	84.5%

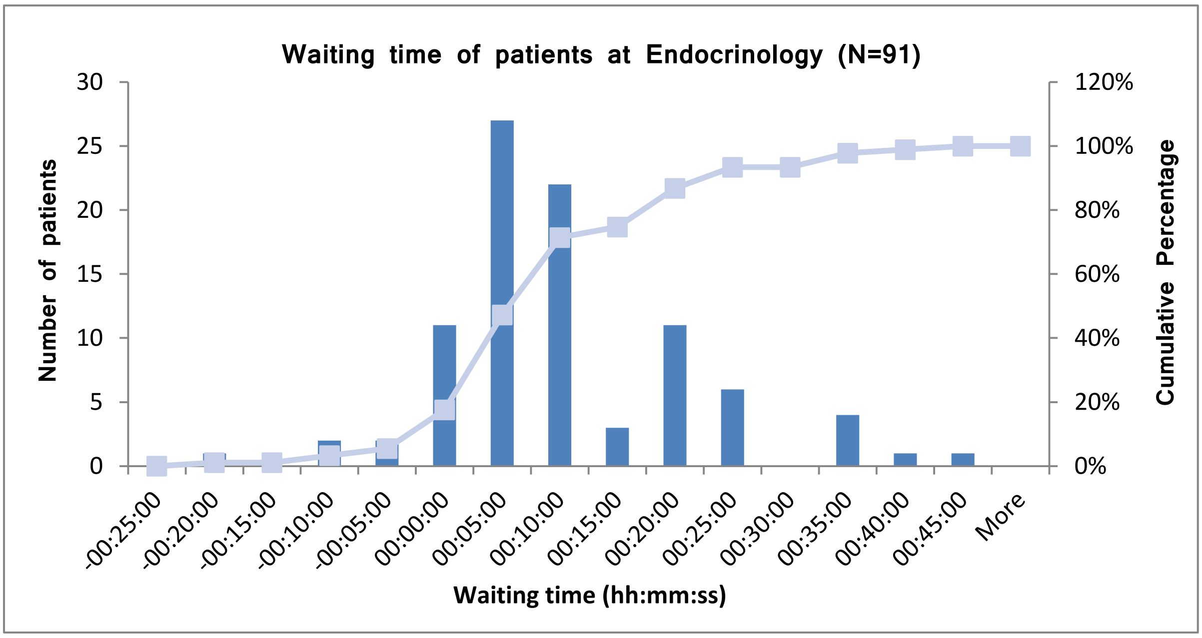


Figure 13: Number of patients and cumulative percentage of the observed patient's waiting time at Endocrinology (N=91)

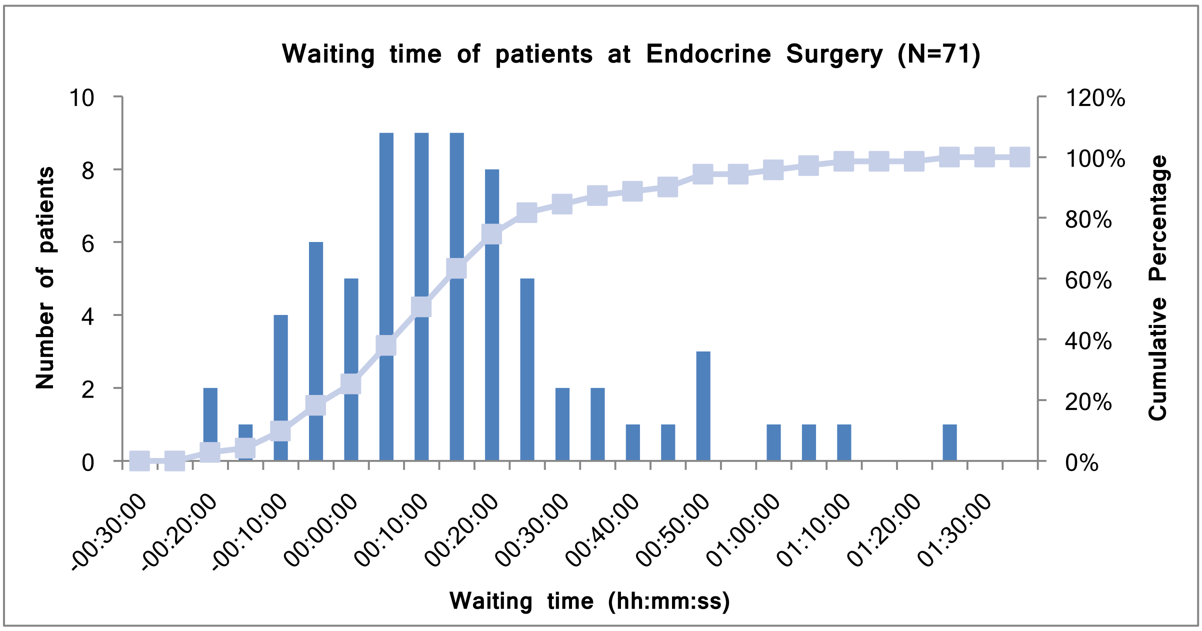


Figure 14: Number of patients and cumulative percentage of the observed patient's waiting time at Endocrine Surgery (N=71)

We see that on average the waiting time at Endocrine Surgery is higher than at Endocrinology. The coefficient of variance is higher at Endocrine Surgery than at Endocrinology. This results in more patients that are treated on time, but at the same time more patients that have to wait longer than 30 minutes.

This large variation at Endocrine Surgery can be the consequence of the presence of a Resident Doctor and the number of (overbooked) appointments during the clinic session.

According to Cayrili et al. (2003), there is a positive relationship between the number of appointments in a clinic session and the waiting times. So if there are more appointments booked than the capacity and no Resident Doctor is present the waiting times can be very high. On the other hand when few appointments are booked and the Resident Doctor is present, the waiting times can become negative.

Other factors that influence the waiting time are the punctuality of patients and doctors, no-shows and variability in the serves times (Cayirli & Veral, 2003). Data analysis shows that towards the end of the consultation session the waiting time increases. These longer waiting times are the result of accumulating variability in service times and punctuality.

Utilization

Utilization is the proportion that a system is operating of the available time. In case of the utilization of the agenda of the specialists the formula is:

$$Utilization = \frac{\text{Number of minutes scheduled in agenda}}{\text{Number of available minutes in agenda}} \cdot 100\%$$

The capacity of the Surgeon is 12 patients per clinic session (200 min.). The capacity of Internist A is 10 patients on Monday (incl. combination hour, 180 min.) and 6 patients on Wednesday (150 min.), the capacity of Internist B is 5 patients on Monday (120 min.) and 6 on Thursday (135 min.), the capacity of the Nurse Specialist is 7 patients on Monday and Wednesday (210 min.) and the capacity of the Genetic Counselor is 2 patients on Monday (60 min.).

Data (from EZIS) in the period of January 2015 to November 2015 has been analyzed to determine the utilization of the Internists and Surgeon. The results are presented in Table 8.

Table 8: Utilization of specialists (January 2015 to November 2015 from EZIS)

	Utilization				
	Surgeon	Internist A	Internist B	Nurse Specialist	Genetic Counselor
Monday (incl. combination hour)	*119% (N=31)*	*53% (N=25)*			
Monday (excl. combination hour)	167% (N=45)	90% (N=34)	85% (N=38)	32% (N=37)	96% (N=35)
Wednesday		82% (N=19)		39% (N=19)	
Thursday			87% (N=38)		

For both Internist A and the Surgeon, the utilization including the combination hour is considerably lower than the utilization excluding the combination hour. The utilization of the combination hour is just 5%, which results in this decrease. Reasons for this low utilization are mentioned in Section 2.1.3 Appointment scheduling processes.

In the calculation of the utilization, the telephone consults are left out of consideration. On average the utilization of the telephone consults is between 150% and 200% at both outpatient clinics, where the data shows a positive trend towards the end of the year. This means that in reality the utilization of both the Internists and Surgeon is higher.

The utilization of the clinic session of Endocrine Surgery is high. This utilization rate can be achieved, because of the assistance of the Resident Doctor. As well, the utilization of the Genetic Counselor is high. This should be seen in perspective, as the Genetic Counselor has currently just 2 timeslots available for appointments.

Overtime

Overtime is the (positive) difference between the desired and actual completion time of the clinic session:

$$O = \frac{\sum_{d=1}^{m} \max\left(0\,,\ \mathrm{C_{end}}'_{n,d} - \mathrm{E}_d\right)}{\mathrm{m}}$$

$C_{end}'_{n,d}$ = Actual consultation end time of last patient at doctor d

E_d = Scheduled finish of consultation session

In the data samples of both clinics, no overtime has been observed. This seems remarkable concerning the high utilization rate of Endocrine Surgery (Section 2.2.2). This observation may be the consequence of the size of the data samples, 11 sessions for Endocrinology and 7 sessions for Endocrine Surgery, which is quite small.

From interviews with both departments, we found that at Endocrinology the doctors do not work often in overtime. When Endocrinology experiences overtime, this is because too many telephone consults are booked at the end of the sessions. As these consultations are flexible, the doctor can perform these at his office or reschedule them to the next day. The specialists at Endocrine Surgery work more often in overtime as a consequence of the overbooked timeslots. With help of the Resident Doctor and positive variability of the service times, overbooking does not always result in overtime. In some cases overtime is inevitable.

Service times

Appendix B shows that different patient classes are assigned to different service times. For example at Endocrinology a CM1 (check-up MEN1) patient gets 20 minutes assigned, while a C (check-up) patient gets 15 minutes assigned.

The actual service times can be calculated with the formula:

$$S = \frac{\sum_{p=1}^{n}\left(C_{end}{'}_{p} - C_{start}{'}_{p}\right)}{n}$$

$C_{start}{'}_{p}$ = Actual consultation start time

$C_{end}{'}_{p}$ = Actual consultation end time

By calculating the average service time according to the factors specialist and patient type, we can decide if the current patient classification is well chosen.

At Endocrinology the service time of Internist A is on average 21 minutes per consultation (N=46) and for Internist B this is on average 20 minutes per consultation (N=38). Statistical analysis shows no significant difference between these internists. In Table 9 a review of the statistical analysis of the service times according to the different patient groups is given.

Table 9: Descriptive statistics of service time according to patient type at Endocrinology

	Endocrinology (Patient Type)						
	N	*C*	*CM1*	*CM2*	*CVL*	*NENDCHI*	*CENDCHI*
N	7	28	25	14	3	2	2
Mean	00:35	00:19	00:22	00:17	00:17	00:18	00:25
Standard Deviation	00:07	00:09	00:08	00:05	00:02	00:07	00:18
Coefficient of variation	0.2	0.5	0.4	0.3	0.1	0.4	0.7
95% confidence interval (LB)	00:29	00:16	00:18	00:13	00:07	00:06	00:12
95% confidence interval (UB)	00:41	00:22	00:25	00:21	00:26	00:31	00:37

The sample for the patient groups CVL, NENDCHI and CENDCHI is too small to draw conclusions, so we will leave these out of consideration. Statistical tests show that the mean service time of new patient (N) differs significantly from check-up patients (C, CM1 and CM2). Within the check-up patients, *no significant differences are identified*. This means that according to the analysis of the actual service times, the consultation of a MEN-patient has the same duration as the consultation of a patient with another diagnosis.

The service times of the Nurse Specialist and Genetic Counselor are left out of consideration. From interviews with both specialists we can conclude that if only one or two patients are scheduled on a day, the specialist takes more time for the consultation, than when more patients are scheduled. This means that our data sample shall give an unrealistic perception of the actual service times.

At Endocrine Surgery the service time of the Surgeon is on average 11 minutes per consultation (N=51) and for the Resident doctor on average 19 minutes per consultation (N=31). The difference between these two specialists is significant (95% confidence). This difference can be explained by the fact that the Surgeon performs supervision to the consults of the Resident Doctor, these supervision consults take on average less time than the other consults. On the other hand the Resident Doctor sometimes has to wait with the patient until the Surgeon is ready for supervision. This results in higher service times for the Resident Doctor. Currently the Surgeon and Resident Doctor share the agenda, so we analyze the results as one group. In Table 10 a review of the statistical analysis of the service times according to the different patient groups is given.

Table 10: Descriptive statistics of service time according to patient type at Endocrine Surgery

	Endocrine Surgery (Patient Type)			
	N	*C*	*CNO*	*SUP*
N	25	19	22	13
Mean	00:21	00:11	00:14	00:08
Standard Deviation	00:11	00:08	00:12	00:07
Coefficient of variation	0.5	0.7	0.9	0.9
95% confidence interval (LB)	00:17	00:06	00:10	00:03
95% confidence interval (UB)	00:25	00:15	00:19	00:13

The patient types CCHIEND, NCHIEND, NO and SHE are left out of consideration, because the sample sizes are too small. Statistical tests show that the mean service time of new patient (N) differs significantly from check-up patients (C), check-up after surgery patients (CNO) and supervision (SUP). The average service time of check-up (C) and check-up after surgery (CNO) patients does not differ significantly. So the current patient classification seems to be a good representative.

2.4 Demarcation of core problem

In this section the most important findings from the previous sections are analyzed and the scope of the research is narrowed down.

During the context analysis of the outpatient clinics Endocrinology and Endocrine Surgery, we have noticed several problems. These problems and their cause-and-effect relationships are presented in Figure 15.

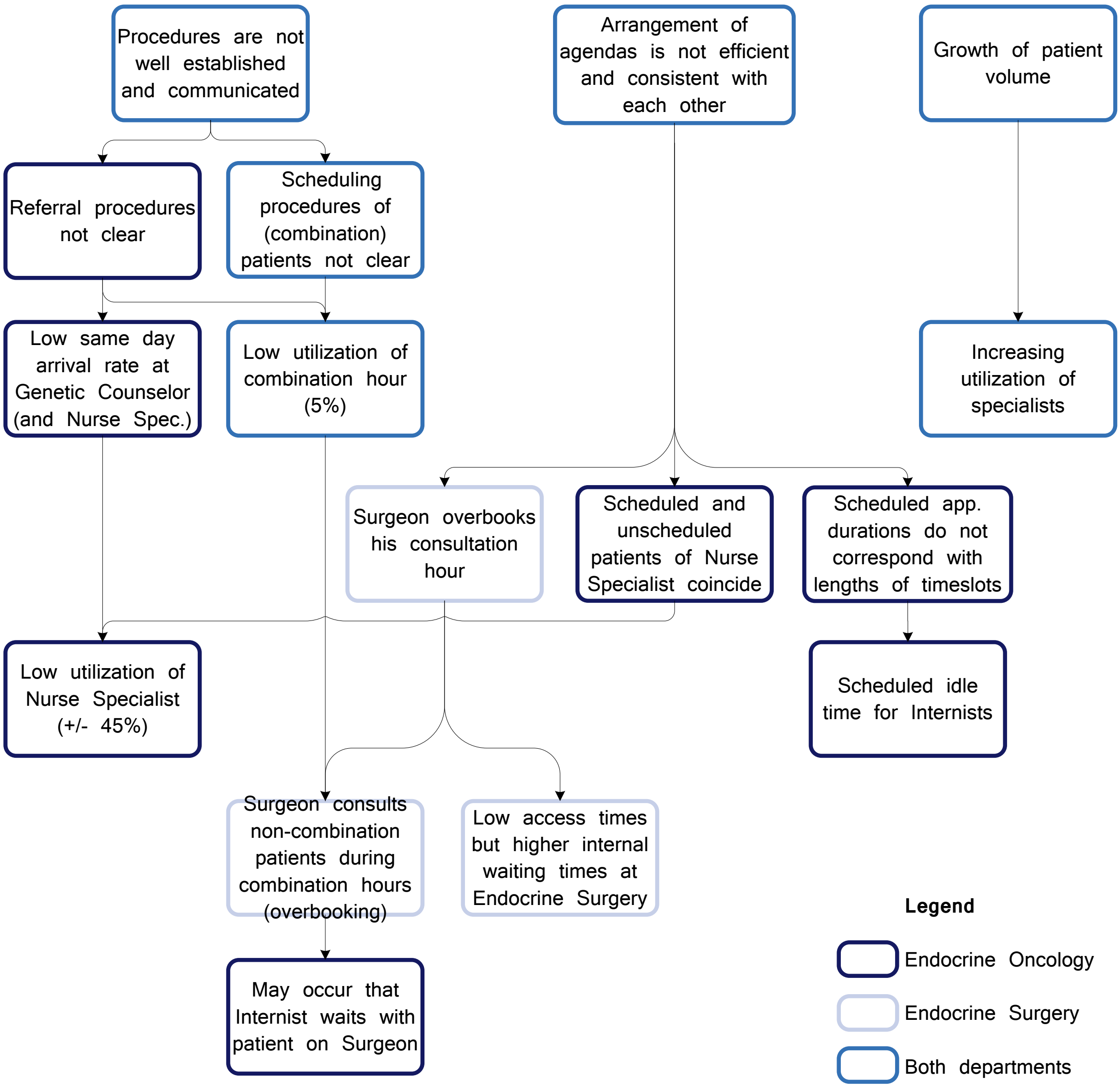


Figure 15: Problem cluster following from the context analysis

All problems in the problem cluster can be traced back to three core problems:

1. Procedures are not well established and communicated;
2. Arrangement of agendas is not efficient and consistent with each other;
3. Growth of patient volume.

The third core problem cannot be influenced. Thus we will see (the growth of) the patient volume as an input parameter of our model. This leaves us to two core problems: the first is a managerial problem and the second is a quantifiable capacity planning problem.

In this study we will focus on developing a more efficient arrangement of the agendas of the specialists. Giving advices concerning the current procedures shall be a sideline activity.

3 Literature study

This chapter presents a review of the available literature concerning the capacity planning of (multidisciplinary) appointments in outpatient clinics. The goal of this review is to gain knowledge about the planning methods described in the literature, resulting in a theoretical framework.

Section 3.1 presents the characteristics of multidisciplinary care in outpatient clinics. Section 3.2 presents the advantages of organizing multidisciplinary care in a carousel. Section 3.3 emphasizes the necessity in the development of a planning instrument for an outpatient clinic with multidisciplinary care. Section 3.4 presents the Health care planning and control framework after which Section 3.5 presents both analytic and simulation approaches to build a planning instrument. Finally, Section 3.6 presents an enumeration of appointment systems together with the performance of these rules. Every section ends with a concluding paragraph, which connects the literature to practice.

3.1 Multidisciplinary care in outpatient clinics

Most outpatient clinics are either organized around a single specialty or around symptoms or a certain disease. Examples of the former are Gynecology or Hematology, the latter includes sleeping disorders or diabetes (Zonderland, 2014). In the first case these clinics are called *monodisciplinary*, “only one medical disciplines involved in the care for patients”, while the second are named *multidisciplinary* (van der Marck et al., 2009). This means that several specialties are involved (Zonderland, 2014). In some cases a distinction between multidisciplinary care and interdisciplinary care is made.

Here, *multidisciplinary* care includes the collaboration of professionals of different disciplines, but without insight in each other’s practice. The professionals work independently and have independent consultations with the patient. *Interdisciplinary* care includes a close collaboration of both the professional team and the patient. This “promotes open and continuing communication between the patient and all involved practitioners” (Prizer & Browner, 2012). Both terms are often used interchangeably (Momsen, Rasmussen, Nielsen, Iversen, & Lund, 2012; Prizer & Browner, 2012).

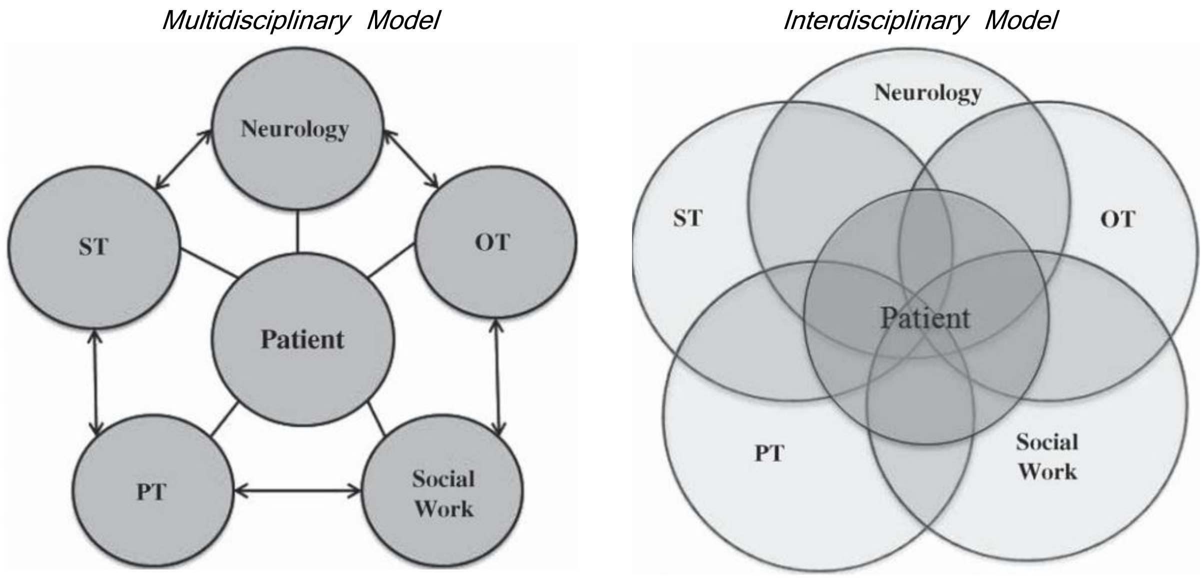


Figure 16: Multidisciplinary and the Interdisciplinary Model of care (Prizer & Browner, 2012)

Multidisciplinary/Interdisciplinary care is preferred in case of complex diseases or symptoms. In these cases specialized professional management is required. Examples are Huntington's disease and Parkinson's disease (van der Marck et al., 2009; Veenhuizen & Tibben, 2009). In order to facilitate the multidisciplinary care, care pathways are introduced. A care pathway is a protocol for all steps in the care process of distinct groups of patients (Zonderland, 2014). This standardizes patient care and results in a more efficient route of the patient through the hospital.

As the terms *multidisciplinary* and *interdisciplinary* care are used interchangeably, we shall from now on use multidisciplinary care as the collective noun. As stated in 1.1.1 UMC Utrecht Cancer Center the complexity of cancer care in general and of the Endocrine Oncology patients (2.1.1 Patient group) in specific is high. This requires "the very best care provided by knowledgeable and passionate multidisciplinary team" as UMC Utrecht Cancer Center promises in the Health Care Concept. To enhance the multidisciplinary care, UMC Utrecht is developing and improving care pathways for patients with identical characteristics.

3.2 Arranging multidisciplinary appointments in a carousel

The focus in health care is changing from an orientation on physicians to an orientation on customers (Chien, Tseng, & Chen, 2008; Leonard, 2014). The interdisciplinary care approach stimulates the patient-centered perspective, as the professionals decide together with the patient on the treatment plan (Prizer & Browner, 2012).

To accommodate the specialized, multidisciplinary care both organizationally and physically, all disciplines involved can be located in a circle of consultation rooms: a carousel. Veenhuizen et al. (2009) give an example of an outpatient clinic in carousel-form for patients with

Huntington's disease. Here, first the patient receives an introduction by the nursing home doctor; where after the patient visits the neurologist, occupation altherapist, etc. (see Figure 17). After these appointments, the multidisciplinary team discusses a care plan which is proposed to the patient.

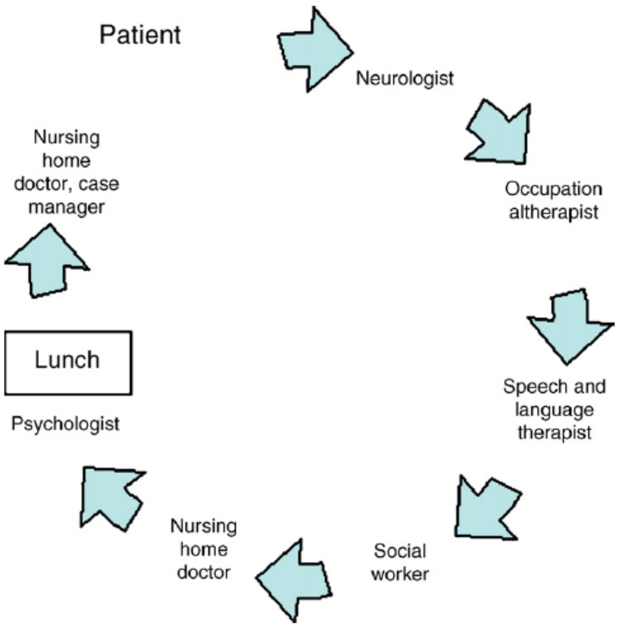


Figure 17: Routing along care providers in outpatient clinic (Veenhuizen & Tibben, 2009)

In the case of Parkinson's disease the carousel-appointments are implemented as well. With this form of assessment, care is standardized which results in the elimination of duplication. At the same time variation in workflow is reduced, which induces stable appointment durations and improved patient flow (Goodridge, Woodhouse, & Barbour, 2013).

With the development of care pathways and multidisciplinary organization of care, the care of UMC Utrecht becomes more standardized and personalized and should therefore result in a higher quality of care. A sensible addition to this is to redesign the outpatient clinics as a carousel to improve efficiency of the processes and to stimulate the patient-centered perspective.

3.3 Improve efficiency in health care

Not only intrinsic motivation, like staying financial viable, stimulates hospitals to become more efficient. The pressure on health providers to improve efficiency is increasing as a consequence of the continuously increasing demand for (chronic) care, ageing of the population, growing expenditures and limited health care budgets (Gupta & Denton, 2008; Hans et al., 2012; Hulshof et al., 2012). According to Hans, van Houdenhoven and Hulshof (2012) in particular in the field of planning and control the health care sector lags behind the manufacturing industry, i.e. in this area much efficiency is to be gained. The organization of planning and control in health care is complicated by the collaboration of professionals in several disciplines with different interests, the division of planning and control tasks over different autonomous departments, the lack of organizational knowledge, etc. (Hans et al., 2012). As the objective of health care organizations is "to provide high-quality care using the limited resources that are available" according to Hulshof et al. (2012), the focus should be on building understanding on how to organize the processes more efficient.

Complimentary to the standardization of patient care, efficient patient scheduling may increase the service quality and process efficiency of the outpatient clinics (Chien et al., 2008). As mentioned in the previous paragraph, in the health care sector the knowledge on efficient scheduling is still limited. Especially in case of multidisciplinary appointments the organization of planning and control is more complex, while at the same time planning deficiencies have a larger negative effect on both the quality of care and the logistical efficiency (Braaksma, Kortbeek, Post, & Nollet, 2014). This makes the importance of a well-functioning planning system even greater.

So the need to improve efficiency in health care is high. There are several ways to do this:

- Standardization of patient care: UMC Utrecht facilitates this with care pathways, multidisciplinary care and carousels.
- Health care planning and control: UMC Utrecht should focus more on the processes involved in planning and control.

3.4 Planning and scheduling

As stated in the previous section, by improving the planning and control the performance of the health care sector can increase. By definition planning and control is the design and organization of processes. The four questions: what to do, how to do it, when to do it and who should do it, form the basis of planning and control. For the health care sector this includes medical, financial and resource decisions (Hulshof et al., 2012).

The Health care planning and control framework can be decomposed into the hierarchical levels strategic, tactical, offline operational and online operational (Hans et al., 2012).

3.4.1 Strategic planning

The strategic planning level has the longest planning horizon and therefore is the most flexible. It involves decisions about the strategy or mission of the organization, that is "structural decision making" (Hans et al., 2012).

3.4.2 Tactical planning

"The organization of the operations and execution of health care delivery processes" is addressed by tactical planning (Hans et al., 2012). Compared to the strategic planning level, the planning horizon is shorter and therefore the planning is less flexible. For example while in the strategic level capacity expansions like the construction of extra consulting rooms belongs to the possibilities, at the tactical level only temporary expansions like hiring extra staff or working in overtime are possible.

3.4.3 Operational planning

Operational planning has the shortest planning horizon. Since "many decisions on higher levels have demarcated the scope for the operational level decision making", there is low flexibility on this level (Hans et al., 2012). The operational planning level can be decomposed into offline and online operational planning. Offline planning concerns making plans in advance, while online planning anticipates on real-time events.

An overview of the different planning levels including examples is given in Figure 18.

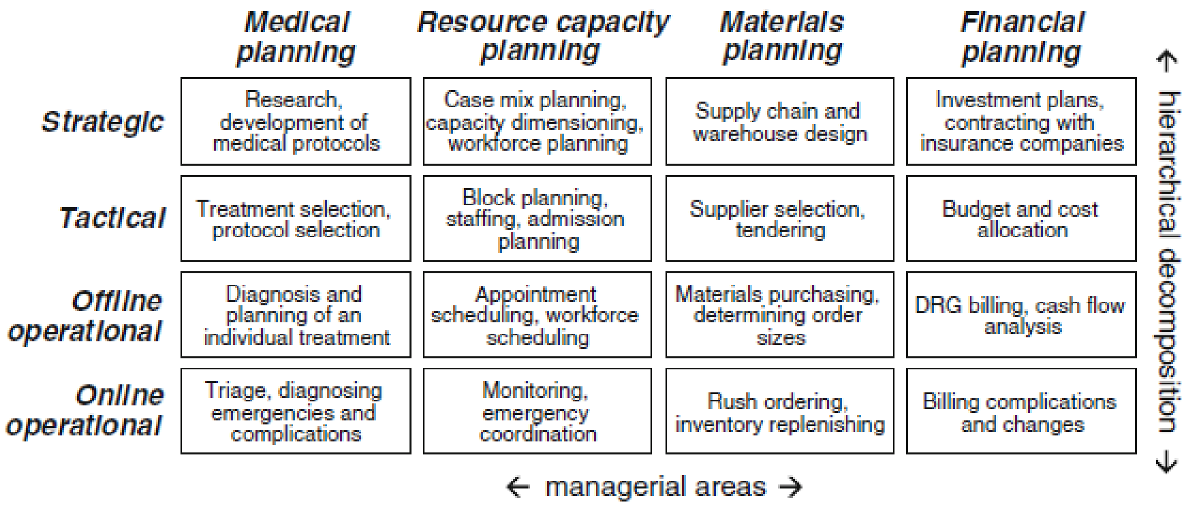


Figure 18: Framework for health care planning and control (Hans et al., 2012)

Planning is mostly covered by the tactical level and scheduling by the operational level. Planning is described as "the process of reconciling supply and demand". Scheduling is described as "defining the sequence and time allocated to the activities of an operation" (Cardoen, Demeulemeester, & Beliën, 2010). In this case planning answers the questions what and where, while scheduling answers the questions when and how. According to Hans et al. (2012) the tactical and the operational planning level both answer the questions: what, where, when and how, only with a different perspective.

From the previous section we concluded that UMC Utrecht has to focus more on the processes involved in planning and control. In this project the focus is on the resource capacity planning, where the tactical planning decisions are restricted by the decisions made on the strategic level.

3.5 Planning models

There exist several methods to analyze and improve operation systems. First a distinction between experimenting with the *actual* system and with a *model* of the system is made, see Figure 19.

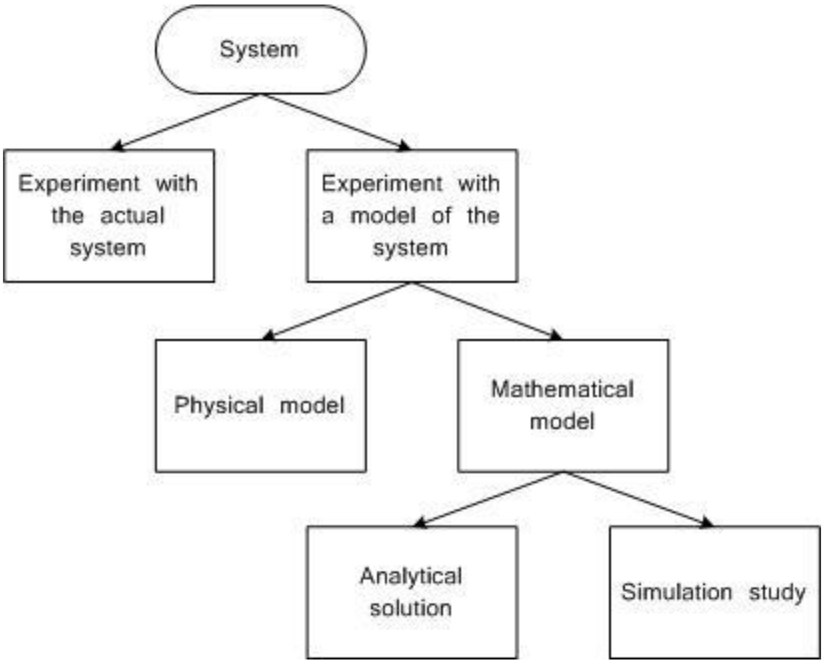


Figure 19: Methods to analyze a system (Law, 2007)

Reasons to experiment with a model of the system are:

- Costs: To analyze the effects of experiments on the actual system, the day-to-day operations are interrupted. This is very costly.
- Time: To experiment with the actual system is time-consuming.
- Control of experiment conditions: To make objective comparisons between experiments, the environmental conditions should be stable. This is harder in the real world than in a model.
- Real system does not exist (Robinson, 2014).

In experimenting with a model of the system a distinction between a *physical* model and *mathematical* model can be made. According to Law (2007), physical models are not of interest in Operations Research, which leaves us to the mathematical models. In the following sections both analytic (3.5.1) and simulation (3.5.2) models will be presented as an approach to plan multidisciplinary care.

3.5.1 Analytic models

Although care in a carousel already is offered in practice, research on multidisciplinary care focuses mostly on the care pathways instead of the planning. Most literature about planning (both tactical and operational) concerns a single-server, single-phase environment (Cayirli & Veral, 2003).

The few studies on the planning of multidisciplinary care shall be presented in this section. The operational planning of multidisciplinary care, i.e. scheduling of patients for a given set of professionals, is in some cases formulated as the hybrid flow shop scheduling problem

(Chien et al., 2008). In a manufacturing environment this includes the scheduling of a set of jobs, which need to be processed in a series of stages (Ruiz & Vázquez-Rodríguez, 2010). See Figure 20 for a visualization of the hybrid flow shop scheduling problem.

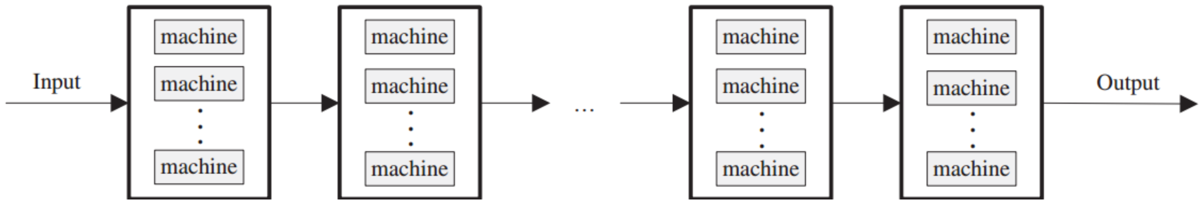


Figure 20: Hybrid flow shop scheduling problem (Eskandari & Hosseinzadeh, 2013)

As the hybrid flow shop scheduling problem is NP-hard, this problem cannot be solved in polynomial time. That is why Chien et al. (2008) propose a Genetic Algorithm (GA), to solve this problem: tasks are swapped/ shifted until the optimal solution is found. The environment in which the algorithm is applied is in rehabilitation planning, where all the treatment steps of the patient are known on forehand. The route of an Endocrine patient through the hospital is not known on forehand; he or she can choose during the consultation with the Internist if additional information by the Nurse specialist is desired. So the required capacity is not known in advance, which makes the use of a Genetic Algorithm not suitable for our problem.

Previous studies present as well Integer linear programming (ILP) models to schedule series of multidisciplinary appointments. In radiotherapy planning an ILP is used to minimize the access time for the patients, while maximizing resource utilization (Conforti, Guerriero, & Guido, 2008). In rehabilitation treatment planning appointments are assigned to a individual patient by use of an ILP (Braaksma et al., 2014). The ILP is restricted by given parameters such as: the number of time slots per day, the number of appointments per discipline, maximum allowed number of appointments with one therapist, etc. The performance of the ILP is rated by seven performance indicators i.a.: access time, lead time, therapist utilization and unscheduled appointments (Braaksma et al., 2014). The ILP-models of Conforti et al. (2008) and Braaksma et al. (2014), both address an appointment scheduling problem, with given boundaries. Thus, these models can be classified as operational planning methods, within the Health care planning and control Framework of Hans et al. (2012). As mentioned in Section 3.5 Planning models, the instrument appropriate for our case study, should concern the tactical planning level. For example, the number of appointments per discipline is flexible as the patient can (for some disciplines) decide ad-hoc if he want to visit the specialist or not. As well patients can be moved from the Surgeon to the resident doctor and the Nurse Specialist can take over patients of the Internist. So decisions on the resource capacity are still open. As well, ILP-models are most suitable for combinatorial optimization problems in a deterministic environment (Kall &

Wallace, 1994). The environment in which the multidisciplinary planning tool has to operate is stochastic. The patient is not obliged to visit every professional; he has the choice to do so. So, with a certain probability a patient moves from “professional A” to “professional B”. These reasons make that the ILP-model is not an appropriate tool in our case.

Zonderland (2014) suggest using a Markov decision process or Queuing theory for appointment planning in outpatient clinics. Both models have stochastic elements and can be applied in the tactical stage, which makes them appropriate for our case study. Still, Zonderland (2014) stresses that Markov and Queuing models require in-depth mathematical knowledge, take effort to derive and lack applicability in the real world.

3.5.2 Simulation models

An alternative approach is conducting a simulation model. Simulation is “the process of designing a model of a system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system” (Shannon, 1975). An advantage of simulation modeling is “the ability to model complex outpatient queuing systems and represent environmental variables, such as server or customer-related attributes” (Cayirli & Veral, 2003). Stochastic variables (retrieved from empirical data) can easily be incorporated in the model with simulation modeling. These characteristics of a simulation model make that this approach is referred to as “one of the most effective ways to help bridge the often present gap between academic rigor and managerial applicability” (Shafer & Smunt, 2004). On the other hand drawing conclusions from a simulation model is time consuming. Analytic models are harder to derive, but generate quite fast solutions (Tino & Khan, 2013).

There are several types of simulation models, for example: Continuous simulation, Discrete-event simulation, Monte Carlo simulation (Law, 2006). Respectively a model with continuous changes of stage, a model where the stage changes at several points in time, a static discrete simulation model and simulation based on a spreadsheet.

In more detail, in a Discrete-event simulation model new events are scheduled (and added to an event list) at the moment an event occurs. The stochasticity in times between two events is guaranteed by drawing a random number from a predefined (from empirical data) distribution.

Simulation studies are used in appointment scheduling in the health care industry. By analyzing the relationship between various environmental factors and performance indicators the best alternative is selected (Cayirli & Veral, 2003). In most cases the focus hereby is on selecting the most appropriate Appointment System. Section 3.6 presents an overview of the Appointment Systems described in the literature.

From the literature study on Planning models, we can conclude that the models (GA, ILP) used in previous research about the planning of multidisciplinary appointments are not desirable for us. Still the choice between an analytic or simulation model cannot directly be made. This means that both options need to be investigated.

3.6 Appointment Systems

According to Cayirli & Veral (2003) an appointment system is designed by making decisions regarding: 1) appointment rules 2) patient classification 3) adjustments to walk-ins, no-shows and/or emergency patients. In the next section several appointment and sequencing rules will be presented and their performance will be analyzed.

3.6.1 Appointment rules

According to the paragraph Appointment rules under Section 2.2 Planning and control, the internist and surgeon currently both use the *individual-block/variable-interval appointment rule*. This means that the patients are individually scheduled and that the intervals vary depending on the patient classification (Cayirli & Veral, 2003). In this section other appointment rules with their influence on the performance indicators are presented.

Appointment rules are described in terms of three variables: 1) block-size (n_i) is the number of patients scheduled to the ith block 2) begin-block (n_1) is the number of patients scheduled to the initial block 3) appointment interval (a_i) the interval between two successive appointment times (Cayirli & Veral, 2003).

The decision spaces for these variables mentioned and experimented in literature are:

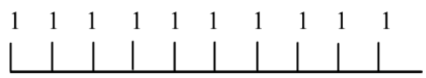
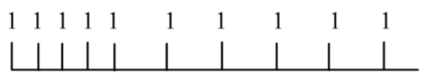
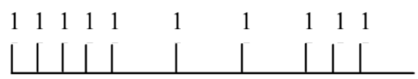
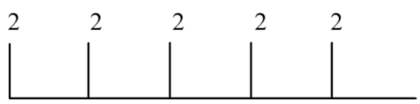
$$n_i \in \{1,2\},$$
$$n_1 \in \{1,2\},$$
$$a_i \in \{fixed, variable\}.$$

We will highlight the five most discussed appointment rules in literature, starting with the benchmark rule: the *individual-block/fixed-interval* rule (IBFI). In this case the combination of the three variables, (n_i, n_1, a_i) is (1, 1, fixed): patients are individually scheduled, where the intervals are equal to the mean service time (μ). This appointment rule is mostly used for primary care: “the routine outpatient care that a patient receives at first contact with the health care system” (Zheng, Yoon, & Khasawneh, 2015).

Variations on this appointment rule are the OFFSET rule and DOME rule, which can be categorized as *individual-block/variable-interval* rules (1, 1, variable). With the OFFSET rule, earlier slots are shorter than average service time and later slots are longer than average service time (Klassen & Rohleder, 1996). In mathematical terms, the initial (k_1 - 1) patients are scheduled a factor β_1 earlier than the benchmarking rule, the rest later a factor β2 later. The DOME rule implies that intervals slightly increase towards the middle and decrease towards the end of the session, i.e. (k_1 - 1) patients are scheduled factor β_1 earlier, patients (k_1 - 1) to (k_2 - 1) factor β_2 later and the rest a factor β_3 earlier than IBFI (Cayirli et al., 2006). *Individual-block/variable-interval* rules are common in specialty clinics, because patients are referred to a specific treatment by their practitioner, where the treatments can be classified according to (mean) service time (Zheng et al., 2015).

As well variations to the benchmarking rule in the amount of scheduled patients exist, the so-called *Individual-block/fixed-interval rule with an initial block of two* (2BEG) and *Multiple-block/fixed-interval* (MBFI). The mathematical representation of these rules is respectively (2, 1, fixed) and (2, 2, fixed). The 2BEG rule is also known as the Bailey-Welch rule, first introduced by Bailey in 1952. This may be the most well-known appointment rule, where two patients are scheduled to arrive at the start of the clinic session, followed by individually scheduled patients. In case of the MBFI rule, two patients are scheduled at the same time with the interval fixed on twice the mean service time (Cayirli et al., 2006). In Table 11, the formulas for the appointment times for patient i (t_i) are given together with an abstract representation of the appointment rule:

Table 11: Appointment rules mentioned in the literature (Cayirli et al., 2006)

Appointment rule	Formula	Representation
IBFI	$t_1 = 0,$ $t_i = t_{i-1} + \mu$ for i > 1.	
OFFSET	$t_i = (i-1)\mu - \beta_1(k_1 - i)\sigma$ for i ≤ k_1, $t_i = (i-1)\mu + \beta_2(i - k_1)\sigma$ for i > k_1.	
DOME	$t_i = (i-1)\mu - \beta_1(k_1 - i)\sigma$ for i ≤ k_1, $t_i = (i-1)\mu + \beta_2(i - k_1)\sigma$ for k_1 < i < k_2, $t_i = (i-1)\mu - \beta_3(i - k_2)\sigma$ for i ≥ k_2.	
2BEG	$t_1, t_2 = 0,$ $t_i = t_{i-1} + \mu$ for i > 2.	
MBFI	$t_i = t_{i+1} = (i-1)\mu$ for i = 1, 3, 5, 7, …	

3.6.2 Patient classification

In a patient classification scheme, patients with the same characteristics are assigned to the same class. A commonly used classification is dividing patients into 'new' and 'return' patients, as research has shown that the mean service time of new patients is higher than that of return patients (Partridge, 1992). Extending this scheme with more classes is not recommended for outpatient clinics as the schedule has to be filled dynamically prior to the clinical session (Cayirli & Veral, 2003). Based on the patient classification scheme patients can be scheduled (in a specific order) to a block. This order is called the sequencing rule (Cayirli et al., 2006). Sequencing rules mentioned by Cayirli et al. (2006) are:

Table 12: Overview of sequencing rules (Cayirli et al., 2006)

Sequencing rule	Representation	Explanation
FCFA	-	Base setting, no sequencing rule
ALTER	(RNRNRNR…)	New and return patients alternating
NWBG	(NNN…RRRR)	New patients in beginning
RTBG	(RRRR…NNN)	Return patients in beginning
NWBND	(NN…RRR…NN)	New patients in beginning and end
RTBND	(RR…NNN…RR)	Return patients in beginning and end

In this case the classification has been made in new and return patients, respectively high and low mean service time. As well the classification can be made on high and low service time variation (Klassen & Rohleder, 1996). Partridge (1992) did not found a relation between the variation of service times and the class of the patients (new or return), so the sequencing rules of Klassen and Rohleder differ from those of Cayirli et al.

Cayirli and Veral (2003) state that by using a sequencing rule, the appointment system becomes less flexible. For example if the NWBG-rule is chosen, but a return patient insists on an early appointment, the sequencing rule has no effect anymore. The appointment system is most flexible when applying no appointment rule: using FCFA.

3.6.3 Performance of Appointment and Sequencing rules

In Section 2.3 Performance, the most important performance indicators are presented: average waiting time per patient $E(W_i)$, average idle time per patient $E(I_i)$ and average overtime per patient $E(O_i)$. To draw conclusions concerning these performance indicators, the decision-maker should decide on an appropriate trade-off between the indicators. According to Cayirli & Veral (2003) this can be done according to different principles: 1) cost based measure 2) time based measure 3) congestion measure and 4) fairness measure. Cost-based performance measures include giving relative weights to the performance criteria and subsequently minimizing the expected total cost, while time-based performance measures evaluate the criteria separately, by setting a maximum level for them. Congestion-based measures focus on queue length and fairness-based measures focus on the distribution of waiting time between the patients (Cayirli & Veral, 2003; Yoon, Khasawneh, & Srihari, 2011).

Cayirli et al. (2006) use a cost-based measure to value these indicators:

$$Total\ costs = E(W_i)C_p + \big(E(I_i) + 1.5E(O_i)\big)C_q.$$

The objective is to minimize the total costs. In case of Cayirli et al. (2006), there is decided that overtime has a more negative effect on costs than idle time (with a factor 1.5). Reason for this assumption, is that idle time during the day can be used productively. C_d/C_p represents the trade-off between doctors and patients. $C_d/C_p \gg 1$, means that the doctors time is more important that the patients time, while $C_d/C_p = 1$ values both times as equally important.

Cayirli et al. (2006) state that sequencing rules have more effect on the performance indicators than appointment rules. The sequencing which has the best overall performance is ALTER according to Cayirli et al. (2006). Klassen and Rohleder (1996) state that scheduling low variance patients at the beginning of the session (LVBEG) leads to the best overall performance. The best appointment rules are the Bailey-Welch (2BEG) rule and MBFI (Cayirli et al., 2006; Hutzschenreuter, 2004).

The performance of the complete Appointment System, which is a combination of an appointment and sequencing rule, depends on the point of focus. For example, if the doctor's time is valued as 20 times more important than the patient's time, 2BEG combined with NWBG is the best option. If the patient's time is decided to be equally valuable to the doctor's time, IBFI or OFFSET combined with RTBG is a better option (Figure 21).

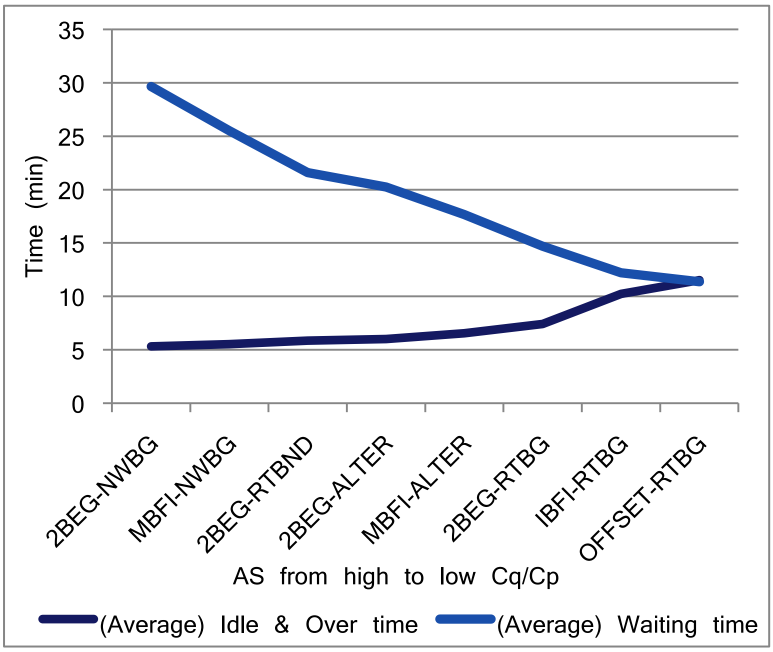


Figure 21: Best appointment systems (Cayirli, Veral, & Rosen, 2006)

3.7 Conclusions

A collaboration of professionals of different disciplines (multidisciplinary or interdisciplinary care) is preferred in case of complex diseases or symptoms, which is the case for Endocrine Oncology patients.

By locating these professionals in a carousel, this close collaboration between specialists is promoted resulting in a more patient-centered perspective (Prizer & Browner, 2012). This is in line with the general trend in health care to an orientation on customers instead of on the physicians (Chien et al., 2008; Leonard, 2014).

Besides this, there is a trend in health care to improve efficiency, which is a consequence the continuously increasing demand for (chronic) care, ageing of the population, growing expenditures and limited health care budgets (Gupta & Denton, 2008; Hans et al., 2012; Hulshof et al., 2012).

In order to cope with these trends, 1) patient care should be standardized and 2) in the field of planning and control improvements should be made (Chien et al., 2008; Hans et al., 2012). UMC Utrecht facilitates the standardization of patient care with care pathways, multidisciplinary care and carousels. By focusing more on planning and control, a lot of efficiency is to gain by UMC Utrecht. In case of this project, the focus is on the tactical planning decision of the resource capacity planning level of the planning and control framework of Hans et al. (2012).

In the choice of a planning model, a distinction between analytic and simulation models can be made. Of the analytic models, a Markov Decision model or Queueing model is the most appropriate for our case study (Zonderland, 2014). In case of a simulation study the Discrete-event simulation is the most appropriate as the state of our system will only change when an event occurs; when a patient moves (from one professional to another).

Most simulation studies in health care focus on selecting the right Appointment System, which depends on the division of emphasis between the patient and doctor.

4 Model selection

In Section 3.5 Planning models both analytic and simulation approaches to the problem are investigated. As mentioned in this section one method is not directly preferred above the other, which makes us consider both. In Table 13 the differences between analytic and simulation studies are summarized.

Table 13: Analytic versus simulation modeling

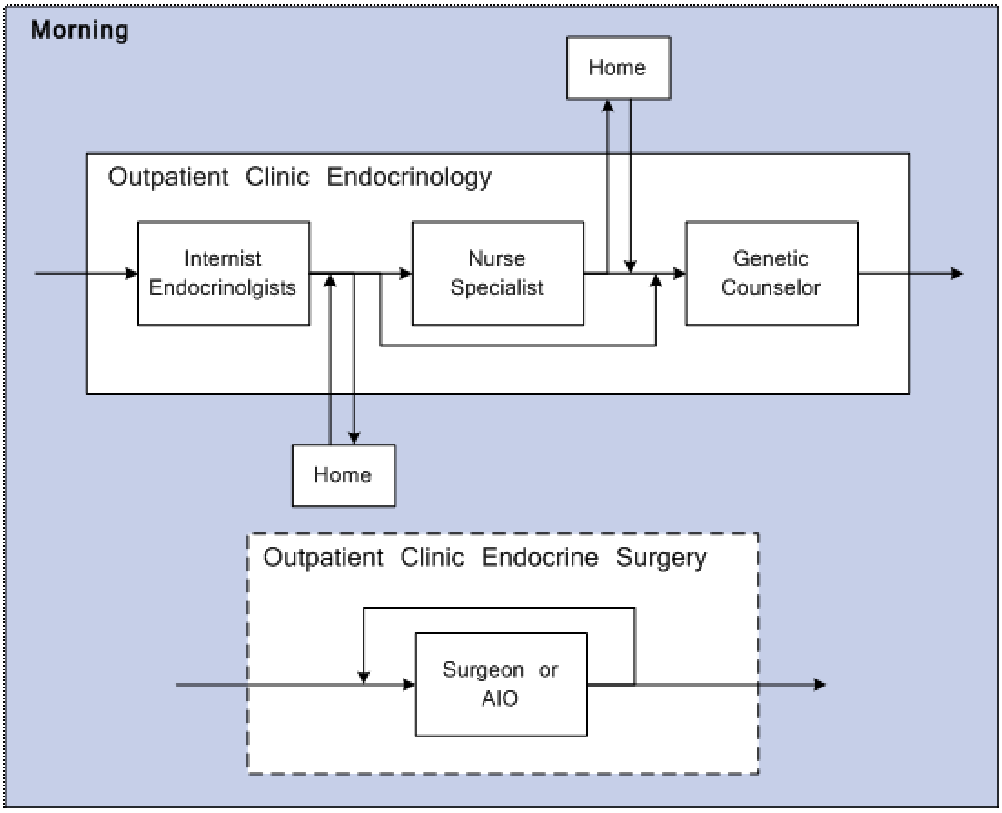
Analytic	Factor	Simulation
Analytic models require in-depth mathematical knowledge and are harder to derive than simulation models (Tino & Khan, 2013; Zonderland, 2014)	**Modeling complexity**	Simulation modeling requires skills in conceptual modeling, validation and statistics (Robinson, 2014).
Analytic models become very quickly inapplicable in case of too complex models. Complexity can be divided into *combinatorial* (the number of components) and *dynamic* (the interconnections and dependencies) complexity (Robinson, 2014).	**System complexity**	Simulation models posses the ability to model complex outpatient queuing systems and represent environmental variables, such as server or customer-related attributes (Cayirli & Veral, 2003).
Few data is required to build and analyze an analytic model.	**Data analysis**	To capture all variability of the system in a simulation model, a lot of data is required (Robinson, 2014).
The outputs of an analytic model are equilibrium measures, which are quite easy to interpret. Analytic models generate quite fast solutions (Tino & Khan, 2013)	**Output analysis**	Simulation models can generate a broad scale of performance outputs. So drawing conclusions from a simulation model is time consuming (Robinson, 2014; Tino & Khan, 2013).
In analytic models often the "average" conditions are used. Modeling assumptions are necessary to capture the system in a model. Such assumptions have to be justified.	**Accuracy**	Simulation modeling is often the only effective model for interconnected systems which are subject to significant levels of variability. Due to the possibility to model variability, fewer assumptions are necessary (Robinson, 2014)

Analytic models lack applicability in the real world (Zonderland, 2014).	**Application**	Simulation modeling is "one of the most effective ways to help bridge the often present gap between academic rigor and managerial applicability" (Shafer & Smunt, 2004). Simulation models are appealing, transparent and give non-experts confidence in the model (Robinson, 2014).
The computational costs of analytic models are typically small.	**Costs**	Simulation software is expensive (Robinson, 2014).

In Table 13 we can see that there are several cases in which the analytic approach is preferred above simulation and vice versa. Still the general rule holds: "Do not simulate if it is easy to calculate!" (Mes, 2013a). Simulation "is recommended as the last resort rather than the preferred option" (Pidd, 1998). So first the possibility to building an analytic model is going to be analyzed.

4.1 Analytic model

In Section 3.5.1 Analytic models, Queuing theory is suggested as the appropriate approach for appointment planning in outpatient clinics (Zonderland, 2014). To analyze the buffers and servers in the current system, a presentation of the route of the patients through the department of Endocrine Oncology and Endocrine Surgery is needed (Figure 22).



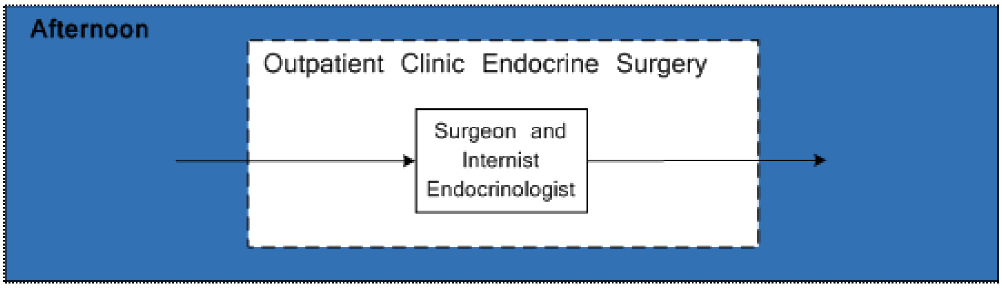


Figure 22: Transitions of patients between specialists

4.1.1 The problem

The problems at the department, which need to be captured in the model, are:

- The agenda's of the Internist Endocrinologists are leading, which results in the arrival of "walk-in" patients at the Nurse Specialist and Genetic Counselor. This leads to conflicting appointments of the scheduled and non-scheduled patients of the Nurse Specialist and Genetic Counselor.
- The Surgeon overbooks his agenda, which may result in high internal waiting times and overtime. This is hard to notice in the data, because most of the times a Resident Doctor supports the Surgeon, which is not registered in EZIS.
- Few patients are scheduled in the combination consultation hour of the Surgeon and Internist Endocrinologist. This results in a gap in the agenda.
- Too many telephone consults are scheduled at the end of the consultation hour. This results in overtime.
- The increase of new patients shall have a (negative) effect on the access and waiting times, this effect needs to be quantified.

These department-specific problems can be generalized to two questions:

1. What is the effect of an appointment system of the first specialist(s) on the subsequent specialists? I.e. how can the walk-in patients at the subsequent specialists be regulated?
2. Which specialists are suitable to join the multidisciplinary carousel? I.e. which division between scheduled and unscheduled (walk-in) patients is suitable in order to minimize waiting times and maximize utilization?

4.1.2 The model

Following the example of Zonderland (2014), the system is modeled as an Open Queuing Network (Jackson Network) in Figure 23. The patients can only enter the system through the counter of the corresponding department. So the model of the counter process is preliminary to the model of Endocrinology and Endocrine Surgery. The patients can leave the system after every consult. The employees act as servers. In some cases these servers are entered through an individual queue (Internists) and in some cases through a shared queue (Surgeon and AIO).

This multi-class queuing network can be reduced to a single class network "by aggregating all patient flows that enter a queue" (Zonderland, 2014). The Endocrinology department exists of five queues (including the counter). Every queue in this system is a single-service queue. The patient arrives at the counter and then is assigned to the queue of one of the Internists (which are physically in the same room). Depending on the care pathways the patient visits other queues or departs the system. At the Internists the patients are served based on: 1) appointment time and 2) arrival time.

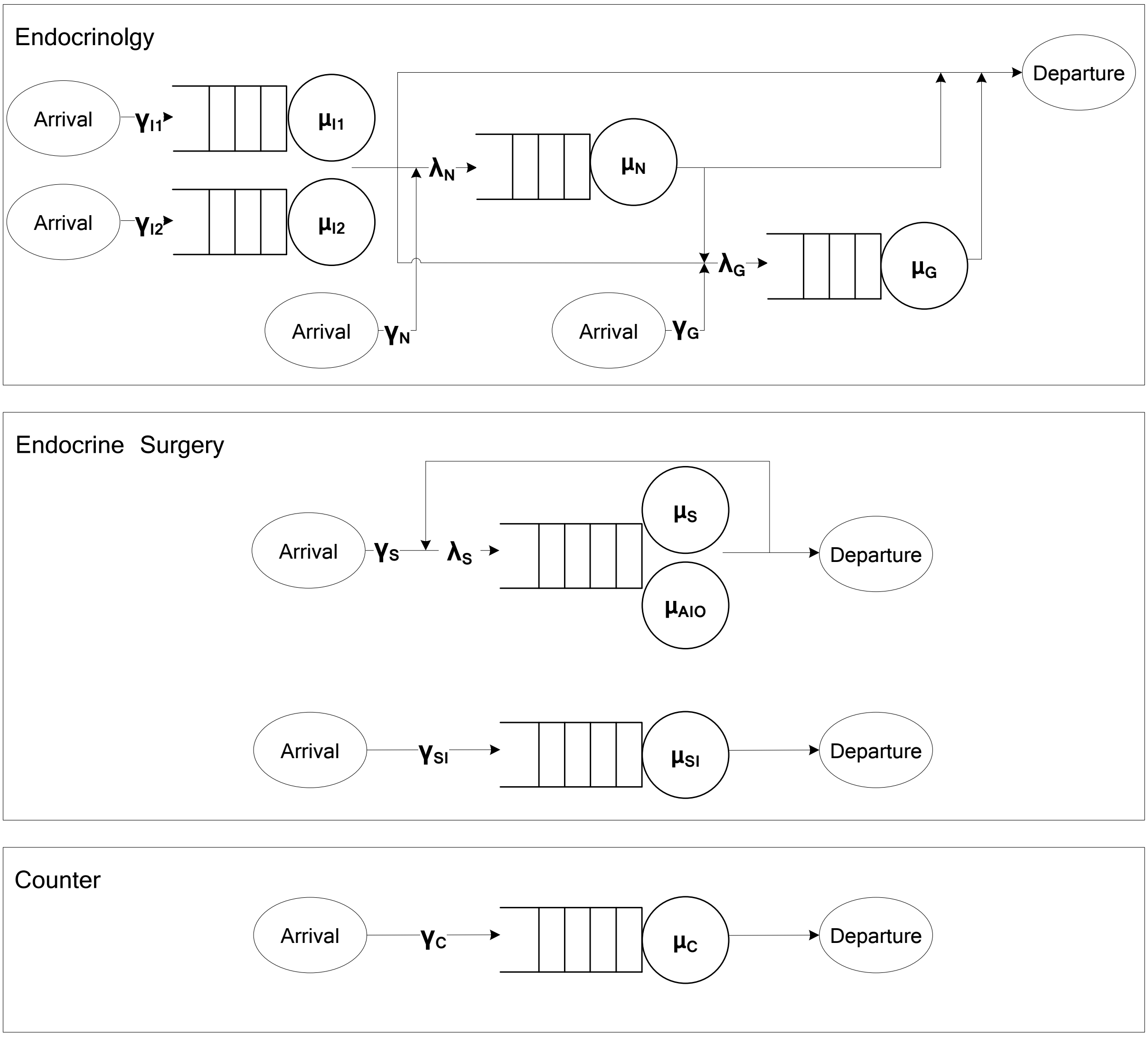


Figure 23: Queuing Network of Endocrine Oncology and Surgery

The department Endocrine Surgery exists of two queues (including the counter). The combined consultation hour is only active when the regular consultation hour is finished. So the server of the Surgeon and the Internist is only active when both the individual server of the Surgeon and the server of the Internist (I1) are not. Prior to the consultation hour, the

Surgeon decides on which patients need to be seen by him (malignant tumors, extraordinary check-up patients). The patients with benignant tumors are shared between the Surgeon. New patients and patients with curiosities rejoin the queue after a consultation with the AIO to be supervised by the Surgeon. These patients have the highest priority to the Surgeon at that moment.

In Table 14 the notations used in Figure 23 are explained.

Table 14: Legend of Open Queuing Model

I =	Internist Endocrinologist	γ_i =	Exogenous arrival rate for specialist i, i ∈ {I, N, G, S, SI, C}
N =	Nurse Specialist		
G =	Genetic Counselor	λ_i =	Total arrival rate for specialist i, i ∈ {I, N, G, S, SI, D, C}
S =	(Endocrine) Surgeon		
SI =	(Endocrine) Surgeon and Internist Endocrinologist	μ_i =	Service rate for specialist i, i ∈ {I, N, G, S, SI, D, C}
D =	Departure		
C =	Counter		

The arrival rate (λ_i) is calculated by:

$$\lambda_i = \gamma_i + \sum_{j=N}^{SI} \lambda_j P_{ji}\ , \qquad i \in \{I, N, G, S, SI\},\ j \in \{N, G, S, SI, D\}$$

where P_{ji} is the routing matrix, which includes the probability of travelling from specialist j to specialist i. Most queuing models focus on the limiting or equilibrium behavior of this system (Adan & Resing, 2015). The long-run steady-state behavior is analyzed to determine the long-run performance indicators for each station in the system (Koizumi, Kuno, & Smith, 2005). Commonly used performance indicators in a queuing model are 1) the distribution of the waiting time and 2) the distribution of the number of customers in the system (length of queue) and the less used 3) mean percentage of time that a server is busy and 4) the distribution of the work left in the system (Adan & Resing, 2015; Koizumi et al., 2005).

4.2 Conclusions

To make the analytic queuing model applicable to our system, the system needs to be stable. This implies that the service times of and arrival rates to the stations are such that all arriving patients can be served, the arrival and service processes are in the long run homogeneous in time and the system is in a steady state. However, in case of the system described in Figure 23, we cannot ensure the system comes in a steady state. For example the Surgeon overbooks his consultation hour; the arrival rate is bigger than the service rate resulting in overtime.

The performance indicators calculated by a queuing model are not as extensive as by a simulation model. As described in Section 2.3 Performance, the performance indicators decided on by the management include access time, idle time and overtime. These cannot be determined with a queuing model.

Our queuing model shall be quite complex. The amount of interconnections and dependencies between stations is high (high dynamic complexity). For example, the combined consultation hour of the Surgeon and Internist. Also the appointment rules and selection rules are complex: Endocrine Surgery’s appointment slots are overbooked and the Endocrine Surgery’s patients are dynamically divided over the Surgeon and Resident Doctor.

Once a simulation model is built it is easy to conduct a large amount of experiments. With an analytic model it is quite easy to built a model, but hard to derive different experiments. One of the goals of the research is to provide a better forecast of the walk-in patients to the supporting specialists. To achieve this goal several interventions need to be assessed.

Thus in this specific environment (complex system, many performance indicators and many interventions) a simulation study is the best approach.

5 Simulation model

By means of a simulation study we will analyze the effect of several interventions on the system (in our case outpatient clinic Endocrine Oncology and Endocrine Surgery). The seven-step approach of Law (2003) shall be used as guidance for our simulation model. Figure 24 presents these seven steps.

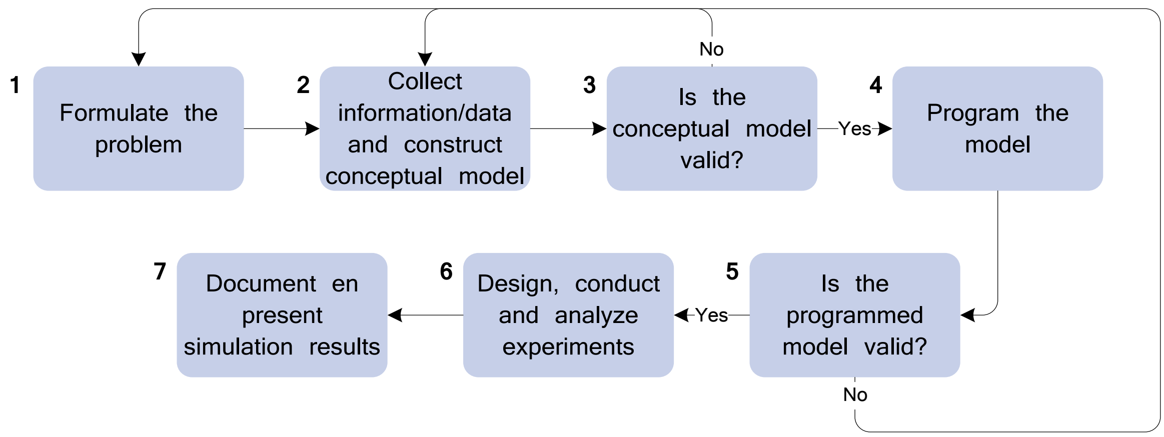


Figure 24: Approach for conducting a simulation study (Law, 2003)

Section 5.1 presents the first step: the problem formulation and partially the second step: the conceptual model. Section 5.2 presents the data and information collection necessary to specify the parameters of the model. Section 5.3 presents the calculation of the warm-up period and run length. Section 5.4 finishes with the model validation.

5.1 Formulate the problem

The first step of the seven-step approach concerns the formulation of the problem. The goal of this step is to obtain a complete understanding of the problem and define the objectives, performance measures and scope of the model (Law, 2003).

Chapter 2 Context analysis presents the core problems of this research by a problem cluster. These core problems have become known through an extensive context analysis.

Scope

The scope of the research is presented in the flowcharts of both outpatient clinics (Figure C-1 and Figure C-2). Hereby, the counter processes are left out of consideration, as no big problems are designated to these processes. Also, the counter processes are shared with the non-oncologic part of Endocrinology, which makes it hard to do interventions in this part. This restricts us to the *scheduling processes* and *doctor's processes*.

The conceptual model of the Scheduling processes and doctor's processes are presented in the two subsequent sections (Section 5.1.1 and Section 5.1.2). The conceptual model is the basis of our simulation model. It contains model assumptions, algorithms and data summaries (Law, 2003).

5.1.1 Scheduling process

This section shall focus on the creation of the patients and the scheduling processes of the Simulation Model.

Patient creation

The scheduling process starts with a patient creation routine. We decided to create 9 sources for Endocrinology: new, check-up and telephone requests for Internist A en Internist B separate, requests for physical and telephone consultations for the Nurse Specialist and requests for physical consultations for the Genetic Counselor. For Endocrine Surgery we created 5 sources: new, check-up, check-up after consultation, combination and telephone requests. These decisions are based on the goodness of fit test performed on the arrival rate of the patients, see Section 5.2.4.

Upon arrival the patient receives several attributes:

- Unique patient ID number
- Consultation type (new, checkup, combined or telephone)
- Diagnosis
- Treating specialist

The diagnosis of the Endocrinology patient is added to indicate whether the patient is a regular check-up patient or a check-up MEN-1 or check-up MEN-2 patient. Subsequently an appointment of 15 minutes (C) or 20 minutes (CM1 or CM2) is scheduled. At Endocrine Surgery the diagnosis is solely divided into benignant or malignant disorders to indicate if the Resident Doctor is able to treat the patient.

Schedule creation

At the start of the simulation empty appointment schedules are created for the entire planning horizon (1 year for Endocrine Oncology and 3 months for Endocrine Surgery). Data of the production weeks of both clinics is used to erase the dates on which the specialists are not present.

At the beginning of a consultation session, the current day is erased from the schedule. No new patients are scheduled to the agenda's on the day of the consultation session (static system). With a certain chance (according to the production weeks) an empty schedule is created for the first day after the planning horizon. In this way a rolling planning horizon is created.

In the current situation, each appointment schedule consists of dedicated slots. So we assign to every slot the:

- Time slot code
- Appointment starting time
- Appointment interval

After the schedules and the patients are created, the patients are assigned to a certain appointment slot and receive an appointment time.

Scheduling

During the scheduling phase, the patient is assigned to the preferred slot code according to consultation type (and diagnosis).

All patient types of Endocrine Surgery can be overbooked (except combination patients). New, check-up after surgery and telephone patients are scheduled at the corresponding timeslot with the fewest patients on it at the upcoming clinic session. Regular check-up patients can be postponed to a later clinic session. So if the upcoming session is fully booked, we look for an empty slot in the next week.

Endocrinology only overbooks telephone patients. Those are scheduled at the corresponding timeslot with the fewest patients on it. For new patients, two empty slots of 20 minutes (at Internist A) or three empty slots of 15 minutes (at Internist B) are required to schedule the patient.

5.1.2 Doctor's processes

This section presents the performance indicators and presents the conceptual model of the processes of the *patients* and *specialists*. Process flows are used to visualize the algorithms in the model.

To recapitulate from Section 2.3 Performance, the performance indicators of our interest are:

1. Access time,
2. Waiting time,
3. Idle time,
4. Utilization,
5. Overtime.

Access time and waiting time relate to the patients and idle time, utilization and overtime to the specialists. In Appendix F the process flows of the patients are presented. In these process flows the scope of the research is made clear and the performance indicators are highlighted.

Figure F-1 shows the process flow of the *patients* at outpatient clinic Endocrinology and Figure F-2 shows the process flow of the patients at outpatient clinic Endocrine Surgery. The process flow of combination patients is presented in Figure F-3. For these patients both the Internist and the Surgeon need to be available.

The process flow of all *specialists* of Endocrinology and Endocrine Surgery is presented in F-4. The blue path in this figure is only relevant for Endocrine Surgery, because at this clinic most of the time (Section 5.2.2) a Resident Doctor is available. Figure F-5 presents the process flow of the Resident Doctor at Endocrine Surgery.

5.1.3 Modeling assumptions

In the simulation model we make the following assumptions:

- Seasonal trends are not included the arrival patterns. We use the same arrival rate during the whole year.
- In the arrival rate, holidays or canceled clinic session are not taken into account when analyzing the working days. For example, if the Internist has clinic sessions on Monday, we categorize every Monday as clinic day. We expect the arrival rate of check-up patients to be higher at clinic days. This is because many patients plan the next check-up appointment during their visit of the outpatient clinic.
- Patients are always scheduled at the earliest possibility. In reality patients may prefer certain days and appointment times when requesting an appointment, but in the model these preferences are neglected. On the long term, the average utilization rate of the model shall not differ substantively from the reality. We do take appointment duration, slot code and specialist in consideration.
- Every clinic session is canceled with a certain probability. This probability is determined by means of the average amount of production weeks.
- Each scheduled patient cancels his appointment with a certain probability. In reality, these patients may request an appointment for another day. However, the model deletes these patients.
- A theoretical distribution is used to model the punctuality of the patients. The punctuality of the patients does not differ over the day. In other words patients in the morning are as punctual as in the afternoon.
- A theoretical distribution is used to model the service times of the specialists. The service times differ between specialists and patient types. Thus, the service times

are independently and identically distributed. The service times do not depend on the amount of patients waiting. In reality, a specialist may increase their service rate during peak hours (Cayirli & Veral, 2003).

- The Resident Doctor attends the clinic session with a certain probability. The model does not schedule more patients when the Resident Doctor is available or less when he is not. This may result in higher waiting times on days the Resident Doctor is not present than in reality.
- In the model, the telephone consults are available from the beginning of the clinic session and are performed if no patients are waiting. In reality, telephone consults are performed at the end of the clinic session or may be performed during a “gap” in the schedule. It can occur that the specialist uses the gap for taking a break or preparing another patient, but this is not included in the model.
- Patients are referred to the Nurse Specialist and Genetic Counselor with a certain probability. As a result, many patients may be referred at the same time to these specialists. These patients shall experience high internal waiting times. In reality, there is much consultation between the different specialists and the referral specialist takes the utilization of the receiving specialist into account.
- In the model, all malignant patients are treated by the Surgeon. In reality, there is much consultation between the Surgeon and Resident Doctor. They decide at the moment if it is possible for the Resident Doctor to consult the patient.
- In the model, the Internist is always on time for the combination consultation. For him, the combination patient has preference above the rest of the patients. In reality, there is much consultation between the Surgeon and Internist. It may occur that the Surgeon is treating the combination patient without the Internist or vice versa.

5.2 Data and information collection

Information and data of the system needs to be collected to specify modeling parameters and probability distributions (Law, 2003). This section presents this data and the corresponding parameters and distributions.

The factors mentioned by Cayirli & Veral (2003) are used as guidance to analyze the planning environment and collect the required data (see Table 15).

Table 15: Relevant factors encountered in appointment planning environments (Cayirli & Veral, 2003)

Modeling of Clinic Environments
Number of services (Single or Multi-stage)
Number of doctors (Single or Multi-stage)
Number of appointments per clinic session
Arrival process (Deterministic or Stochastic)
Punctuality of patients
Presence of no-shows
Presence of regular and emergency walk-ins
Presence of companions
Service times (Empirical or Theoretical distribution)
Lateness of doctors and their interruption levels (i.e. gap times)
Queue discipline (FCFS, by appointment time, by priority)

The presence of companions is left outside of our scope, as no data about the presence of companions was collected.

5.2.1 Number of services and doctors

In Chapter 2 Context analysis an extensive elaboration of the modeling environment is presented. In Figure 23 this model is simplified to the buffers (waiting rooms), servers (doctors) and links between them (route of the patients).

All the doctors have a responsibility to the outpatient clinic and a fixed amount of weeks per year to take off. However, the Resident Doctor is not always able to attend the clinic session. When the Resident Doctor leaves at the finish of the internship, it may take some time to find a new Resident Doctor. That is why the percentage of clinic session with a Resident Doctor needs to be determined.

5.2.2 Percentage of clinic sessions of Endocrine Surgery with a Resident Doctor

Based on interviews, the expectation is that the attendance of a Resident Doctor during the consultation session of Endocrine surgery has a large influence on the waiting time. With the attendance of the Resident Doctor, two patients can simultaneously receive a consultation. Just a few minutes extra time of the Surgeon is needed to supervise the Resident Doctor. This results in a higher productivity of the Endocrine Surgery clinic.

Between the period of 24 November 2014 and 26 October 2015 Endocrine Surgery has conducted 42 consultation sessions. Of these sessions, 30 sessions where accompanied by a Resident Doctor. During 10 sessions there was no Resident Doctor assigned to the consultation hour and during 2 sessions the assigned Resident Doctor was not available.

So, the estimation is that approximately 70% of the clinic sessions are attended by a Resident Doctor.

5.2.3 Number of appointments per clinic session

Appendix E present an extended overview of the number of appointment slots per clinic session, thus the capacity of the system. This section presents information about the actual production in 2015 and the amount of production weeks per year.

Production

On average, the monthly production at Endocrinology has been 26 physical consults for Internist A, 29 for Internist B, 11 for the Nurse Specialist, 6 for the Genetic Counselor and 57 physical consults at Endocrine Surgery. See Table 16 for the production numbers in the period of January to December 2015.

Table 16: Production of Endocrinology and Endocrine Surgery (from January 2015 to December 2015 from EZIS)

	Consultations	
	Physical	Telephone
Internist A	290	338
Internist B	335	648
Nurse Specialist	125	213
Genetic Counselor	67	
Endocrine Surgery	644	172

Production weeks

Based on data from January 2015 to December 2015 from EZIS, the number of production weeks at Endocrinology is on average 42 weeks (of the 52 weeks). At Endocrine Surgery this is 47 weeks.

5.2.4 Arrival process

In a deterministic arrival process patients “arrive at fixed multiples of a basic slot (i.e., every slot, every other slot)” (Robertazzi, 2012). When uncertainty in the arrival is taken into account it is called a stochastic process. According to Zonderland (2014), using stochastic elements in the model is very important to obtain reliable outcomes. She highlights that especially in health care settings this is the case, because of the high variability in this environment.

When taking uncertainty into account, the (theoretical) arrival of appointment requests holds the “lack-of-memory” property. This means that after a request has occurred, the probability of a request arriving in the first minute after the occurrence is the same as the probability of a request arriving in the second minute after the occurrence. The distribution which fits this "lack-of-memory" is the Exponential distribution, which considers the time between consecutive occurrences. The mean interarrival time is calculated as: $E[X] = \frac{1}{\lambda}$, where λ is the mean arrival rate per time unit (from the Poisson distribution).

The arrival rate to the Outpatient Clinics is based on the number of appointment requests from January 2015 to November 2015. Figure H-1 in Appendix H presents a complete overview of the mean arrival rate per (working) day, per specialist and per patient type.

The Chi-Squared test is used to compare the observed data with the expected data (from the Poisson distribution) according to the hypothesis that there is no significant difference between both. In general $p > 0.05$ is used to accept the hypothesis.

In some cases the null hypothesis was rejected, which means the observed data is significant different from the expected values. This was for example the case for new patients of Internist A. With a low arrival rate (<0.1) it is exceptional to have 2 arrivals on one day. In reality this can occur. For example due to the genetic disposition of the syndrome, which means that 2 family members request an appointment at the same time or due to the decision of another hospital to refer two patients consequently. The exceptional low values can occur because holidays and other non-working days are not taken into account. This means that some days are counted as working day, while in reality this was not the case.

These exceptional values are extracted from the data and assigned to a Uniform distribution. All remaining data accepts the null hypothesis and therefore fits the Poisson distribution.

5.2.5 Punctuality of patients

The arrival rate of the patients to the clinic is influenced by the punctuality of the patients. As a result, the performance of the system is affected by this factor (Cayirli & Veral, 2003).

"Punctuality of a patient is defined as the difference between a patient's appointment time and actual arrival time, and it accounts for both earliness and lateness" (Cayirli et al., 2006). Swartzman (1970) and Cayirli et al. (2006) both state that the normal distribution is a good fit for empirical data of patient's punctuality. The mean patient's punctuality observed in these studies where respectively -2 and -17 minutes.

During the period of 21 September 2015 to 9 November 2015 data is collected at Outpatient Clinic Endocrinology and Endocrine Surgery. The collected data was: the arrival time of the patient at the counter, the start/end time of the preparation for a patient by a specialist, the start/end time of the consultation and the start/end time of the administration for a patient. The punctuality of a patient is calculated by subtracting the scheduled appointment time of the observed arrival time of the patient.

Statistical analysis shows a significant difference between the punctuality of patients of Endocrinology and Endocrine Surgery patients. No significant difference is shown between new and check-up patients (See Appendix I). This means, the data of Endocrinology of Endocrine Surgery need to be analyzed separately, but we do not have to take the patient types into account. The estimation that our punctuality data of Endocrinology and Endocrine Surgery is normally distributed is not rejected by the Kolmogorov-Smirnov test with α = 0.05, so we can state that our data is normal distributed (See Appendix I). Table 17, Figure 25 and Figure 26 present the statistical analysis of the measured punctuality of patients.

Table 17: Descriptive statistics of patient's punctuality

Endocrinology		*Endocrine Surgery*	
N	101	N	71
Mean	-00:16:45	Mean	-00:08:36
Standard Deviation	00:18:00	Standard Deviation	00:15:56
Percentage of patients on time	92.1%	Percentage of patients on time	81.7%
95% confidence interval (LB)	-00:20:18	95% confidence interval (LB)	-00:12:23
95% confidence interval (UB)	-00:13:12	95% confidence interval (UB)	-00:04:50
Confidence Level (95,0%)	00:03:33	Confidence Level (95,0%)	00:03:46

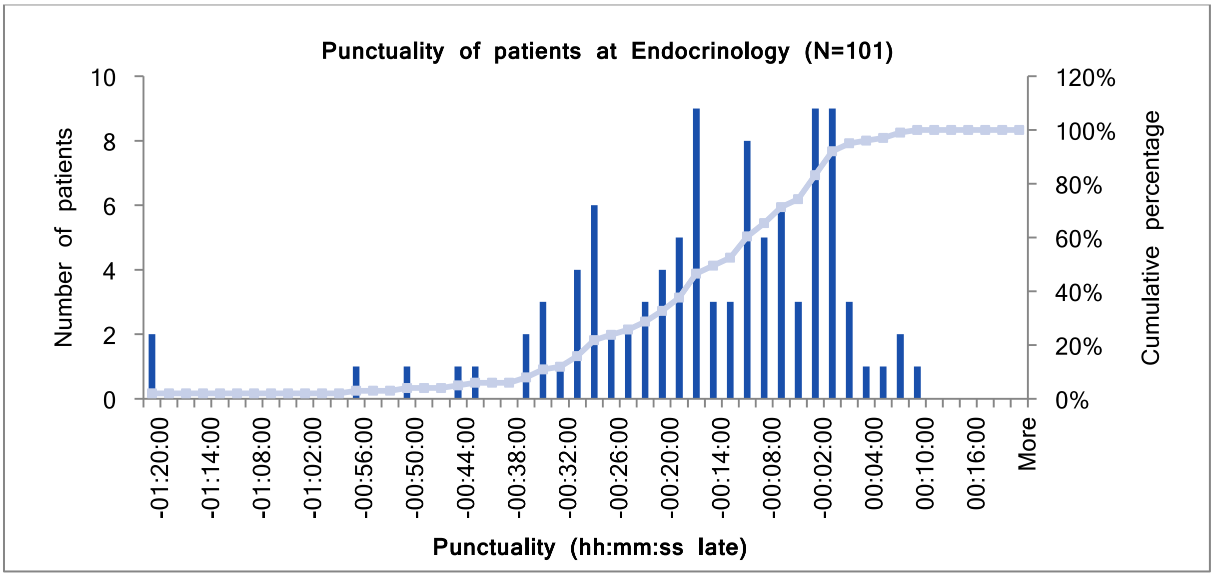


Figure 25: Number of patients and cumulative percentage of the observed patient's punctuality at Endocrinology (N=101)

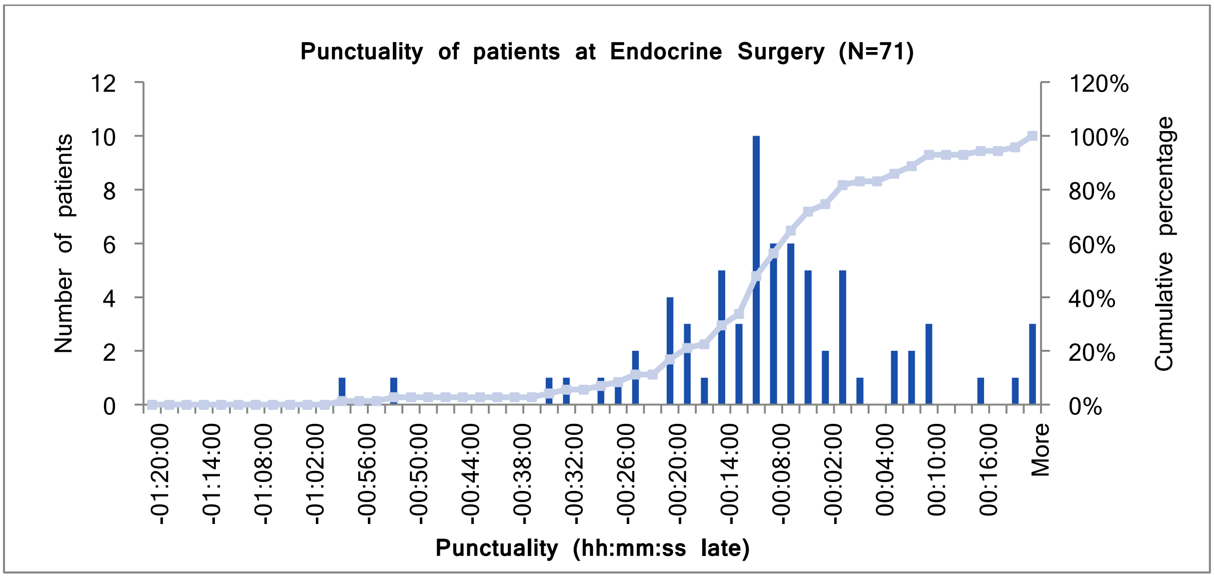


Figure 26: Number of patients and cumulative percentage of the observed patient's punctuality at Endocrine Surgery (N=71)

5.2.6 Presence of no-shows and rescheduled appointments

From January 2015 to half November 2015, at Endocrinology 573 appointments were scheduled for the internists in total (leaving telephone and e-consults outside of consideration). Of this total, 4.4% of the patients did not show up. On average 39.1% of these appointments has been rescheduled. At Endocrine Surgery 550 appointments were scheduled in this period. Of this total, 2.0% of the patients did not show up and 14.5% has been rescheduled.

The larger amount of displacements and no-shows at Endocrinology in comparison with Endocrine Surgery can be explained by the length of the planning horizon (respectively 1 year against 3 months). As patients have a longer external waiting time, the no-show rate tends to increase (Kim & Giachetti, 2006).

See Table 18 and Table 19 for a complete overview of the no-shows and displacements at Endocrinology and Endocrine Surgery.

Table 18: Amount of no-shows and displacements at Endocrinology (Jan 2015 - Nov 2015)

	Endocrinology							
	Internist A		Internist B		Nurse Specialist		Genetic Counselor	
Scheduled appointments	288		302		117		103	
No-show	16	(5.6%)	11	(3.6%)	3	(2.6%)	4	(3.9%)
Amount of displacements	103	(35.8%)	124	(41.1%)	20	(17.1%)	16	(15.5%)

Table 19: Amount of no-shows and displacements at Endocrine Surgery (Jan 2015 - Nov 2015)

		Endocrine Surgery
Scheduled appointments	570	
No-show	11	(1.9%)
Amount of displacements	83	(14.6%)

The reasons for the displacements differ remarkably between specialists and departments. For example, at Endocrinology the displacements of the appointments are quite often a request of the practitioner (Between 23.5% for Nurse Specialist and 40.3% for Internist A). At Endocrine Surgery, this is in 15% of the requests the case. At Endocrine Surgery by far most displacements are the consequence of the request of the patient (61.7% compared to an average of 40% at Endocrinology). For the Nurse Specialist most displacements (35.3%) are the consequence of an incorrect booking. This can be the results of many patients referred by the Internist for which an appointment needs to be booked on the day of appointment. See Appendix J for a complete overview.

5.2.7 Presence of walk-ins

In Section 2.2.3 Offline operational and Section 2.2.4 Online operational we can read that both Internists at Endocrinology and the specialists at Endocrine Surgery have a static agenda. This means that all regular appointments are scheduled prior to the doctors' processes. The experienced amount of emergency walk-in patients is very low, so we decide to neglect these numbers in our study.

Both the Nurse Specialist and the Genetic Counselor have a dynamic agenda. Thus appointment can be scheduled prior to and during the consultation session. If a patient is referred to the Nurse Specialist or Genetic Counselor by the Internist, we call the patient a walk-in patient.

We can recognize these walk-in patients from the data of EZIS by selecting the patients where the date of appointment request is equal to the actual date of treatment, in other words the Access time is zero days. Looking at data from January to December 2015, we see that for the Nurse Specialist, the amount of walk-in patients on Monday is 45 (of the 146 patients of Internist A and 89 patients of Internist B) and on Wednesday is 38 (of the 87 patients of Internist A). The amount of walk-in patients for the Genetic Counselor is 0.

See Figure 27 for the referral rates included in the flowchart of the Endocrinology patients.

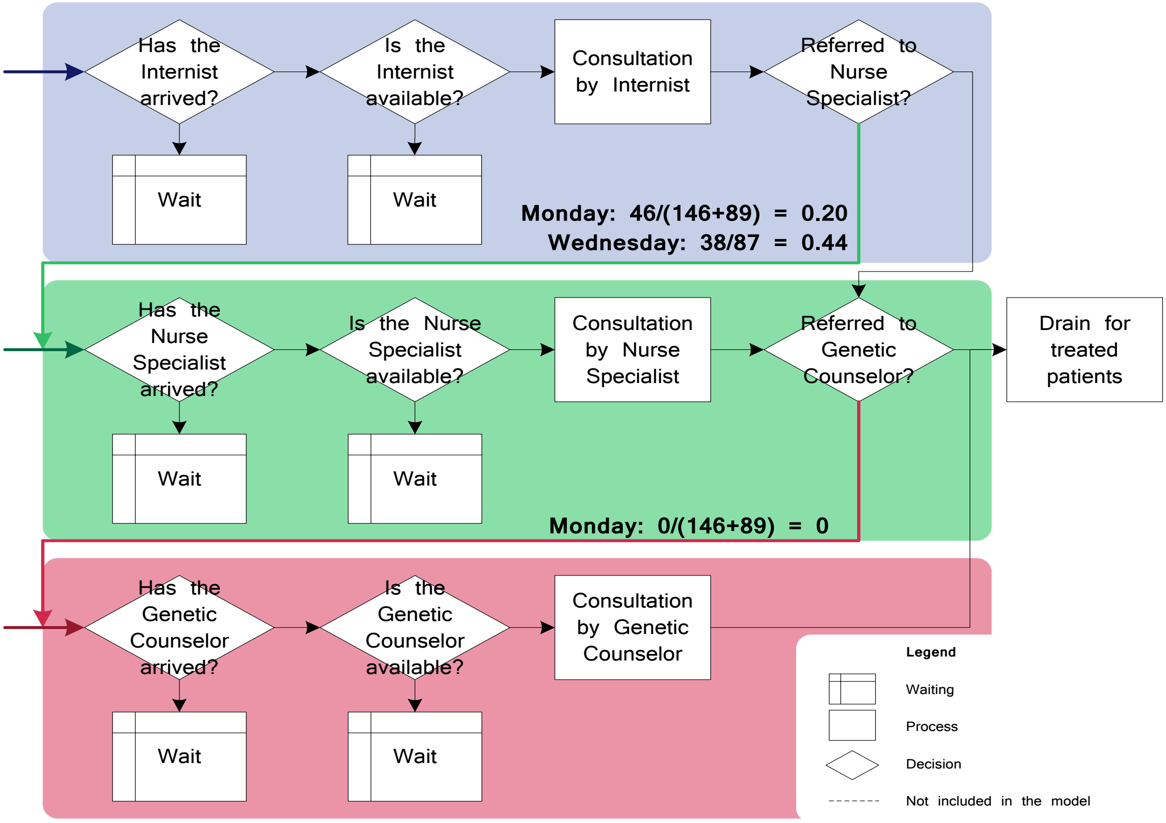


Figure 27: Flowchart of patients at Endocrinology incl. referral rates

5.2.8 Service times

Figure 28 and Figure 29 show histograms of the net and gross consultation times of Endocrinology and Endocrine Surgery. Based on this graphical display we estimate that the Gamma distribution will be a good fit to this data. In the remainder of this section we will assess this assumption by means of a goodness-of-fit test.

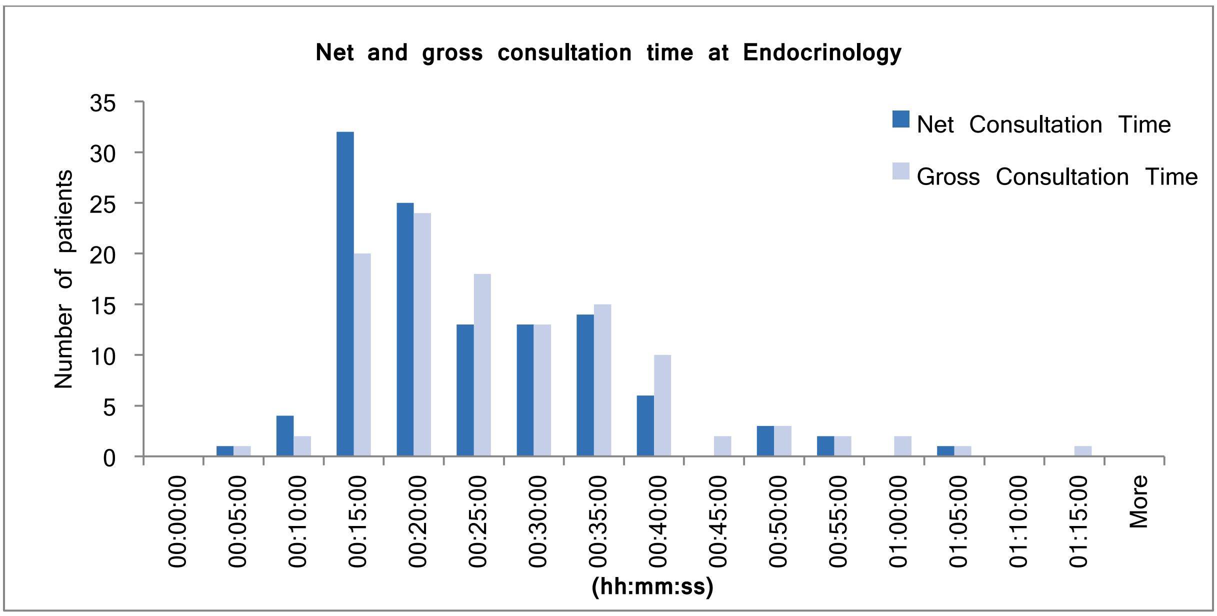


Figure 28: Net and gross consultation time at Endocrinology (from 21 Sept. to 9 Nov. 2015, N=114)

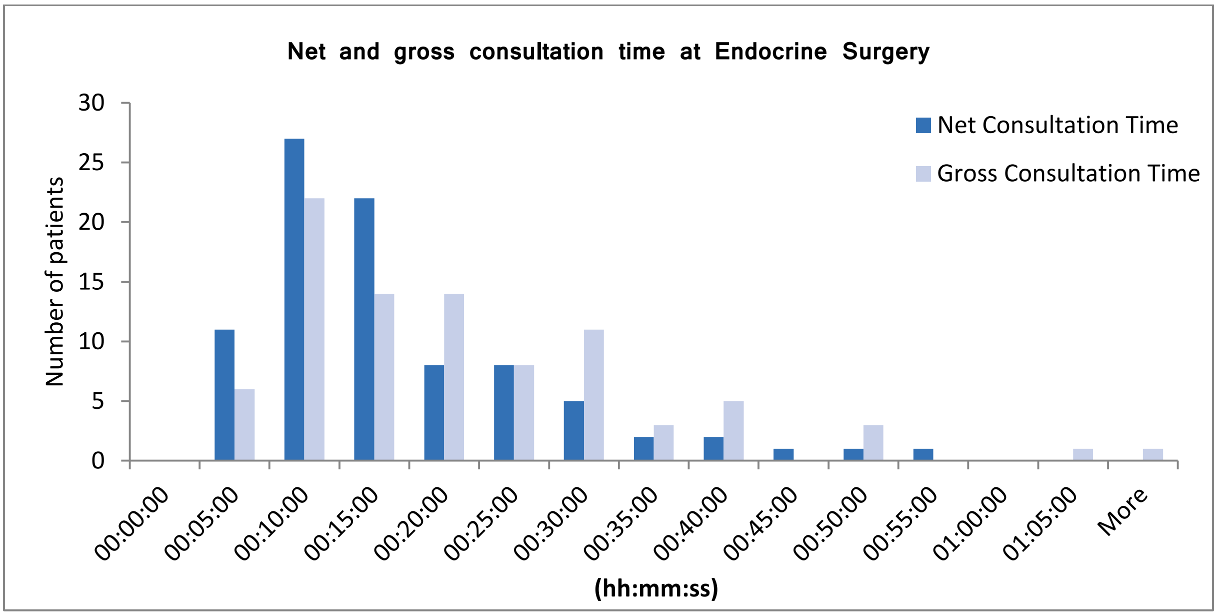


Figure 29: Net and gross consultation time at Endocrine Surgery (from 21 Sept. to 9 Nov. 2015, N=88)

Data (including the consultation times) is collected from the period of 21 September to 9 November 2015. We group this data by specialist and consultation type and set the parameters for the Gamma Distribution (Appendix K).

Internist A and Internist B form one group: Internists. Considering the net consultation times of Endocrinology, the general check-up patients and check-up MEN-1 and check-up MEN-2 patients are grouped. Considering the net consultation times of the Surgeon of Endocrine Surgery, the general check-up patients and check-up after surgery patients are grouped. We call these groups cluster check-up (cluster C). The motivation behind these groupings is presented in the section Service Times within Section 2.3 Performance for the motivation.

A goodness-of-fit test is performed to analyze whether the Gamma Distribution fits the sets of data. The probability plots of all groups show a straight line and a p-value larger than 0.20 is calculated. Thus we accept (with a reliability of 95%) the null hypothesis that the data fits the Gamma Distribution. Note that for some groups, the sample size is very small (for example for combination patients N=4). This results in a wide confidence interval (i.e. margin of error) which has a hard time indentifying outliers. However, in comparison to the size of the clinic session, walk-in patients, no-show rate and punctuality of patients and doctors, the variability in service time has significant less impact on the performance of the system (Oh, Muriel, Balasubramanian, Atkinson, & Ptaszkiewicz, 2013).

5.2.9 Lateness of doctors and their interruption levels

According to Cayirli and Veral (2003) lateness of doctors (to the first appointment) has a large effect on the internal waiting time. The mean unpunctuality of the specialists at Endocrinology is 3 minutes, at Endocrine Surgery this is 8 minutes. Because of the low amount of observations (minimal 3 and maximal 8 clinic sessions per specialist), we do not find a theoretical distribution to fit the data.

As mentioned in Section 2.3.1 idle time and thus the interruption levels of the specialists are left outside of consideration, because it is hard to record and specify these factors.

5.2.10 Queuing disciplines

In most studies it is assumed that patients are served according to the first-come-first-served (FCFS) principle. This implies that patients are served in order of their appointment times, when all patients are punctual (Cayirli & Veral, 2003). The same goes for our study.

5.3 Program the model

Our simulation model is a non-terminating simulation. This is the case when the performance measures depend on steady state cycles and no natural event ends the simulation run. For example the workload of the specialist is day-depended (Mes, 2013b).

To go from “transient system behavior”, where the performance depends on initial conditions to “steady state behavior”, where performance does not depend on initial conditions, some actions need to be taken. In case of a non-terminating simulation, the warm-up period (Section 5.3.1) and the run length (Section 0) are determined.

5.3.1 Warm-up period

In a real clinic environment with a finite number of patients the steady state is never reached (Cayirli & Veral, 2003). Still the system can reach a steady state concerning the performance indicators.

It takes some time to reach this steady state as at the beginning of the simulation the model is empty. This unrealistic beginning state can result in initialization bias (Hoad, Robinson, & Davies, 2010). When data during this period is gathered and included in the analysis wrong conclusions are drawn. By determining and deleting the warm-up period this can be prevented.

We use the performance indicator utilization to determine the warm-up period. The utilization of the specialists influences the waiting time and access time of the patients, thus it is sufficient to analyze the utilization. To smooth out the high-frequency oscillations in the data, the moving average is calculated:

$$Y_i(w) = \frac{1}{2w+1}\sum_{s=-w}^{w} Y_{i+s}$$

With the window: $w \leq \left\lfloor \frac{1}{4} m \right\rfloor$, where m is the amount of observations (run length) and $w = i - 1$ if $i \leq w$. We use a run length of 7 years, resulting in 459 observations for Endocrinology (Internist A) and 358 observations for Endocrine Surgery. So the maximum window is 89. From the configuration representing the current situation, with $w = 25$, we conclude that a warm-up period of 12 months (130 working days) will be sufficient. See Figure 30 and Figure 31.

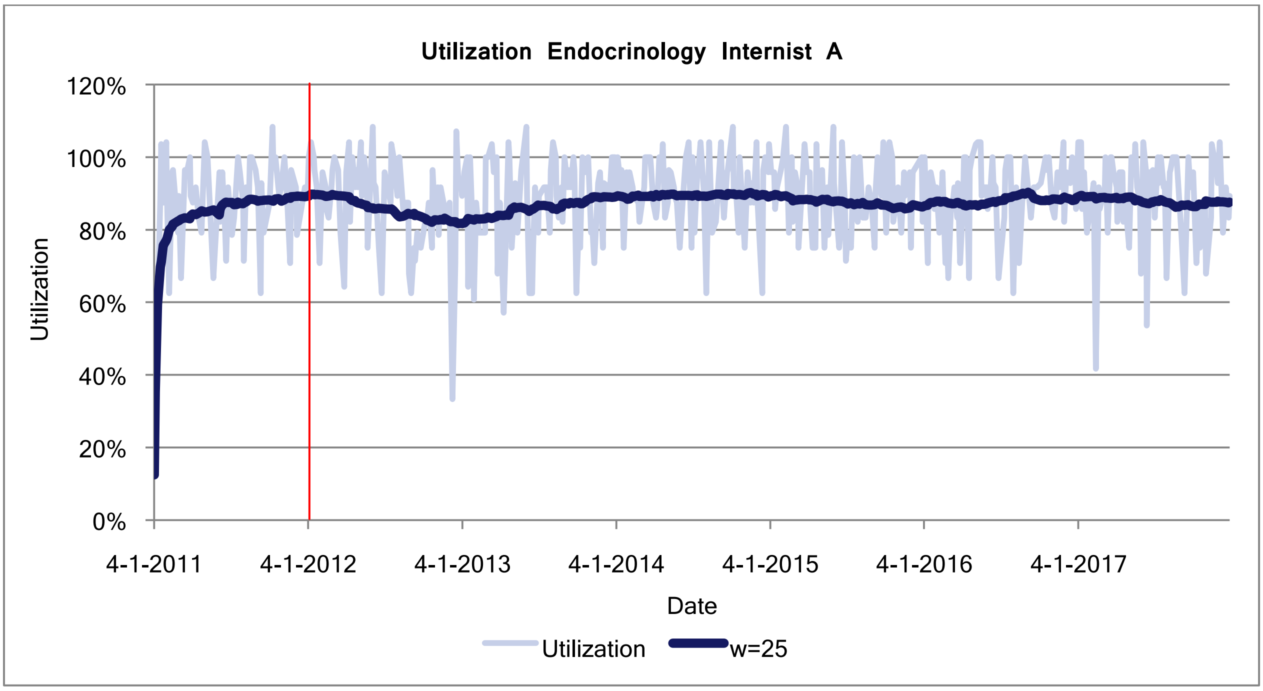


Figure 30: Utilization Internist A at Endocrinology with warm-up period (m=323)

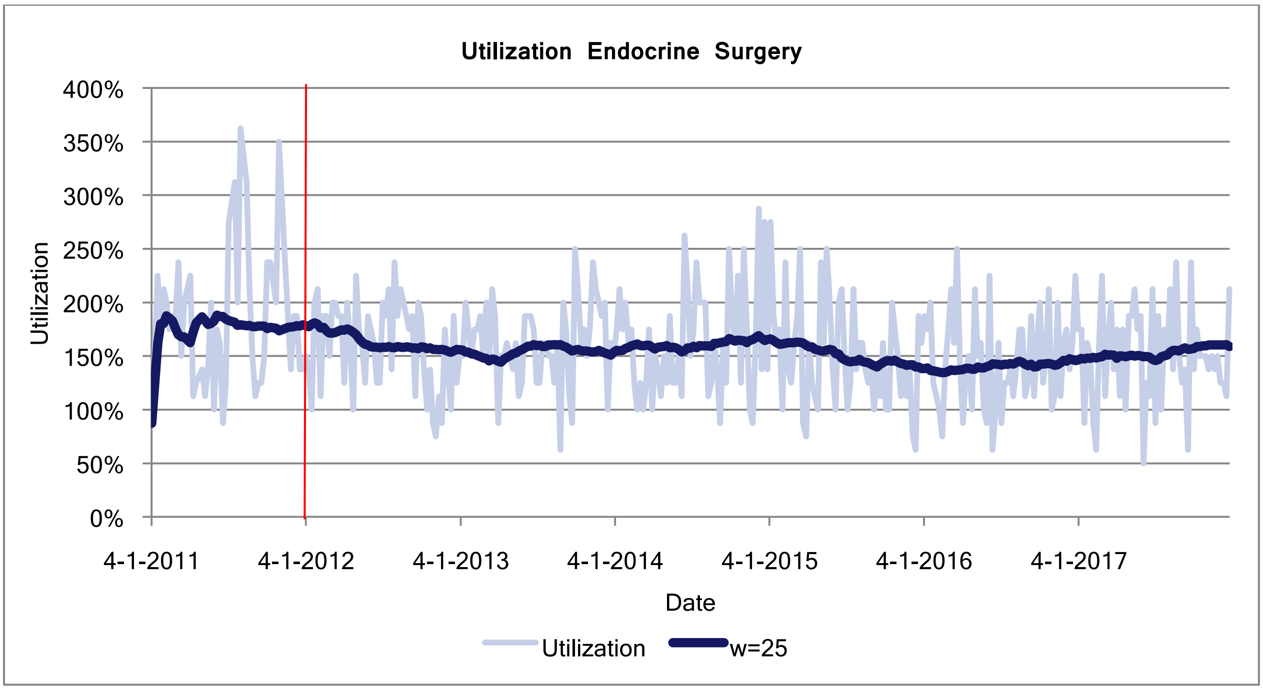


Figure 31: Utilization Endocrine Surgery with warm-up period (m=254)

The negative outliers in the utilization of Internist A (Figure 30), like on 12 December 2012, can be explained by the calculation of the utilization and the planning rules. Both in the calculation of the utilization with data from EZIS and data from the Simulation model, only the minutes of accomplished appointments are taken into account. For example, when a new patient does not show up on the day of appointment, this leads to 45 unscheduled minutes and thus a lower utilization. Also scheduling a general check-up patient (15 minutes) on a general timeslot (20 minutes) leads to 5 unscheduled minutes.

5.3.2 Run length

In a non-terminating simulation the analysis of the steady state performance can be performed with the replication/deletion approach or the batch means method (Mes, 2013b). The first consists of N runs (and thus N warm-up periods), while the second consists of 1 run with N batches (and 1 warm-up period). Although in our case the warm-up period is considerably long, we prefer to execute of multiple (shorter) replications instead of one long run. In this case we can assure independency between the results of different runs.

The accuracy of the simulation model increases with the increase of the simulation run length. Still it is not desirable to pick a too high simulation run length as executing a run is time consuming. With the sequential approach, suggested by Law and Kelton (2000), a proper tradeoff between accuracy and time is performed.

The objective of the sequential approach is to run the model until the width of the relative confidence interval of the performance indicators is sufficiently small (Mes, 2013b). In other words, how many running days are required to obtain a chosen relative error? To find the answer the following steps need to be taken:

1. Run the model for $n_0 \geq l$ days, with n_0 the run length in days and l the warm-up period in days. Set $n = n_0 - l$.
2. Calculate the sample mean ($\bar{X}_n$) and variance (S_n^2).

$$\bar{X}_n = \frac{1}{n}\sum_{i=1}^{n} X_i$$

$$S_n^2 = \frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X})^2$$

3. Calculate the confidence interval half-width ($\delta(n, a)$).

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

   Here, $t_{n-1,1-\alpha/2}$ is the student distribution with $n-1$ degrees of freedom and a $100(1-\alpha)$ percent confidence interval.

4. The optimal run length is found when:

$$\frac{\delta(n,a)}{|\bar{X}_n|} \leq \gamma'$$

Here, γ' is the preferred relative error.

$$\gamma' = \frac{\gamma}{\gamma + 1}$$

If the optimal run length is not found yet:

$$n = n + 1$$

Return to step 2.

We use as performance indicator the average waiting time, because this indicator is independent between any two days. We set $\alpha = 0{,}05$ as we prefer a 95% confidence interval. We set $\gamma = 0{,}1$.

With these setting we find a run length of 435 working days for both Endocrinology and Endocrine Surgery. With a minimum of one consultation session a week (52 weeks a year), this results in a run length of 8 years. Including the warm-up period, we decide to run the model for 9 years (3285 days).

5.4 Validation of the model

Verification concerns the determination whether (programmed) simulation model is an accurate representative of the conceptual model. Validation is the process of determining whether, concerning the objectives of the study, the Simulation model is an accurate representative of the real system (Law, 2003; Robinson, 1997). Respectively, building the model correctly and building the right model.

The verification phase takes place during the programming of the model. This concerns “debugging” the model, to make sure that the conceptual model is well represented.

To validate the model, we compare data from the Simulation model with real data from EZIS. The performance indicators: access time, waiting time, idle time and overtime all depend on the utilization rate. So, we use the utilization rate together with the production numbers as comparison criteria.

A paired (two-tail) t-test was performed to determine if the model represents the reality. Considering the utilization rate (Figure 32), the mean difference (M=0.222, SD=6.078, N=9) was not significantly greater than zero, because the p-value (0.915) is greater than the significance level (0.05). The same goes for the mean difference of the production rate (Figure 33, M=15.889, SD=34.880, N=9) with a p-value of 0.209, which is greater than the significance level. This provides evidence that the model represents the reality.

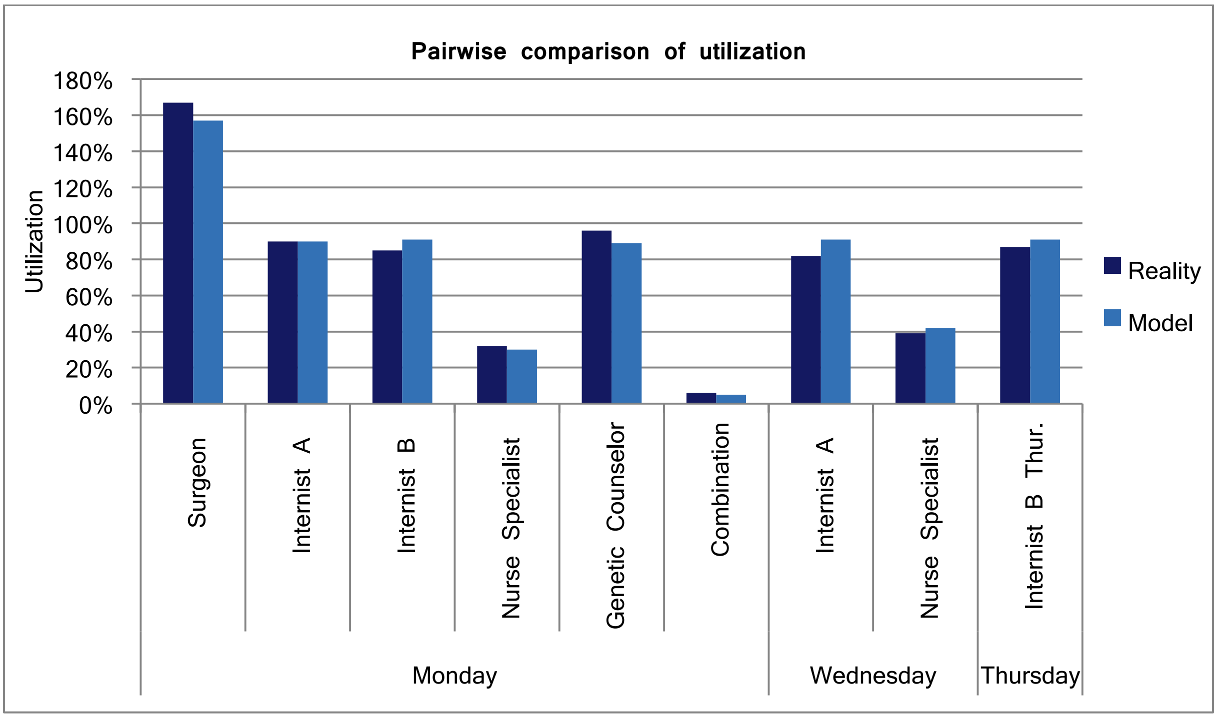


Figure 32: Pairwise comparison between real data of Utilization from EZIS (January to December 2015) and data from the Simulation Model

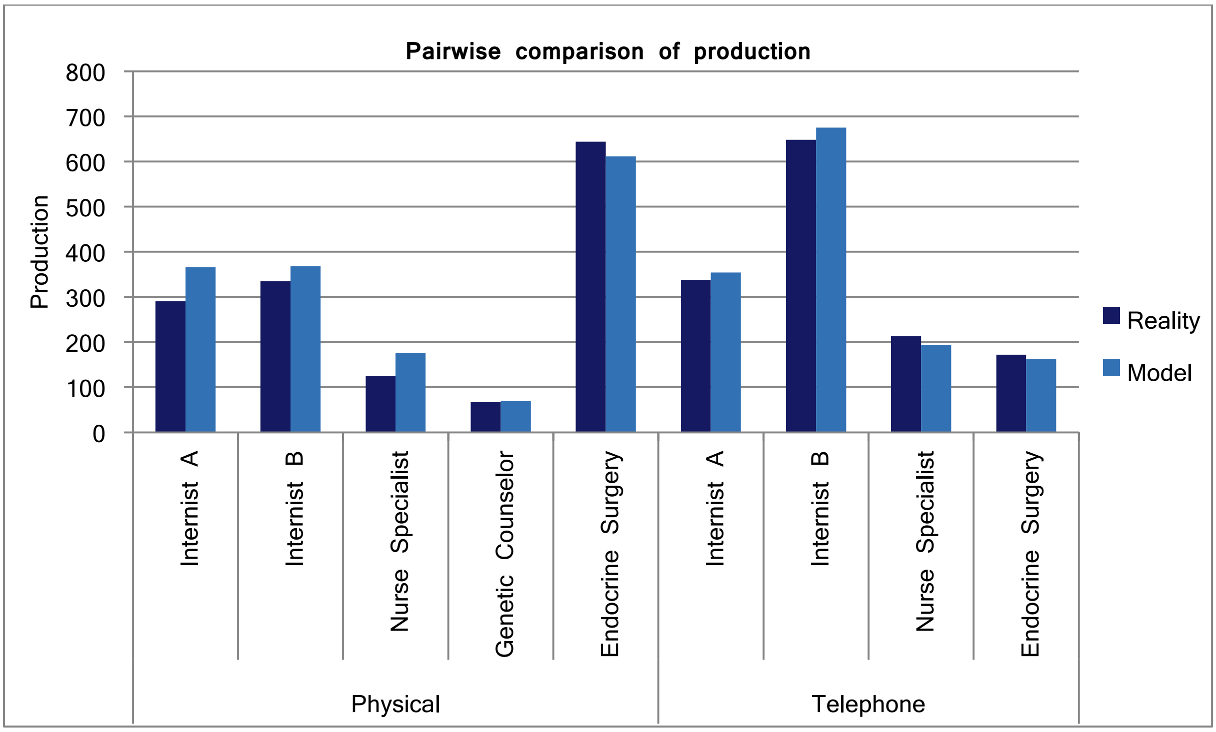


Figure 33: Pairwise comparison between real data of Production from EZIS (January to December 2015) and data from the Simulation Model

5.5 Conclusions

The simulation study in our research is performed according to the seven steps of Law (2003).

First the *problem is formulated* and the scope is made clear. In our case, the scope contains the scheduling processes and doctor's processes of the Outpatient Clinic. These processes are translated into a *conceptual model* existing of flowcharts, algorithms and modeling assumptions.

During the second step *data is collected* to specify the modeling parameters and probability distributions. In our case the factors mentioned by Cayirli and Veral (2003) are use to select the required data: 1) Number of services and doctors, 2) Percentage of clinic sessions of Endocrine Surgery with a Resident Doctor, 3) Number of appointments per clinic session, 4) Arrival process, 5) Punctuality of patients, 6) Presence of no-shows and rescheduled appointments, 7) Presence of walk-ins, 8) Service times, 9) Lateness of doctors and their interruption levels and 10) Queuing disciplines.

The *validity of the conceptual model* is discussed with the specialists involved, where after the *model is programmed*. During this fourth step, the warm-up period and run length is determined. After smoothing the data, an analysis of the utilization over 7 years provides us the evidence to choose a warm-up period of 1 year (130 working days). The simulation model we built is non-terminating and we prefer to use the replication/deletion method. By means of the calculation of Mes (2013b) we find a run length of 9 years (3285 days).

In the fifth step the *programmed model is validated*. This validation is done by comparing data from the Simulation model with data from EZIS. We find no significant differences between these two, so we conclude the model is a good representation of the reality.

Chapter 6 presents the experimental design, which is part of the sixth step of the approach of Law (2003): "Design, conduct and analyze experiments". Chapter 7 presents the simulation results.

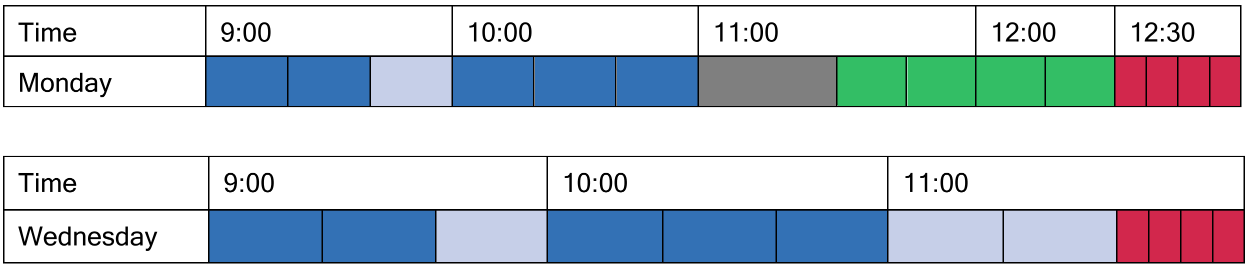
6 Experimental Design

This section presents the experimental design of the Simulation study. The experimental design is drafting a detailed experimental plan prior to the execution of the experiments. “In an experiment, we deliberately change one or more process variables (or factors) in order to observe the effect the changes have on one or more response variables” (NIST/SEMATECH 2013). Section 6.1 presents adjustments to the appointment system, starting with a visualization of the current situation and Section 6.2 presents the changes in parameters (sensitivity analysis).

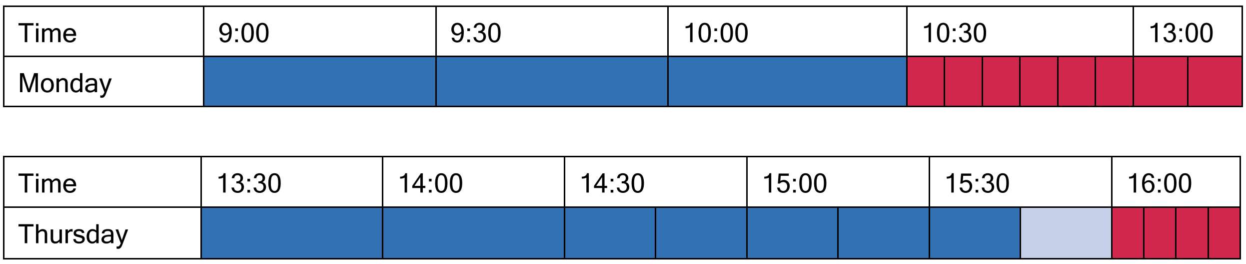
6.1 Adjustments to the appointment system

In the current system, the specialists independently decide on the implementation of an appointment system. This results in low coordination on a tactical planning level. On the operational level the specialists make up for this lack of coordination, by maintaining close relationships. In the current situation the schedules of the specialist differ in: length of the clinic session, duration of consults, amount of consults, etc. Figure 34 gives a graphical representation of the current agenda’s.

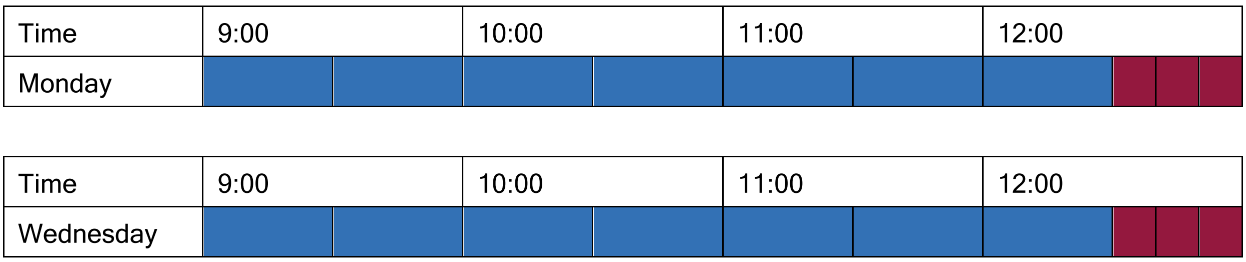
Internist A



Internist B



Nurse Specialist



Genetic Counselor

Time	10:30	11:00
Monday		

Endocrine Surgery

Time	8:30	09:30	10:30	11:30
Monday				

Figure 34: Graphical representation of the current agenda's of the specialists (from EZIS)

	Legend
	Regular timeslot (15 - 30 min.)
	Supervision timeslot (15 - 20 min.)
	Combination timeslot (15 min.)
	Timeslot for check-up patients (15 min.)
	Timeslot for new patients (20 min.)
	Telephone timeslot (5 min.)
	Telephone timeslot (10 min.)

Endocrine Surgery has dedicated timeslots corresponding with the appointment durations of the regarding patient type. However, at Endocrinology the appointment duration of the patient type does not always match the timeslot. For example a check-up patient booked in the agenda of Internist A gives a gap of 5 minutes, while a check-up MEN1 patient booked in the agenda of Internist B results in 5 minutes overbooking (in the 15 minutes slots). Table 20 presents a recap of the duration per patient type at Endocrinology.

Table 20: Current duration per patient type at Endocrinology

Patient type (suitable for regular slots)	Duration
New	45 min.
(general) Check-up	15 min.
Check-up MEN1, MEN2, VHL	20 min.

Now that the current situation is clear, we define the experiments concerning the appointment. Section 6.1.1, 6.1.2 and 6.1.3 present interventions following from the context analysis. Section 6.1.4 and 6.1.5 present interventions following from the literature study.

6.1.1 Improved appointment classification

The analysis of the service times of Endocrinology patients has shown that the duration of an general check-up patient does not differ significantly from the duration of a check-up MEN1 or MEN2 patient (See Section *Service times* in Section 2.3). The average duration of new patients is less than 35 minutes, which is significant less than the dedicated 45 minutes. So, following the example of Oh et al. (2013), we shall adapt the appointment classification to two types of patients (high service time: new, and low service time: check-up). Here, the *high* service time patients take up two consecutive slots of *low* service time patients. This means the slot of *new* patients is twice the duration of *check-up* patients. See Table 21 for the adapted duration per patient type.

Table 21: Adapted duration per patient type at Endocrinology

Patient type (suitable for regular slots)	Duration
New	40 min.
Check-up	20 min.

In anticipation to the adapted patient types, the agenda of Internist B has general appointment slots of 20 minutes (See Figure 35).

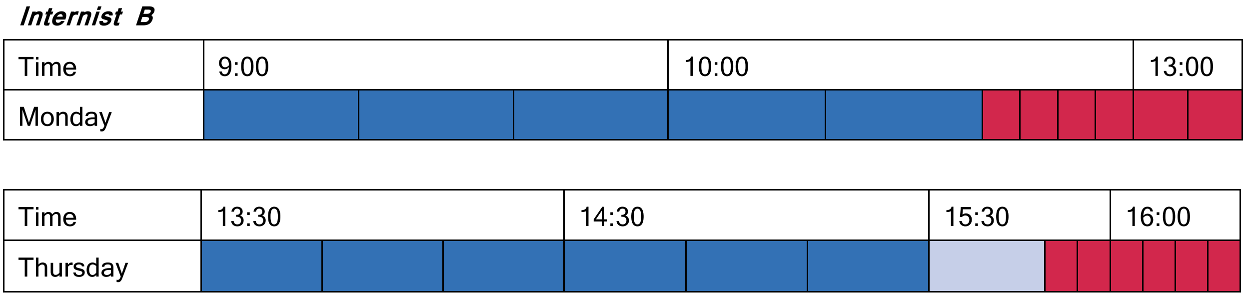


Figure 35: Agenda of Internist B with improved appointment classification

6.1.2 Move combination patients to beginning and adapt for arrival rate (CBG)

Section 2.4 shows that as a consequence of the overbooking of the agenda of Endocrine Surgery, the internal waiting time increases towards the end of the clinic sessions. This results in waiting time for the combination patients and thus waiting time for Internist A to start the combination consultation. We suggest moving the combination slots towards the beginning of the consultation session.

The utilization of the combination consultation is low (5%). This unused capacity results in idle time for the specialist. So we decide to halve the appointment slots dedicated for combination patients. See Figure 36 for these adaptations.

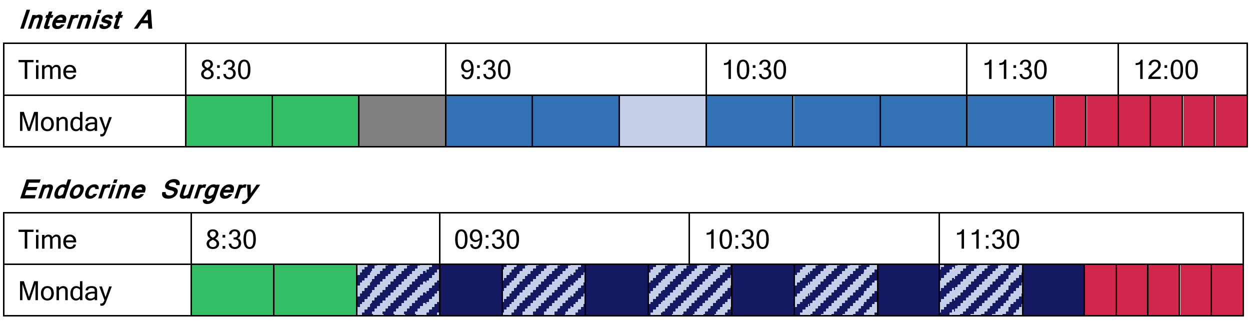


Figure 36: Agenda of Internist A and Endocrine Surgery with adapted combination slots

6.1.3 Dedicated appointment slots for scheduled and unscheduled patients of supporting specialists (DSNS)

Currently the agenda of the Nurse Specialist is highly flexible. No dedicated slots are reserved for patients who request an appointment prior to the clinic session (scheduled patients) and patients can request an appointment during the clinic session (unscheduled patients). With a mixed system like this, the access time of scheduled patients and the internal waiting time for unscheduled patients can be balanced (Kortbeek et al., 2014). However, when appointment patients are scheduled at the moment the arrival rate of walk-in patients is high; this results in high internal waiting time resulting in high variability in demand and thus low utilization (Kortbeek et al., 2014).

An improvement to the appointment system of the Nurse Specialist shall be: dedicated timeslots for scheduled patients at the moment the walk-in rate is low. In our case these moments are hard to determine, because the referral procedures (to send patients from the Internists to the Nurse Specialists) are not clear (Section 2.4).

We use information of the agendas of the Internist to determine the slots for appointment patients. This information is:

- The first patient can be referred at 09:15 on Monday and 09:20 on Wednesday.
- The last patient can be referred at 10:30 on Monday and 11:00 on Wednesday.

So we decide to reserve one slot in the beginning and two slots at the end of the consultation session of the Nurse Specialist for appointment patients (Figure 37).

Nurse Specialist

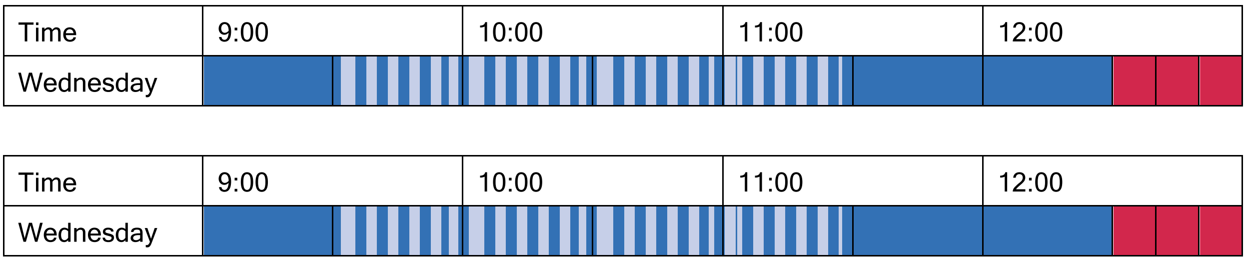


Figure 37: Agenda of Nurse Specialist with dedicated slots for appointment and walk-in patients (version 1)

When we analyze the available historical data about the walk-in arrival rates of the Nurse Specialist, we see that most patients are referred at 10:30 AM and 11:40 AM. Figure 38 presents the complete overview of the amount of referrals per timeslot in 2015.

We decide to experiment with another Appointment System for the Nurse Specialists, with dedicated timeslots for scheduled patients at the time the arrival rate of walk-in patients is low. Thus in this case, dedicated timeslots for scheduled patients are reserved at 9:00 AM, 11:00 AM and 12:00 AM (Figure 39).

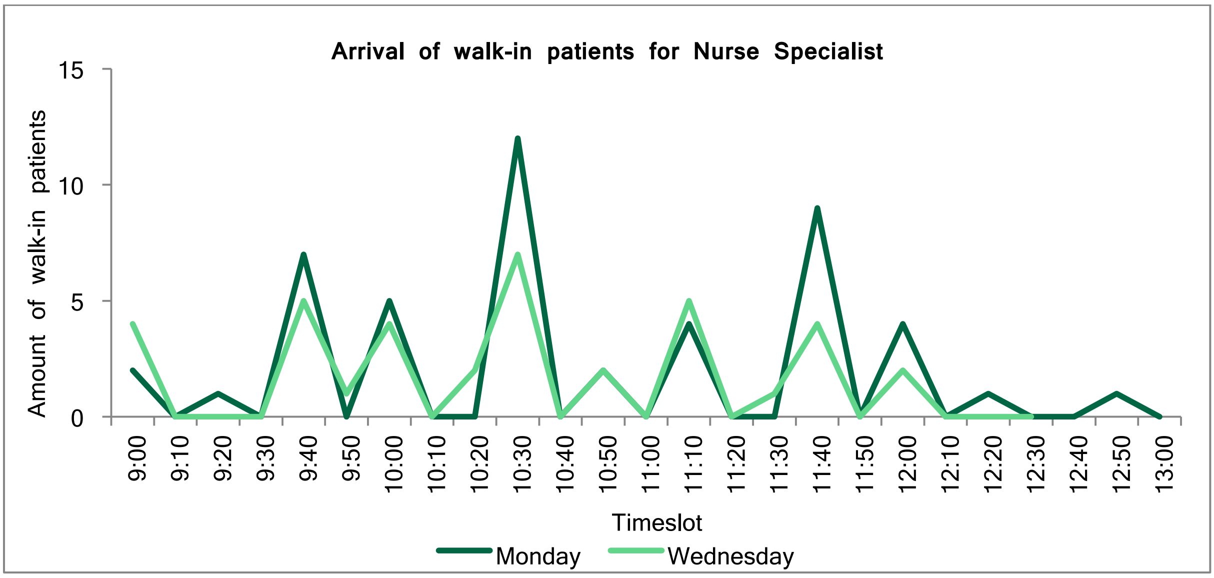


Figure 38: Arrival of walk-in patients for Nurse Specialist (January 2015 to December 2015, from EZIS)

Nurse Specialist

Time	9:00	10:00	11:00	12:00
Wednesday				

Time	9:00	10:00	11:00	12:00
Wednesday				

Figure 39: Agenda of Nurse Specialist with dedicated slots for appointment and walk-in patients (version 2)

6.1.4 Using patient classification

The appointment system becomes less flexible with the use of a sequencing rule (Cayirli & Veral, 2003). For example if the ALTER-rule is chosen, but the arrival rate of check-up patients is a lot higher than the arrival rate of new patients, this can result in a low utilization and high idle time. Instead of NCNCNCNC, the schedule becomes …C…C…CNC. Because, at Endocrinology the arrival rate of check-up patients is a lot higher than the arrival rate of new patients (29:1 for Internist A and 4:1 for Internist B), it is not desirable to use a sequencing rule.

However, at Endocrine Surgery this ratio is a lot smaller (1.6:1). So at Endocrine Surgery these sequencing rules can have a (positive) effect on the performance indicators. The base-rule at Endocrine Surgery is ALTER (new and return patients alternating). The effect of the other rules is going to be investigated:

- New patients in beginning (NWBG),
- Return patients in beginning (RTBG),
- New patients in beginning and end (NWBND),
- Return patients in beginning and end (RTBND).

See Figure 40 to Figure 43 for the graphical representation of these rules.

Endocrine Surgery

Time	8:30	09:30	10:30	11:30
Monday				

Figure 40: Agenda of Endocrine Surgery with sequencing rule: NWBG

Endocrine Surgery

Time	8:30	09:30	10:30	11:30
Monday				

Figure 41: Agenda of Endocrine Surgery with sequencing rule: RTBG

Endocrine Surgery

Time	8:30	09:30	10:30	11:30
Monday				

Figure 42: Agenda of Endocrine Surgery with sequencing rule: NWBND

Endocrine Surgery

Time	8:30	09:30	10:30	11:30
Monday				

Figure 43: Agenda of Endocrine Surgery with sequencing rule: RTBND

6.1.5 Using appointment rules

As mentioned in Section 2.2.2 Endocrine Surgery makes use of overbooking. This means that instead of the base-rule: *individual-block/variable-interval* (IBVI). Endocrine Surgery currently uses the *multiple-block/variable-interval* rule (MBVI). The interval is variable and corresponds to the mean service type of the corresponding patient type. Because Endocrine Surgery prioritizes a low access time (strive to consult every patient within one week) above low internal waiting times, it is not desirable to adapt this appointment rule to an individual-block rule or a MBVI-rule with twice the mean service time.

Endocrinology currently uses the *individual-block/variable-interval* rule (IBVI). Based on the performance of the appointment rules according to Cayirli and Veral (2006), we will investigate the effect of the following appointment rules:

- OFFSET rule,
- Bailey-Welch rule (2BEG),
- Multiple-block/fixed-interval rule (MBFI).

We omit the DOME rule (Section 3.6.2 Patient Classification), because this rule is comparable to the OFFSET rule.

For the OFFSET rule we choose the parameters: β1 = 0.15, β2 = 0.30, k1 = $\frac{1}{2}$n, with n the amount of appointment slots. The formulas for the OFFSET rule are:

$$t_i = (i-1)\mu - \beta_1(k_1 - i)\sigma \text{ for } i \leq k_1,$$

$$t_i = (i-1)\mu + \beta_2(i - k_1)\sigma \text{ for } i > k_1,$$

The patient types are divided into new patients ($\mu = 35$ and $\sigma = 7$) and Checkup patients ($\mu = 20$ and $\sigma = 8$).

See Figure 44 and Figure 45 for the graphical representation of the Bailey-Welch rule and the Multiple-block/fixed-interval rule.

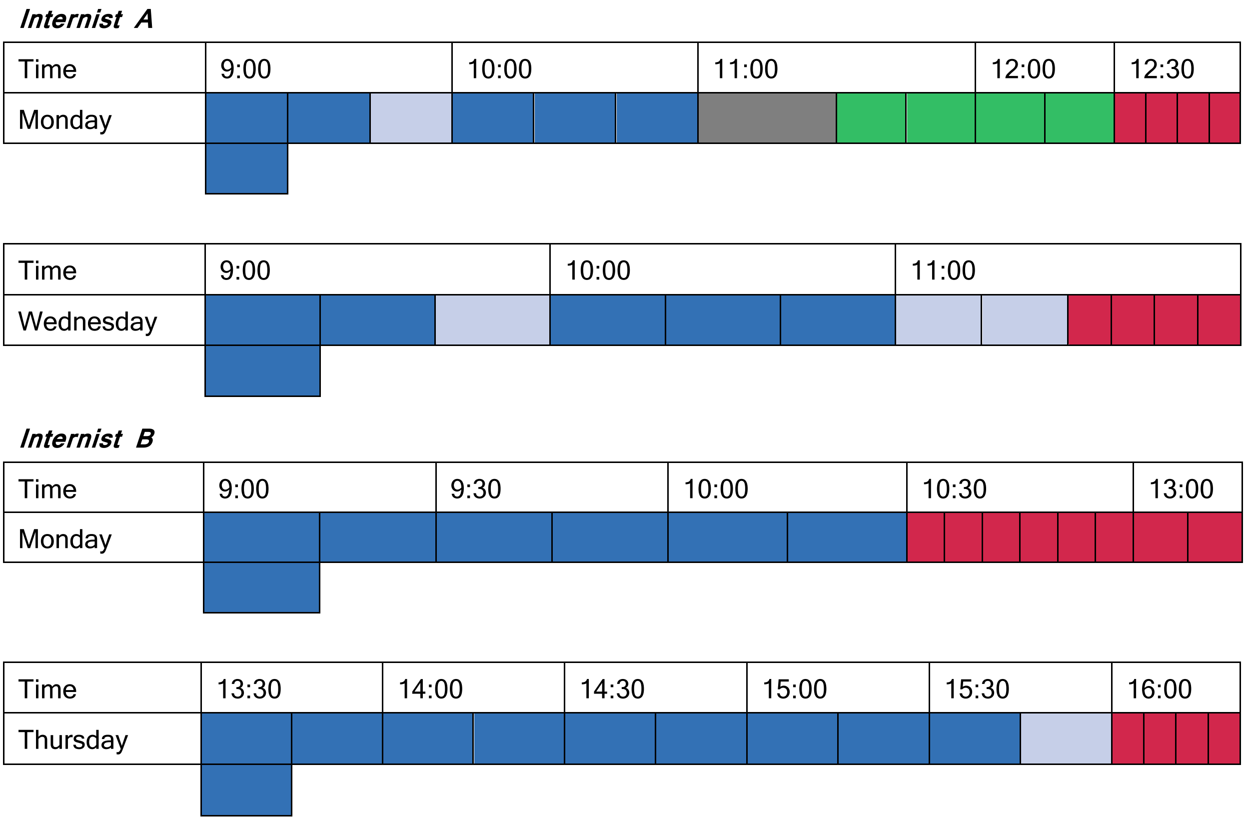
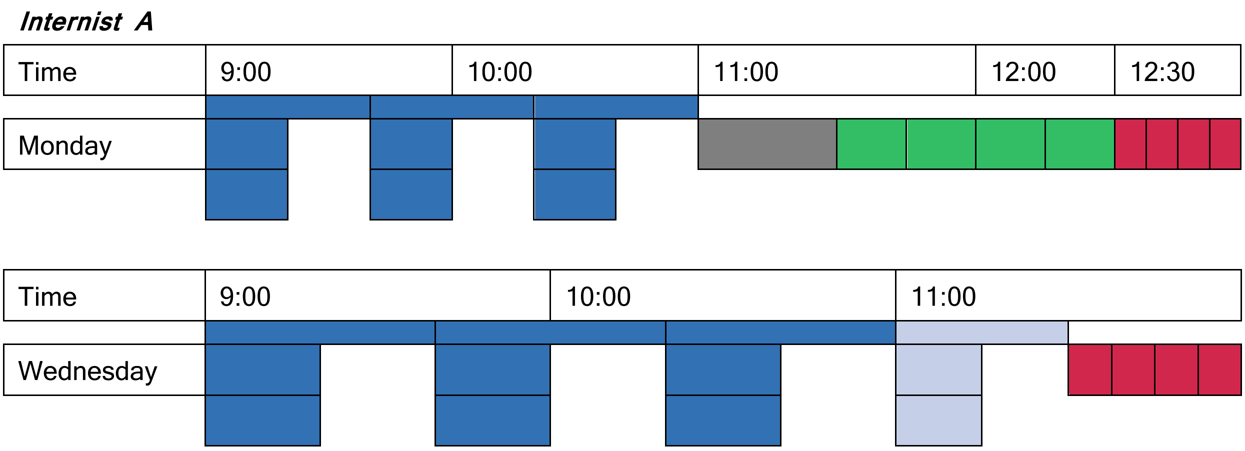


Figure 44: Agenda of Internist A and Internist B of Endocrinology with appointment rule: 2BEG



Internist B

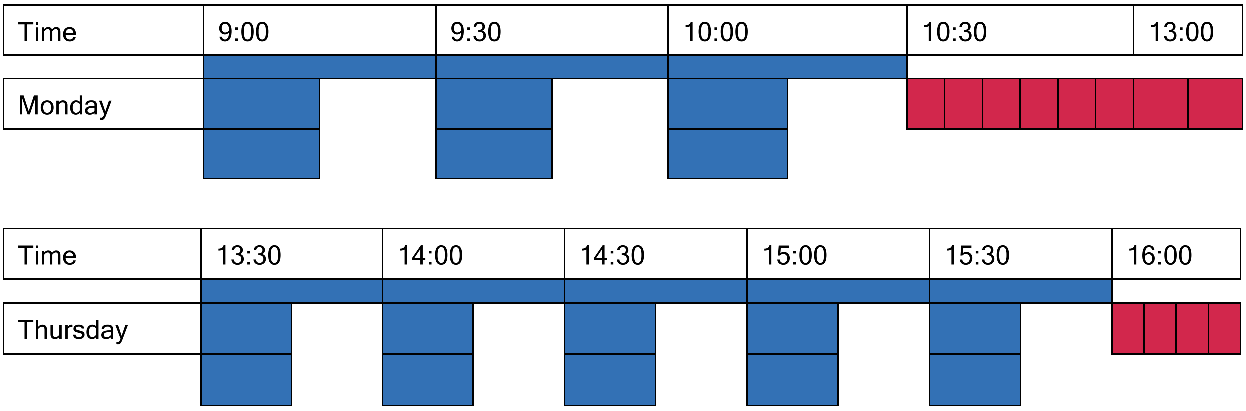


Figure 45: Agenda of Internist A and Internist B of Endocrinology with appointment rule: MBFI

6.2 Changes in parameters

Next to the adjustments to the appointment systems presented in Section 6.1 also structural decisions can be made to influence the performance indicators. These are called qualitative factors by Law en Kelton (2000).

In Section 2.4 Demarcation of core problem several problems are presented, which can be solved by making structural decisions. For example: 1) improvement of referral procedures of patients from the Internists at Endocrinology to the Nurse Specialist (and Genetic Counselor), 2) improvement of scheduling procedures of (combination) patients. These improvements can respectively result in an increase of the walk-in patient for the Nurse Specialist (and Genetic Counselor) and in an increase of the amount of requests for combination consultations.

Furthermore, from the context analyzes we conclude that the amount of appointment requests for Endocrinology increases (Section 2.1.1), patients can be reassigned from the Internists to the Nurse Specialist (Section 3.4.1) and the punctuality of the specialists can be improved (Section 5.2.9).

So the impact of the interventions presented in Table 22 on the performance measures is investigated.

Table 22: Interventions on parameters of the Simulation model

	Interventions	
Arrival rate to Internists (Endocrinology)	*110%	*90%
Arrival rate to Endocrine Surgery (incl. combination patients)	*110%	*90%
Arrival rate of Appointment patients to Nurse Specialist	*110%	*90%
Arrival rate of Walk-in patients to Nurse Specialist	*120%	
Punctuality of doctors	- 5 minutes	+ 5 minutes

Additionally, we expect that the number of production weeks of the Internists has a large effect on the access times to these specialists and we expect that the presence of the Resident Doctor has a large effect on the waiting time at Endocrine Surgery. Thus we analyze the effect of interventions on these parameters (Table 23) on the performance indicators.

Table 23: Interventions on parameters of the Simulation model

	Interventions	
Production weeks (Endocrinology, current is 42 weeks)	- 5 weeks	+ 5 weeks
Presence of Resident Doctor (current is 70%)	50%	90%

6.3 Conclusions

Our experimental design exists of adjustments to the appointment system and changes in the input parameters.

The interventions on the appointment system can be separated in interventions following from the context analysis and interventions following from the literature study. Interventions from the context analysis are:

- Improvement of the appointment classification of the Internists (referred to as the adapted individual-block/variable-interval rule: adapted IBVI).
- Moving of the combination hour to the beginning of the clinic session and adapt for the arrival rate of combination patients (CBG-rule).
- Dedicated appointment slots for scheduled and unscheduled patient of supporting specialists (DSNS-rule).

Interventions from the literature study are:

- Using patient classification (for Endocrine Surgery) consisting of the following rules: 1) ALTER (the base rule), 2) NWBG, 3) RTBG, 4) NWBND and 5) RTBND.
- Using appointment rules (for the Internists) consisting of the following rules: 1) IBVI (the base rule), 2) OFFSET, 3) Bailey-Welch (2BEG) and 4) MBVI.

Changes to the input parameters include: 1) variations in the arrival rate to the Internists (Endocrinology), 2) variations in the arrival rate to Endocrine Surgery (incl. combination patients), 3) variations in the arrival rate of *appointment* patients to the Nurse Specialist (Endocrinology), 4) variations in the arrival rate of *walk-in* patients to the Nurse Specialist (Endocrinology), 5) variations in the punctuality of the specialists, 6) variations in the production weeks (Endocrinology) and 6) variations in the presence of the Resident Doctor (Endocrine Surgery).

Chapter 7 presents the results of the interventions presented in the Experimental Design.

7 Results

This chapter presents the analysis of the computational results of the simulation model. We will start with an analysis of the zero-measurement, to see what the long-term consequences of the current situation are in Section 7.1. Section 7.2 presents the effect of interventions in the appointment system. Section 7.3 presents the effect of adaptations to the parameters.

7.1 Current situation

In the current situation, according to the model, the average access time to Internist A is the highest: 75 days (in the period of 9 years), compared to 16 days for Internist B, 1 day for the Nurse Specialist, 18 days for the Genetic Counselor, 8 days for Endocrine Surgery and 5 days for combination patients (see Figure 46). Respectively the utilization of the specialists over the same period is: 88%, 87%, 35%, 88%, 169% and 6%.

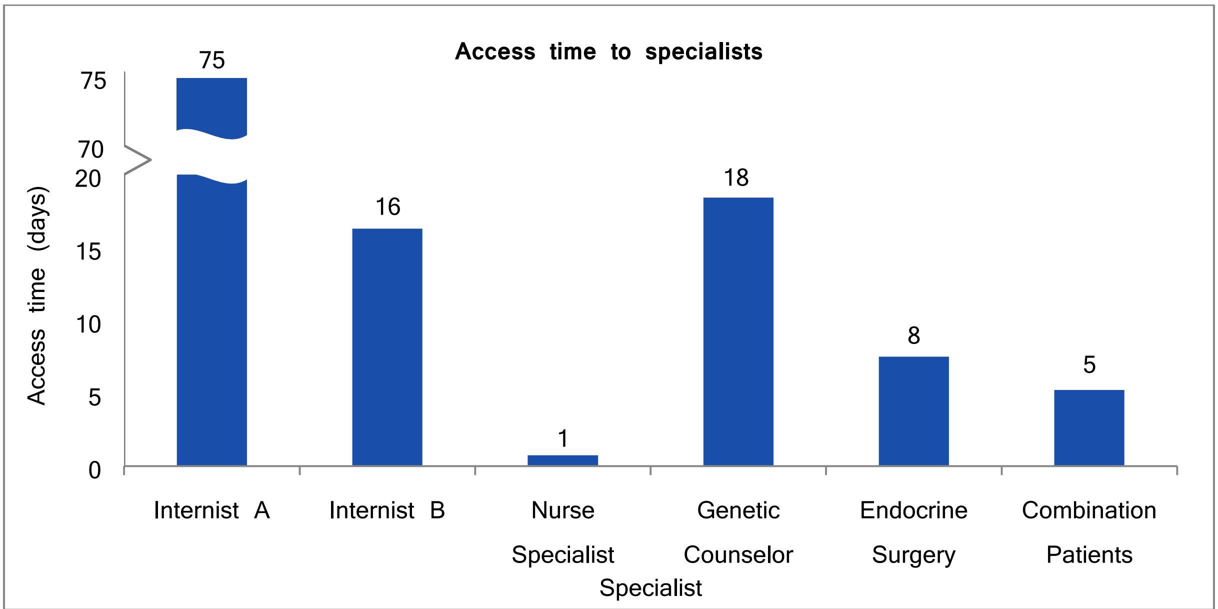


Figure 46: Average access time to specialists (a period of 9 years from the Simulation model)

To draw fair conclusions from Figure 46, the average access time of every specialist should be assessed individually.

The access time of the Nurse Specialist is low. This matches our expectations as between 20 and 44 percent of the appointments are walk-in patients. Also the capacity of the Nurse Specialist is a lot higher than the demand, resulting in a low utilization. The access time to the Genetic Counselor is within proportion (in line with the "Treeknormen"). Also the average access time of 18 days seems reasonable with the high utilization of 88% on average. We can conclude the same for Internist B: the access time is within in proportion and seems reasonable for the high utilization. In reality the access time to the Genetic Counselor may be lower as in some cases the capacity of the Genetic Counselor is anticipated to the (increased) demand. The access time to Endocrine Surgery is low (8 days), as this outpatient clinic strives to see all patients within a week and uses overbooking to achieve this. The capacity for the combination patients is a lot higher than the demand, resulting in a low utilization and therefore low access times.

Thus, only the average access time to Internist A asks for extra investigation. Figure 47 shows the growth of the access time to Internist A over the years. In comparison with Internist A, the access time to Internist B is stable, resulting in an average access time of 16 days (in the period of 9 years).

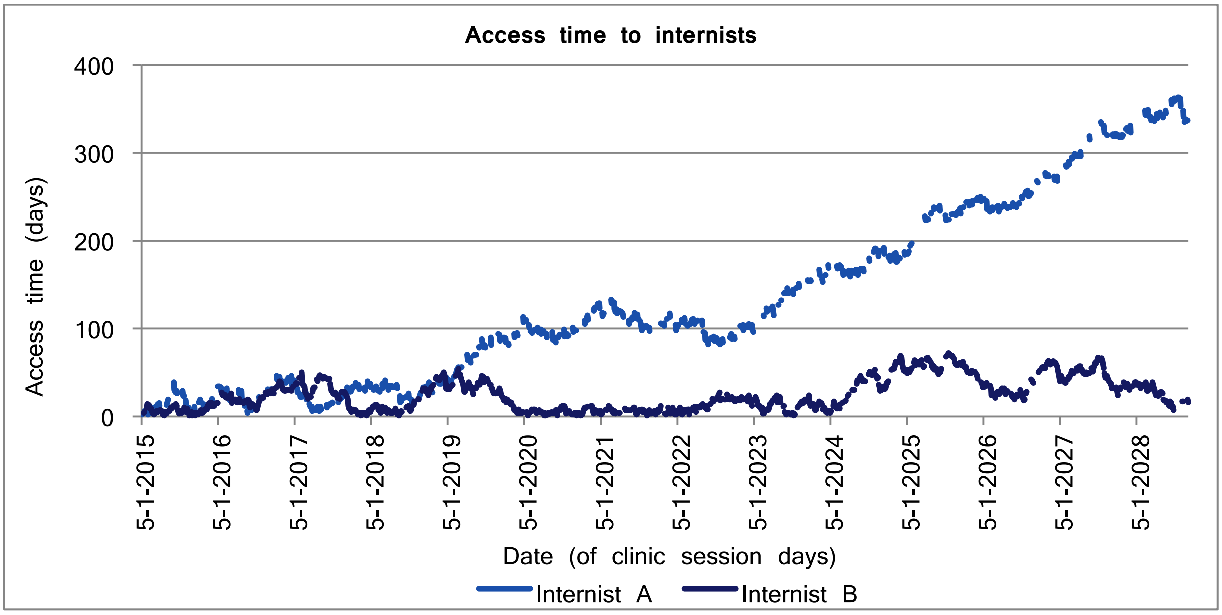


Figure 47: Access time to internists (a period of 13 years from the Simulation model)

Reasons for the increasing access time of Internist A can be: 1) the long term demand for the service (in this case: consultation of Internist A) is higher than the capacity, 2) "there is a fundamental mismatch between the variation in demand and the variation in capacity", 3) a queue is maintained to ensure a high utilization rate of recourses (Silvester et al., 2004).

With a simple calculation we check if the demand does not exceed the capacity of Internist A and Internist B (see Appendix L). The average demand of Internist A is 153 min per week and of Internist B is 179 min per week. Respectively, the average capacity is 190 min and 240 min per week.

Yearly the relationship between demand and capacity should be:

$$Capacity_{weekly} \cdot Production\ weeks \gg Demand_{weekly} \cdot Weeks\ per\ year$$

If we fill in this formula for Internist A, we come to:

$$190 \cdot 42 = 7{,}980 \quad > \quad 153 \cdot 52 = 7{,}956$$

For Internist B, we come to:

$$240 \cdot 42 = 10{,}080 \quad \gg \quad 179 \cdot 52 = 9{,}308$$

Thus, we see that the first statement is not the explanation for the increasing access times.

Also, the management does not intentionally preserve a waiting list to ensure a certain utilization rate. So also the third statement is not an explanation for the high access time to Internist A.

Fluctuations in demand and capacity do occur. The same amount of patients does not report at the outpatient clinic every week. Due to holidays, illness and meetings, the capacity fluctuates as well. This can result in high access times, because when the demand is greater than the capacity, the excess will be passed to the next week. When the demand is less than the capacity, the excess will be lost, as spare capacity cannot be passed forward (Figure 48). Thus we can conclude from the Simulation model that the current capacity of Internist A is not sufficient to deal with variations in demand and capacity.

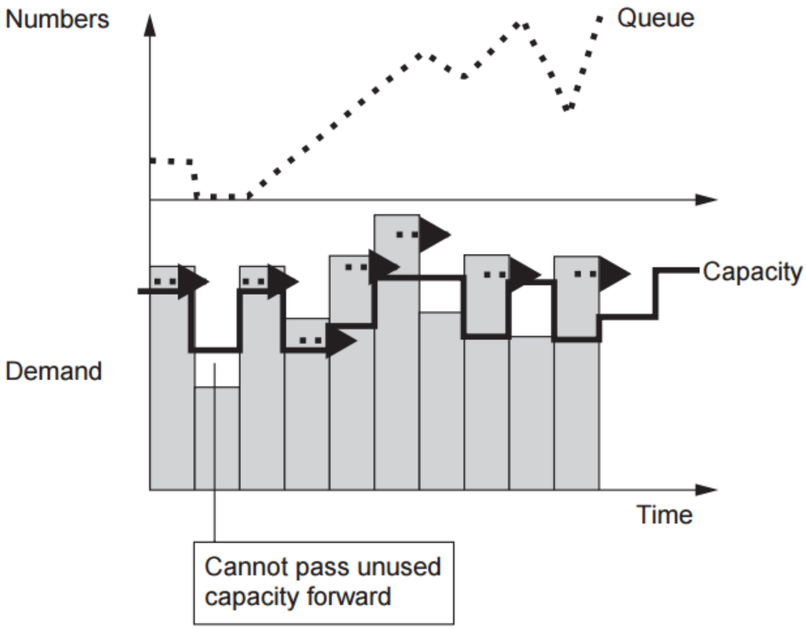


Figure 48: "Average demand equals average capacity in the presence of variation" (Silvester, Lendon, Bevan, Steyn, & Walley, 2004)

7.2 Appointment system

This section presents the results of the interventions on the appointment system presented in Section 6.1. First we analyze the effect on the access time (Section 7.2.1), where after the effect on the waiting time, idle time and overtime is analyzed (Section 7.2.2).

7.2.1 Access time

In this section we present and analyze the interventions with the biggest effect on the access time. The access time to the Nurse Specialist, Genetic Counselor, Endocrine Surgery and combination patients is left outside of consideration. The interventions do not have a significant effect on the access time of these specialists as respectively the capacity is a lot higher than the demand, no interventions on capacity are tested and the scheduling policy ensures a low access time.

Figure 49 shows the effect of interventions on the access time of the internists. The configurations with the highest effect on the access time of the Internists are presented (Table 24).

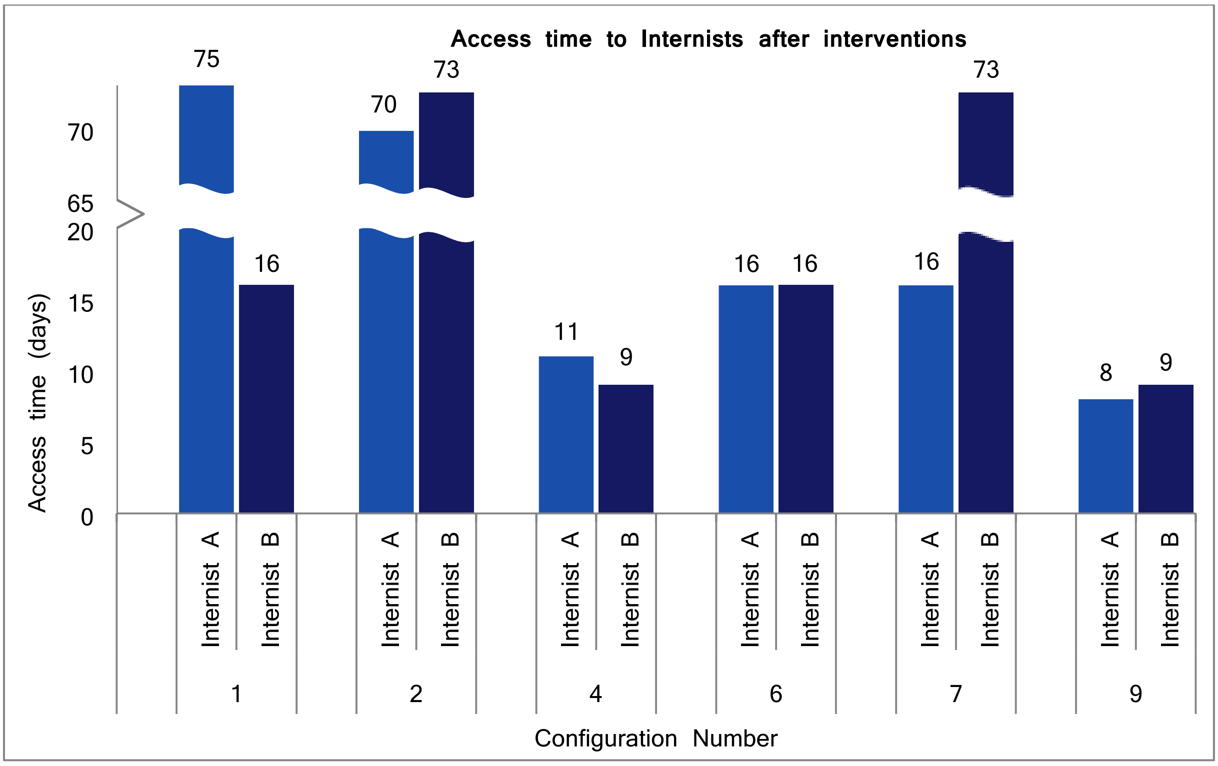


Figure 49: Access time to Internists after interventions (a period of 9 years from the Simulation model)

Table 24: The configurations with the biggest effect on the access time to the Internists

Configuration number	Agenda Internist A	Agenda Internist B	Appointment duration	Sequencing rule
1	Current	Current	Current	IBVI
2	Current	Adapted (6.1.1)	Adapted (6.1.1)	IBVI
4	Current	Adapted (6.1.1)	Adapted (6.1.1)	Bailey Welch (6.1.5)
6	CBG (6.1.2)	Current	Current	IBVI
7	CBG (6.1.2)	Adapted (6.1.1)	Adapted (6.1.1)	IBVI
9	CBG (6.1.2)	Adapted (6.1.1)	Adapted (6.1.1)	Bailey Welch (6.1.5)

We see that for Internist B, configuration 1 corresponds with configuration 6, 2 with 7 and 4 with 9 as there are no changes for Internist B in those configurations. Hereby, configuration 2 (and 7) has a negative effect on the access time, while configuration 4 (and

9) has a positive effect. For Internist A all configurations have a positive effect, with configuration 9 as best configuration.

The observed results match our expectation. Configuration 2 (and 7) uses adapted appointment durations. So, the appointment duration go from 45 min for new patients, 20 min for check-up patients and 15 minutes for check-up MEN patients to 40 min for new patients and 20 min for check-up patients. This increases the average demand of Internist B from 179 min per week to 204 min per week. The average demand of Internist A remains practically the same. The capacity of both Internists remains the same.

In this case the yearly demand of Internist B exceeds the yearly capacity (see calculation below) and thus we expect the access time to increase.

$$\begin{array}{rcl} Capacity_{yearly} & < & Demand_{yearly} \\ 240 \cdot 42 = 10{,}080 & < & 204 \cdot 52 = 10{,}608 \end{array}$$

When the appointment rule changes to the Bailey Welch rule (configuration 4 and 9), two patients are booked on the first time slot, resulting in extra capacity of 20 minutes (check-up patients on first slot) or 40 minutes (new patients on first slot). So the weekly capacity increases to minimal 225 min per week for Internist A and 280 min per week for Internist B. This results in stable access times for both Internists (see Figure 50 and Figure 51), so the average access time to Internist A is 11 days and 9 days to Internist B.

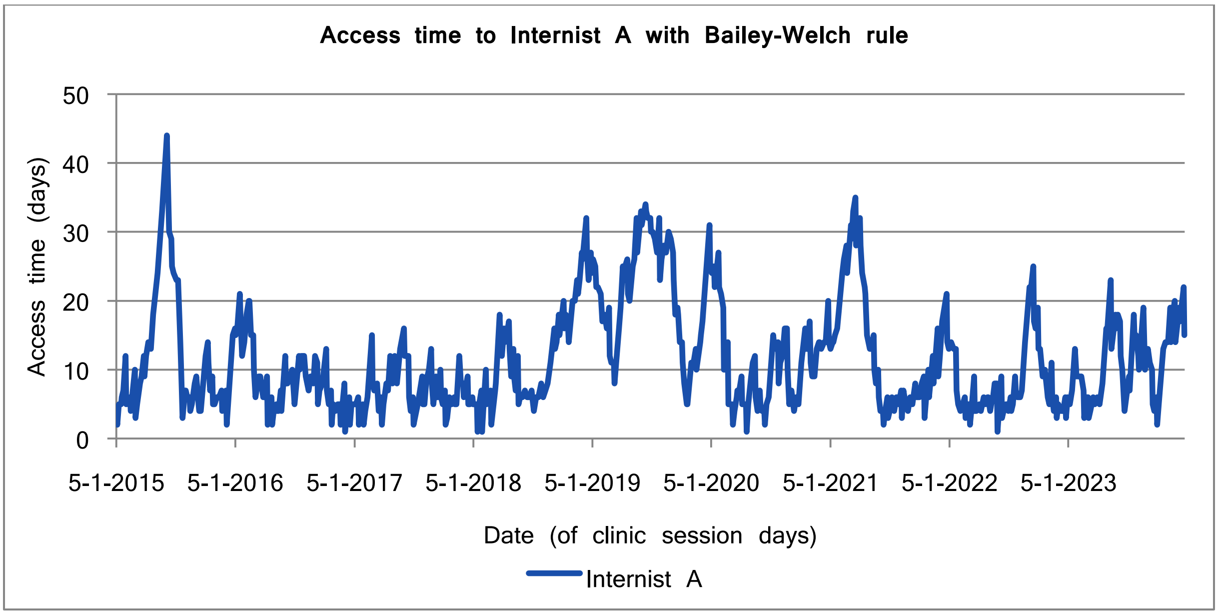


Figure 50: Access time to Internist A with Bailey-Welch rule (a period of 9 years from the Simulation model)

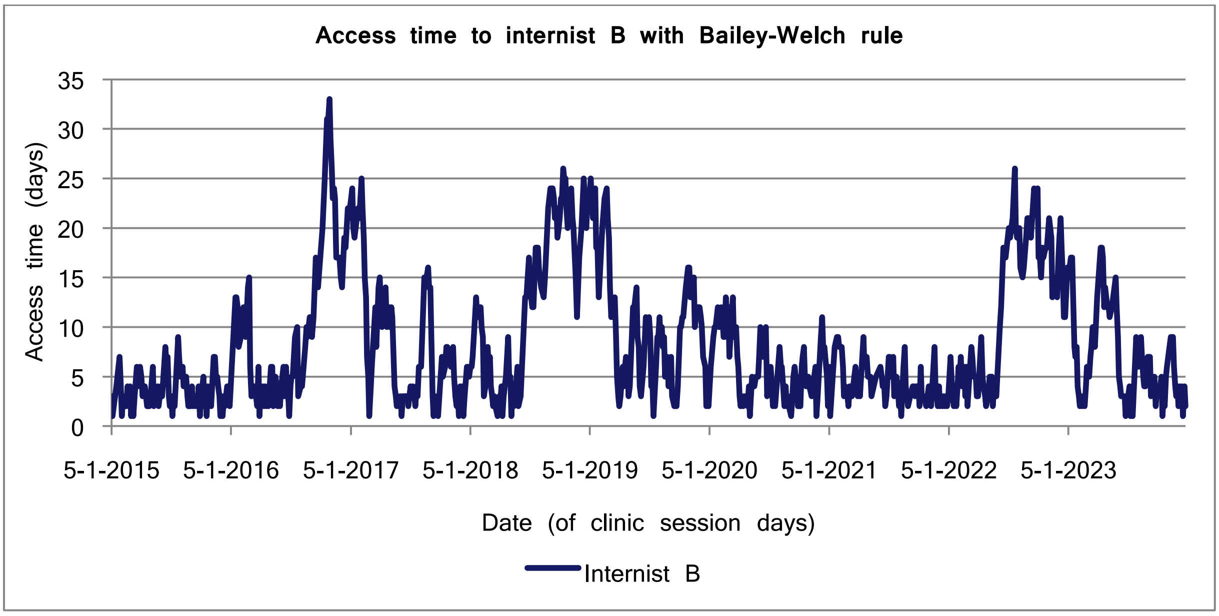


Figure 51: Access time to internist B with Bailey-Welch rule (a period of 9 years from the Simulation model)

For Internist A the above described effects are amplified by the adapting the schedule to the combination patients at beginning rule (CBG). In this case, the capacity for the combination patients is reduced and for the other patient types the capacity is increased. The capacity becomes 210 minutes per week.

7.2.2 Waiting time, Idle time and Overtime

This section presents the effects of the interventions on the performance indicators: waiting time (patient's performance), idle time and overtime (doctor's performance).

Following the example of Cayirli et al. (2006), we use a cost-based measure to value these indicators. We value the negative effect of overtime as twice as important as idle time, because idle time is not always perceived as lost time by the specialist. As long as the idle time does not take on extreme values, it is even desirable. We use the following formula to determine the total costs of an intervention:

$$Total\ costs = E(W_i)C_p + \big(E(I_i) + 2E(O_i)\big)C_q.$$

In this formula C_d/C_p presents the trade-off between doctors and patients (Section 3.6.3). In order to assess the effect of an intervention on several performance indicators, efficient frontiers are used (Cayirli & Veral, 2003; Klassen & Rohleder, 1996). The relative patient's performance is balanced against the relative doctor's performance.

The interventions in Section 6.1 are combined to form mutually exclusive configurations. The effect of these configurations on the performance indicators is presented by specialist. The

Genetic Counselor is excluded from the analysis as no intervention presented in Section 6.1 affects the performance of the Genetic Counselor.

Internists

Starting with the Internists, the effect of the configurations presented in Table 25 on the performance indicators is presented in Figure 52 for Internist A and Figure 53 for Internist B. Configuration 6 to 10 are excluded from the analysis of Internist B as these do not affect the performance of Internist B.

Table 25: Configurations which affect the performance of the Internists

Configuration number	Agenda Internist A	Agenda Internist B	Appointment duration	Appointment rule
1	Current	Current	Current	IBVI
2	Current	Adapted (6.1.1)	Adapted (6.1.1)	IBVI
3	Current	Adapted (6.1.1)	Adapted (6.1.1)	OFFSET (6.1.5)
4	Current	Adapted (6.1.1)	Adapted (6.1.1)	Bailey Welch (6.1.5)
5	Current	Adapted (6.1.1)	Adapted (6.1.1)	MBVI (6.1.5)
6	CBG (6.1.2)	Current	Current	IBVI
7	CBG (6.1.2)	Adapted (6.1.1)	Adapted (6.1.1)	IBVI
8	CBG (6.1.2)	Adapted (6.1.1)	Adapted (6.1.1)	OFFSET (6.1.5)
9	CBG (6.1.2)	Adapted (6.1.1)	Adapted (6.1.1)	Bailey Welch (6.1.5)
10	CBG (6.1.2)	Adapted (6.1.1)	Adapted (6.1.1)	MBVI (6.1.5)

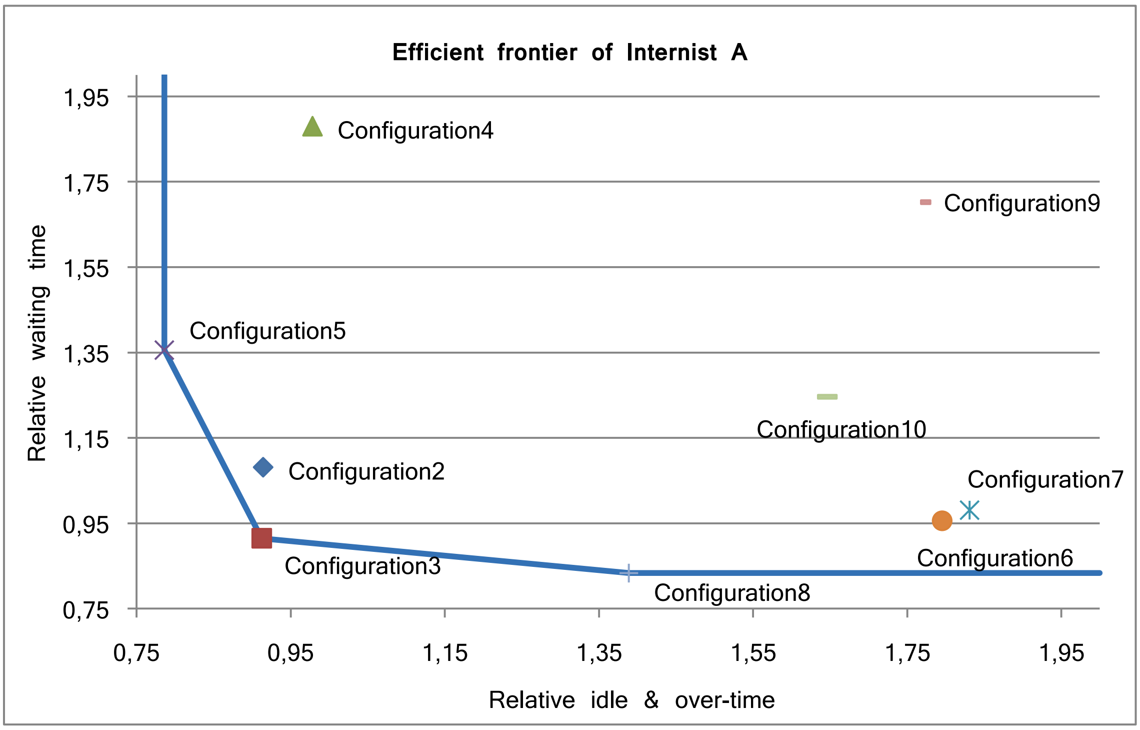


Figure 52: Efficient frontier of Internist A

In Figure 52, we see that only one of the configurations scores both better than the current situation for both the patient's and the doctor's performance: Configuration 3.

The change of the agenda of Internist A to an agenda where combination patients are moved to the beginning (CBG) has a larger effect on the performance than the appointment rules. In particular, the CBG rule results in less overtime for the Internist, but (a lot) more idle time. The increase in idle time by the CBG rule can be explained by the fact that in the Simulation model, Internist A arrives at the start of clinic session (so at 9 AM in the current situation and at 8:30 AM with the CBG rule, in case he is punctual). With the CBG rule, this results in 60 minutes idle time when no combination patients are scheduled. In reality, the specialist may arrive later to the clinic session when no patients are scheduled on the first timeslots.

The current system supplemented with appointment rules has in general the opposite effect: more overtime, but less idle time. See Appendix M for the configurations which have a positive effect on the performance indicators. In Appendix M we see that the effect of the configurations on overtime is not significant, where this do applies for the effect of the configurations on idle time.

The CBG rule supplemented with appointment rule results in lower relative waiting times than the counterparts without the CBG rule.

Of the appointment rules, the OFFSET rule (configuration 3 and 8) has the largest positive effect on the waiting times, followed by the adapted IBVI (configuration 2 and 7). The MBVI (configuration 5 and 10) and Bailey-Welch rule (configuration 4 and 9) both have a negative effect. This is in line with the expectations as respectively at every timeslot one patient has to wait the duration of the patient booked on the same slot and the by overbooking the waiting times do increase.

The effect of the appointment rules on the doctor's performance is not as straightforward as the patient's performance. In the current situation the MBVI rule (configuration 5) has the best performance as this rule leads to lower idle time and overtime. Combined with the CBG rule the OFFSET rule (configuration 8) has the best performance.

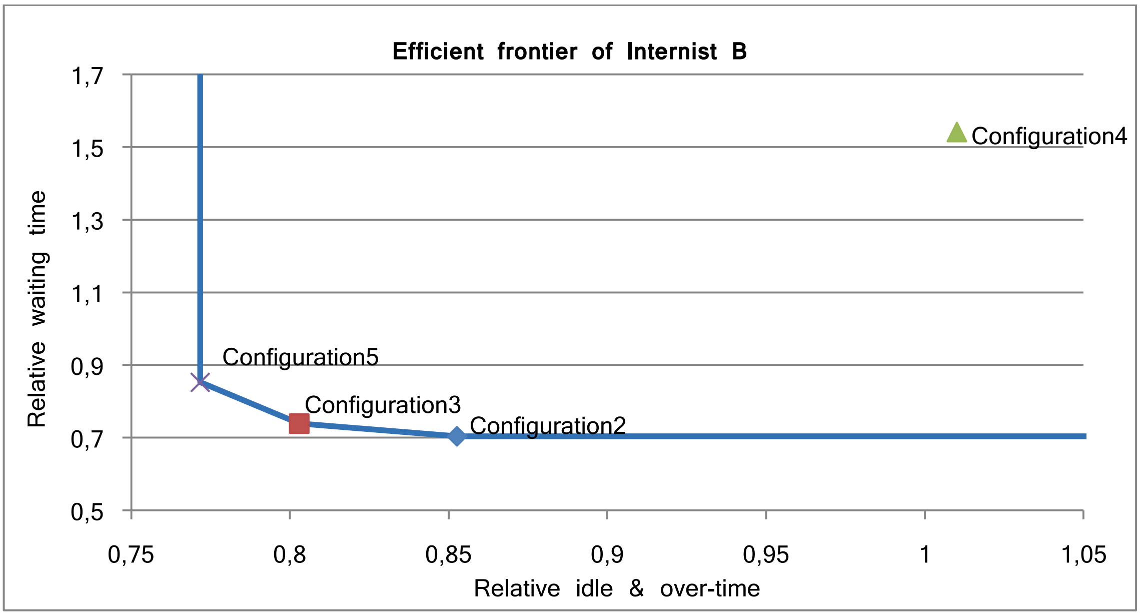


Figure 53: Efficient frontier of Internist B

In Figure 53, we see that three of the four configurations of Internist B score better than the current situation on both axes: Configuration 2, 3 and 5.

The effect of the appointment rules on the waiting time of patients and idle time and overtime of Internist B is largely similar to the effect on Internist A. The biggest difference is the effect of configuration 2. For Internist B this configuration is on the efficient frontier and results in the lowest average waiting time for the patients. Changing the appointment durations has a larger effect on Internist B, because the agenda of Internist B has to be adapted accordingly (Section 6.1.1) and no slots are overbooked anymore (in the current situation when a CMEN1 patient is booked on a regular slot of 15 minutes, this results in 5 minutes overbooking).

Nurse Specialist

In case of the Nurse Specialist not only interventions on the agenda of the Nurse Specialist himself, but as well interventions on the agenda's of the Internists can be of influence on the performance indicators. The appointment rules of the Internist influence the rate of walk-in patients to the Nurse Specialist and thereby the patient's and doctor's performance. So the effect of Configuration 2 to 10 (Table 25) on the performance of the Nurse Specialist is analyzed as well.

Additionally configurations are analyzed, which exist of changes in the agenda of the Nurse Specialist: dedicated appointment slots for scheduled and unscheduled patients of Nurse Specialist (DSNS, see Section 6.1.3) combined with interventions in the agenda's of the Internists (Section 6.1.1 and 6.1.5). Table 26 presents these configurations.

Table 26: Configurations which affect the performance of the Nurse Specialist

Configuration number	Agenda Nurse Specialist	Appointment duration Internists	Appointment rule Internists
1	Current	Current	IBVI
11	DSNS version 1 (6.1.3)	Current	IBVI
12	DSNS version 1 (6.1.3)	Adapted (6.1.1)	IBVI
13	DSNS version 1 (6.1.3)	Adapted (6.1.1)	OFFSET (6.1.5)
14	DSNS version 1 (6.1.3)	Adapted (6.1.1)	Bailey Welch (6.1.5)
15	DSNS version 1 (6.1.3)	Adapted (6.1.1)	MBVI (6.1.5)
16	DSNS version 2 (6.1.3)	Current	IBVI
17	DSNS version 2 (6.1.3)	Adapted (6.1.1)	IBVI
18	DSNS version 2 (6.1.3)	Adapted (6.1.1)	OFFSET (6.1.5)
19	DSNS version 2 (6.1.3)	Adapted (6.1.1)	Bailey Welch (6.1.5)
20	DSNS version 2 (6.1.3)	Adapted (6.1.1)	MBVI (6.1.5)

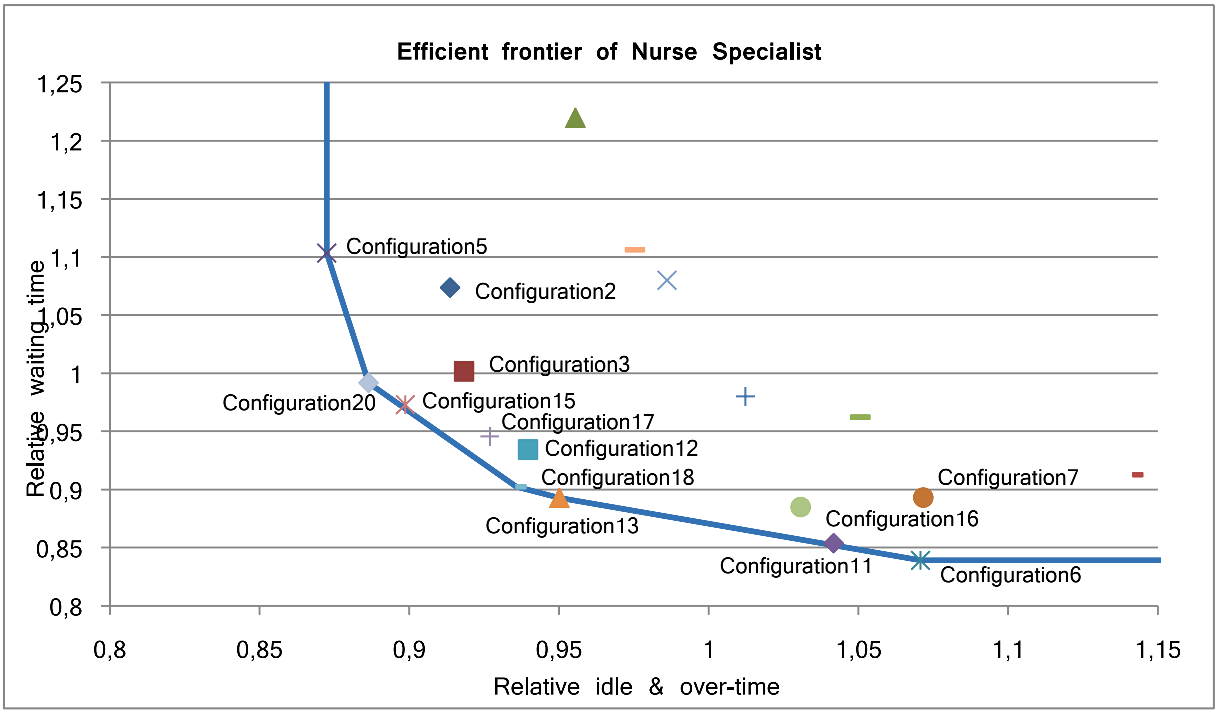


Figure 54: Efficient frontier of Nurse Specialist

In Figure 54, we see that six configurations of the Nurse Specialist score better than the current situation on both axes: Configuration 12, 13, 15, 17, 18 and 20.

Figure 54 shows that Configuration 2, 3, 5, 15 and 20 score best on relative idle and over-time. Remember that for the Internists the MBVI and OFFSET rule result in the lowest overtime, followed by the adapted IBVI rule (Appendix M). In line with these findings we see that the overtime of the Nurse Specialist is lowest in combination with the MBVI rule

(Configuration 5, 15, 20), adapted IBVI rule (Configuration 2, 17) or OFFSET rule (Configuration 3). The same goes for idle time, where for the Internists, the Bailey-Welch rule and MBVI rule score best (resp. Configuration 4 and 5), which also score best for the Nurse Specialist. An explanation for this is that if the Internists have less overtime, fewer patients are referred to the Nurse Specialist at a later timeslot, and therefore the Nurse Specialist has less overtime. The same goes for idle time, if the Internists have large gaps between the arrivals of patients, there will be larger gaps between the patients referred to the Nurse Specialists.

The change of the agenda of Internist A to an agenda where combination patients are moved to the beginning (CBG) has a positive effect on the waiting times of patients referred to the Nurse Specialist and therefore on the average waiting time (Configuration 6 and 7). Also the change of the agenda of the Nurse Specialist to an agenda with dedicated time slots for scheduled patients, combined with the current agenda of the Internists, has a positive effect on the waiting time (Configuration 11, 16). With the CBG rule the first patient than Internist A can refer to the Nurse Specialist is at 9:50 AM (Internist B still at 9:15 AM), this results in low average waiting times of the first referrals. As the location of the dedicated timeslots for scheduled patients of the Nurse Specialist are based on the current situation of the agenda's of the Internists (version 1) and the current walk-in rate at the Nurse Specialist (version 2), it is no surprise that these rules combined with the current agenda's of the Internists result in low average (referral) waiting times.

At last we see that the DSNS version 1 rule has a better patient's performance than the DSNS version 2 rule, but the doctor's performance is worse. This may be, because the arrival pattern of walk-in patients in the Simulation model does not match the reality (Figure 38). This means more walk-in patients than expected do arrive at the timeslot dedicated for scheduled patients and thus the (average) waiting time increases. However, less patients are schedule at the end of the consultation session and thus the Nurse Specialist may leave the clinic earlier in case of version 1 (compared to version 2), resulting in lower idle and over-time.

Remark that few of the observed values differ significantly from the base scenario (Appendix M) and thus we should be considered using these findings.

Endocrine Surgery

For Endocrine Surgery, we analyze the effect of moving combination patients to the beginning (CBG, see Section 6.1.2) combined with four different sequencing rules (6.1.4). Currently the sequencing rule ALTER is used, which makes this the base rule. The configurations for Endocrine Surgery are presented in Table 27. Figure 55 present the efficient frontier of the Endocrine Surgeon.

Table 27: Configurations which affect the performance of Endocrine Surgery

Configuration number	Agenda Endocrine Surgery	Sequencing rule
1	Current	ALTER (6.1.4)
6	CBG (6.1.2)	ALTER (6.1.4)
21	Current	NWBG (6.1.4)
22	Current	RTBG (6.1.4)
23	Current	NWBND (6.1.4)
24	Current	RTBND (6.1.4)
25	CBG (6.1.2)	NWBG (6.1.4)
26	CBG (6.1.2)	RTBG (6.1.4)
27	CBG (6.1.2)	NWBND (6.1.4)
28	CBG (6.1.2)	RTBND (6.1.4)

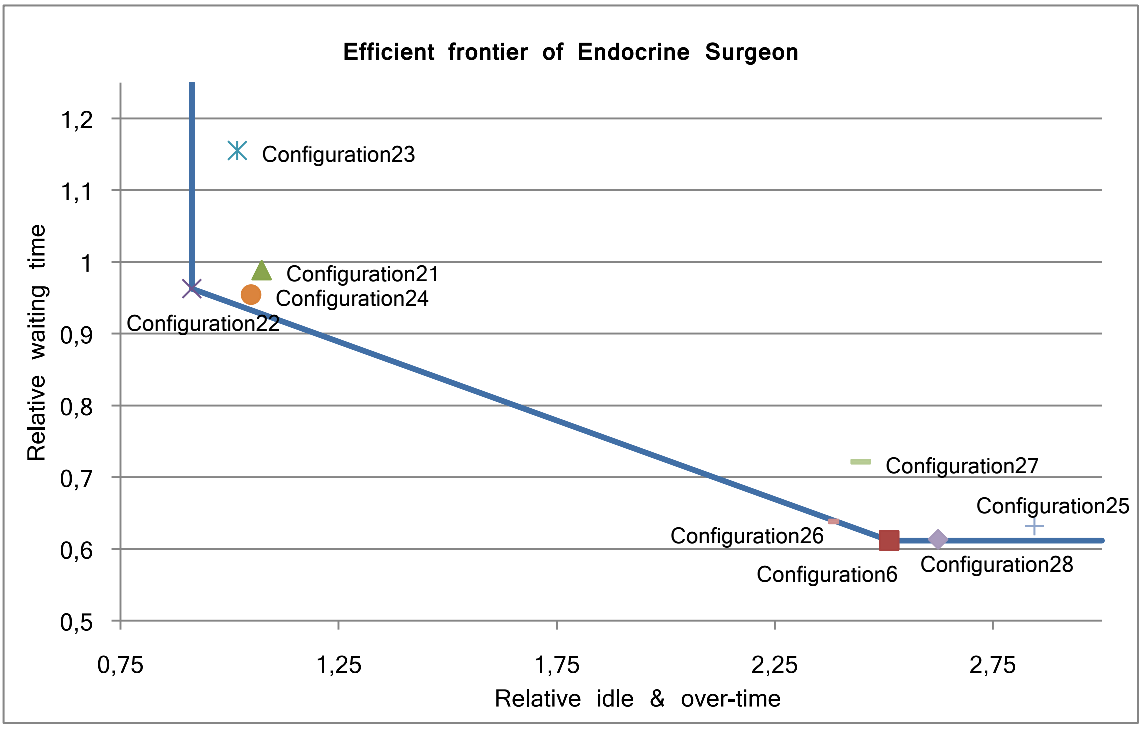


Figure 55: Efficient frontier of Endocrine Surgeon

In Figure 55, we see that only one of the configurations scores both better than the current situation for both the patient's and the doctor's performance: Configuration 22.

Similar to the effect of the CBG rule on Internist A, this rule implies a worse doctor's performance but better patient's performance than the current agenda. In case of the CBG rule not only the idle time is a lot higher than in the base scenario (for explanation, see Internists), but as well the overtime is higher than in the base scenario.

There is no sequencing rule that is performing significantly better than the base rule: ALTER. The NWBND (Configuration 23 and 27) does results in a significant increase in waiting time. The NWBG rule (Configuration 21 and 25) results in a significant increase in the idle time of the specialist. This is in line with the observations of Cayirli et al. (2006).

Conclusions

This paragraph will present the rules with the best performance (per specialist).

To guarantee stable and therefore low access times to the Internists the Bailey-Welch rule is the best performing rule. For Internist A the *combination patients in beginning rule* (CBG) results in low access times as well. The OFFSET rule and adapted IBVI rule result in the lowest waiting times with a reasonable doctor's performance. Although the CBG rule has a bad doctor's performance we do take this rule in consideration, because the high idle time may not representative.

We consider the *dedicated slots for scheduled patients rule* version 1 and 2 as combined with the OFFSET rule at the Internists as the best performing (both patient's and doctor's performance) rule of the Nurse Specialist. Also the DSNS-1 and DSNS-2 rule combined with the adapted IBVI gives a relative good performance, although it is not on the efficient frontier.

For Endocrine Surgery, the RTBG rule performs best (in combination with the CBG-rule or not). The CBG rule combined with the sequencing rule ALTER lies on the efficient frontier as well.

7.3 Parameters

In Section 7.3 the sensitivity of the parameters presented in Section 6.2 on access time (Section 7.3.1) and waiting time and overtime (Section 7.3.2) is tested. The conclusions of Section 7.2.2 present the configurations on which these interventions are tested.

7.3.1 Access time

This section presents the effect of changes in the parameters on the access time of the Internists. The other specialists are left out of consideration (see 7.2.1 for the explanation). Table 28 presents changes to the parameters which may affect the access time to the Internists.

Table 28: Interventions on parameters for the Internists concerning the access time

	Interventions
Production weeks	- 5
Production weeks	+ 5
Arrival rate to Internists (Endocrinology)	*110%
Arrival rate to Internists (Endocrinology)	*90%

The configurations on which these interventions are tested are presented in Table 29, where configuration 1 is called the Base scenario.

Table 29: Chosen configurations of the Internists concerning access time

Configuration number	Agenda Internist A	Agenda Internist B	Appointment duration	Appointment rule
1	Current	Current	Current	IBVI
2	Current	Adapted (6.1.1)	Adapted (6.1.1)	IBVI
4	Current	Adapted (6.1.1)	Adapted (6.1.1)	Bailey Welch (6.1.5)
6	CBG (6.1.2)	Current	Current	IBVI
7	CBG (6.1.2)	Adapted (6.1.1)	Adapted (6.1.1)	IBVI
9	CBG (6.1.2)	Adapted (6.1.1)	Adapted (6.1.1)	Bailey Welch (6.1.5)

Figure 56 and Figure 57 show the sensitivity analysis of the access times to Internist A and Internist B.

The access time to Internist A and Internist B increases significantly when the specialists have 37 production weeks a year instead of 42. For Internist A the access time increase to on average more than 200 days (≈ 7 months) in case of configuration 1 and 2. The same goes for Internist B in case of configuration 2. With 5 production weeks a year extra, the access time to both Internist A and Internist B decreases significantly (with a 95% confidence interval). At most 79% for Internist A and 88% for Internist B, both when configuration 2 is used.

When the arrival rate to Internist A and Internist B increases with 10% the access time to these specialists increases (between 63% and 538%) too. The reverse goes for a decrease of 10%.

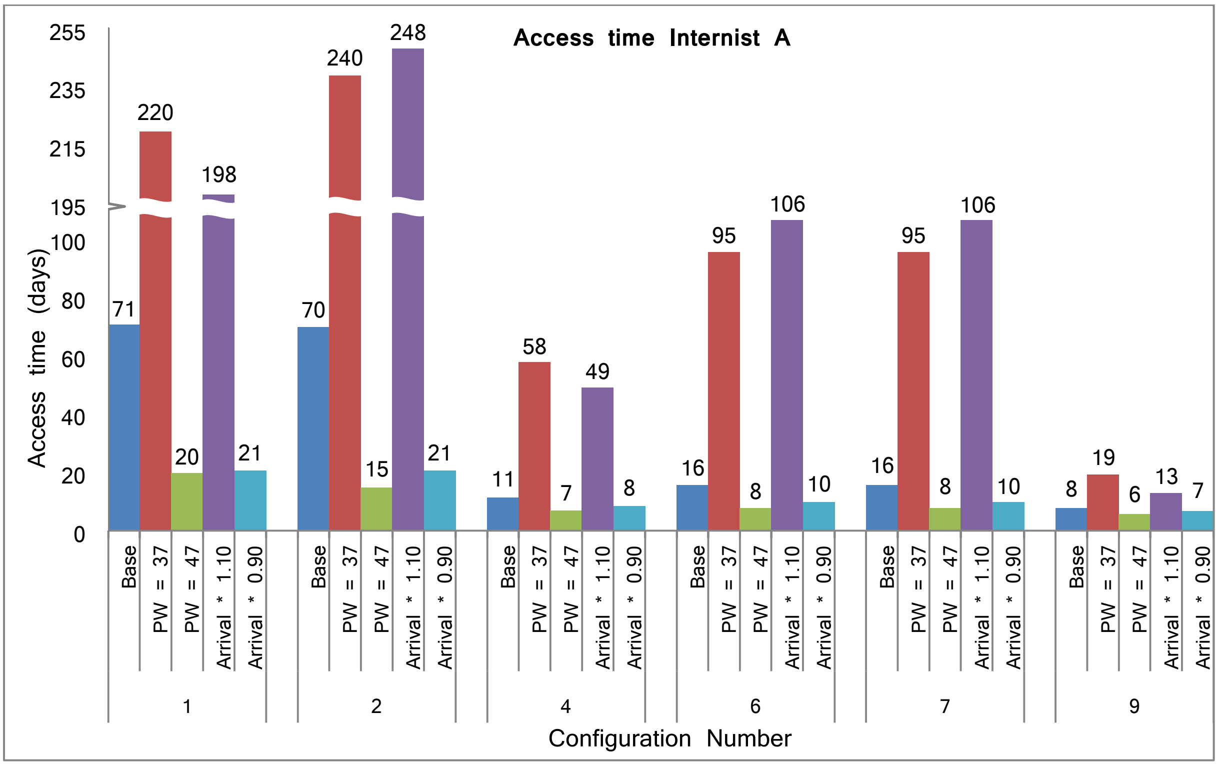


Figure 56: Sensitivity of the access time to Internist A

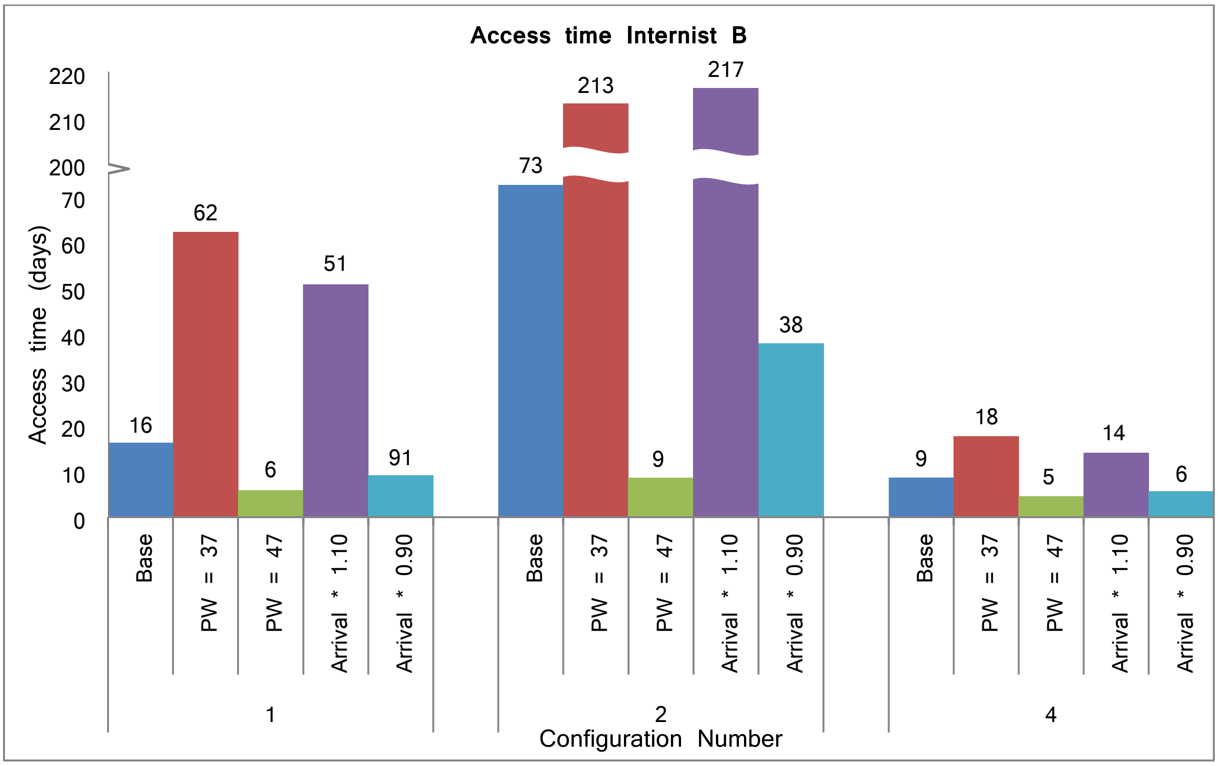


Figure 57: Sensitivity of the access time to Internist B

7.3.2 Waiting time and overtime

In this section, the effect of changes in the parameters of the Simulation model on the waiting time and overtime is tested. Idle time is left outside of consideration, because as mentioned before: 1) idle time is not perceived as lost time and 2) the calculation of the idle time in the model is an upper bound, in reality this number may be lower.

Internists

Table 30 presents changes to the parameters which may affect the performance of the Internists (Section 6.2. gives a complete overview of the interventions).

Table 30: Interventions on parameters for the Internists concerning the waiting time and overtime

	Interventions
Punctuality of doctors	+ 5 minutes
Punctuality of doctors	- 5 minutes
Arrival rate to Internists (Endocrinology)	*110%
Arrival rate to Internists (Endocrinology)	*90%

The configurations on which these interventions are tested are presented in Table 31, where configuration 1 is called the Base scenario.

Table 31: Chosen configurations of the Internists concerning the waiting time and overtime

Configuration number	Agenda Internist A	Agenda Internist B	Appointment duration	Appointment rule
1	Current	Current	Current	IBVI
2	Current	Adapted (6.1.1)	Adapted (6.1.1)	IBVI
3	Current	Adapted (6.1.1)	Adapted (6.1.1)	OFFSET (6.1.5)
6	CBG (6.1.2)	Current	Current	IBVI
7	CBG (6.1.2)	Adapted (6.1.1)	Adapted (6.1.1)	IBVI
8	CBG (6.1.2)	Adapted (6.1.1)	Adapted (6.1.1)	OFFSET (6.1.5)

We see (in Appendix N), that only a few of the interventions have a significant effect (at a 95% confidence interval) on the waiting time and overtime. For Internist A, we notice that arriving on average 5 minutes late increases the waiting time significantly. For configuration 1 to 3 and 6, the waiting times increases with 14% to 20%. Also for Internist B, arriving late results in an increase of the waiting time of maximal 24% (configuration 3). Arriving on average 5 minutes early only has a significant effect for Internist B in case the OFFSET rule is adapted.

A growth of the appointment requests of 10% has a significant effect on the overtime of Internist A with Configuration 6 and of Internist B with Configuration 1: respectively, an increase of 25% and 12%. A decline of the number of appointment requests with 10%

results in significant lower overtime for Internist A in case of Configuration 7 (-33%) and for Internist A in case of Configuration 1 (-20%).

Nurse Specialist

Table 32 presents changes to the parameters which may affect the performance of the Nurse Specialist.

Table 32: Interventions on parameters for the Nurse Specialist

	Interventions
Punctuality of doctors	+ 5 minutes
Punctuality of doctors	- 5 minutes
Arrival rate to Nurse Specialist	*110%
Arrival rate to Nurse Specialist	*90%
Arrival rate of Walk-in patients to Nurse Specialist	*120%

The configurations on which these interventions are tested are presented in Table 33.

Table 33: Chosen configurations of the Nurse Specialist

Configuration number	Agenda Nurse Specialist	Appointment duration Internists	Appointment rule Internists
1	Current	Current	IBVI
11	DSNS version 1 (6.1.3)	Current	IBVI
12	DSNS version 1 (6.1.3)	Adapted (6.1.1)	IBVI
13	DSNS version 1 (6.1.3)	Adapted (6.1.1)	OFFSET (6.1.5)
16	DSNS version 2 (6.1.3)	Current	IBVI
17	DSNS version 2 (6.1.3)	Adapted (6.1.1)	IBVI
18	DSNS version 2 (6.1.3)	Adapted (6.1.1)	OFFSET (6.1.5)

For the Nurse Specialists only one intervention has significant effects (95% confidence interval) on the waiting time and overtime: increasing the arrival rate of walk-in patient to the Nurse Specialist with 20%. The increase of the waiting time can reach up from 21% in the base scenario to 31% for configuration 11 and 16. The increase in overtime is only significant for configuration 12 and 17, which experience an increase of respectively 28% and 29%. As the utilization of the clinic session of the Nurse Specialist is on average lower than 50% it is not unexpected that increasing or decreasing the arrival rate does not have a big influence on the performance indicators. The same goes for the punctuality of the doctor. See Appendix N for a complete overview of the effects of the interventions on the performance of the Nurse Specialist.

Genetic Counselor

For the Genetic Counselor changes in a single factor are tested: the punctuality of the doctor. The agenda of the Genetic Counselor is unprepared to schedule walk-in patients, because currently no patients are referred to the Genetic Counselor. Increasing the arrival rate of walk-in patients to the Genetic Counselor asks for a new agenda arrangement, which should be done in consultation with the management. This new arrangement asks for a more thorough study than just a sensitivity analysis.

Being unpunctual results in an increase of the average waiting time of at least 1.5 minutes and at most 4 minutes. Arriving early has no positive effect on the performance of the Genetic Counselor.

Endocrine Surgery

Table 34 presents changes to the parameters which may affect the performance of the Endocrine Surgeon.

Table 34: Interventions on parameters for Endocrine Surgery

	Interventions
Punctuality of doctors	+ 5 minutes
Punctuality of doctors	- 5 minutes
Arrival rate to Endocrine Surgery (incl. combination patients)	*110%
Arrival rate to Endocrine Surgery (incl. combination patients)	*90%
Presence of the Resident Doctor	50%
Presence of the Resident Doctor	90%

The configurations on which these interventions are tested are presented in Table 35.

We see (in Appendix N) that the punctuality of the Surgeon has no consequences in case of the combination patients in beginning rule (CBG). This makes sense, because the first two slots of the surgeon have a utilization of just 11%. In case of configuration 22, arriving on average 5 minutes late results in an increase of the waiting times of 15%.

Table 35: Chosen configurations of Endocrine Surgery

Configuration number	Agenda Endocrine Surgery	Sequencing rule
1	Current	ALTER (6.1.4)
6	CBG (6.1.2)	ALTER (6.1.4)
22	Current	RTBG (6.1.4)
26	CBG (6.1.2)	RTBG (6.1.4)

When the percentage of the clinic sessions where the Resident Doctor is present decreases to 50%, the waiting time in the clinic increases 14% to 25% and the overtime increases 22% to even 63%. Only in case of configuration 6 (waiting time) and 22 (waiting time and overtime) this increase is significant. When there is no Resident Doctor present, the Surgeon has to consult all the patients himself. However, the Surgeon does not have to provide supervision anymore.

Increasing the presence of the Resident Doctor to 90% of the consultation sessions the waiting time decreases significantly (in case of configuration 1, 22 and 26). This decrease is at most 27%. The presence of the Resident Doctor has less influence on the overtime: only for configuration 26 this makes a significant difference.

At lasts, the performance of outpatient clinic Endocrine Surgery is highly sensitive to the amount of appointment request to the clinic. When this amount grows with 10%, this results in a significant increase in waiting time and overtime for all configurations (except configuration 26). The opposite goes for a crimp of 10%. The increase in waiting time and overtime is maximal 30% and 74%. The decrease is maximal 36% and 49%. This sensitivity is the result of the overbooking of the agenda. In other words a higher arrival rate results in a higher utilization and therefore more waiting time and overtime, compared to Endocrine Oncology where a higher arrival results just in a little increase of the utilization but a strong increase of the access times.

8 Conclusions and recommendations

This chapter presents the conclusions of our research followed by recommendations to outpatient clinic Endocrine Oncology and Endocrine Surgery and recommendations for further research.

8.1 Conclusions

Various trends in healthcare (both nationally and internal) have been the motivation for this research with the objective:

*Develop a prototype **flexible resource capacity planning** instrument that supports the decision-making of the capacity plans of the **multidisciplinary team** in the **outpatient clinics**, where the objective is to **maximize the quality of care**, while **maximizing the utilization of professionals and consulting rooms**.*

From the context analysis we identified three core problems:

1. Procedures are not well established and communicated;
2. Arrangement of agendas is not efficient and consistent with each other;
3. Growth of patient volume.

The first is a managerial problem and the third is parameter that cannot be influenced. So the focus of our research is on the second problem: improving the efficiency of the agenda's of the specialists. Possible improvements to the current system are presented in the experimental design, which exists of appointment systems from the literature and reasonable (self-invented) adaptations to the current system.

Internists

We see that with the current system the access time to *Internist A* increases continuously, in the long term. Adapting the current system to an appointment system with just two types of patients (new patients which take 40 minutes and check-up patients which take 20 minutes) results in higher access times for *Internist B* too. This means that interventions need to be done in order to comply with the "Treeknormen" and to keep the patients satisfied. Experiments show that a way to do this is, is by adapting the Bailey-Welch rule, where the first timeslot is overbooked and thus the capacity increases. In this case the access time will be on average 11 days for Internist A and 9 days for Internist B. For Internist A as well the configuration where combination patients are moved to the beginning and the capacity for combination patient is halved (CBG rule) results in a decrease of the access time.

The access times to the Internists are highly sensitive to the number of consultation sessions the Internists perform (production weeks) and the number of appointment requests to the clinic, because these factors influence the balance between capacity and demand. The sensitivity analysis has shown that in order to stay within the norms of the access times, the Internists should always strive to have at least 42 production weeks per year. With less than 42 weeks (37 weeks), the average access time increases drastically. The Bailey-Welch rule and CBG-rule are best resistant to the increase of the appointment requests.

The current waiting time, idle time and overtime concerning the Internists do not give rise to drastic changes. Still it is important to see whether possible changes, to decrease access time or increase the performance of supporting specialists, influence the performance of the Internists. The Bailey-Welch rule, which is suggested to improve access times, results in a significant increase of the waiting times of the patients in the clinic. Meanwhile, the adapted IBVI rule has the second best performance concerning waiting time (after OFFSET) and idle time and overtime (after MBVI). The CBG rule results in lower waiting times, but causes much idle time when the timeslots reserved for combination patients are not filled.

The configuration with the adapted IBVI (in combination with the CBG rule) shows no sensitivity to unpunctuality of doctors or an increase in the arrival rate of patients, where the configuration representing the current situation or the OFFSET rule does. This makes us prefer the appointment system with adapted durations.

Nurse Specialist

Changes to the appointment system of the *Nurse Specialist* have little impact on the waiting time of patients or the doctor's performance. Appointment rules which have a positive effect on the idle time or overtime of the Internists accordingly have a positive effect on the performance of the Nurse Specialist too. The CBG rule adapted by Internist A or dedicated timeslots for scheduled patients for the Nurse Specialist have a positive effect on the waiting times of the patients. Still just a few of these effects is significant, which makes adaptations to the agenda of the Nurse Specialist not desirable.

Improving the procedures for referring patients to the Nurse Specialist and thus increasing the amount of walk-in patient (with 20%) to the Nurse Specialist has significant effects on the performance of the Nurse Specialist. The punctuality of the Nurse Specialist or arrival rate of scheduled patients has no significant effect.

Genetic Counselor

In 2015 no patients are referred to the *Genetic Counselor.* This may identify that the referral procedures to the Genetic Counselor are not clear. However, the agenda of the

Genetic Counselor is not arranged to easily take on walk-in patients, because two timeslots in the middle of the clinic session are dedicated for scheduled patients. The utilization of those two slots is high for the Genetic Counselor (>90%), so it is important for the Genetic Counselor to be punctual. Arriving late results in an increase of the average waiting time.

Combination hour

The utilization of the combination hour performed by *Internist A* and the *Endocrine Surgeon* was just 5% in 2015. This can be the consequence of badly communicated procedures or because the size of the patient population is misjudged. Also those patients who do have combined consultation often experience high waiting times. This is mostly the result of the overbooked consultation session of Endocrine Surgery. Adapting the CBG-rule results in lower waiting times for the combination patients (and Internist A). However, still the utilization remains low and when the timeslots dedicated timeslots for combination patients are not used this results in loss of valuable time.

Endocrine Surgery

The observed waiting time at Endocrine Surgery is on average 12 minutes and 24 seconds (with a maximum of 1 hour and 25 minutes). During all observed consultations the Resident Doctor was available to assist the Surgeon, so in reality this value may be higher. Experiments have shown that there is no sequencing rule that outperforms the base setting: ALTER. The performance of outpatient clinic Endocrine Surgery is highly sensitive to the amount of appointment requests to the clinic. With an increase of 10%, the waiting time increases maximal 30% and the overtime even 74%. This sensitivity is the result of the overbooking of the agenda; hereby the utilization increases along with the increasing amount of appointment requests. Thus we do not advice to take on another sequencing rule, but to reconsider the overbooking model.

Summarized, for the Internists we recommend to adapt the patient classification to two groups: new (40 minutes) and check-up (20 minutes). This implies that the length of the timeslots of Internist B is changed from 15 minutes to 20 minutes. The consequence of this change is that the average waiting times of the patients decreases for both Internists. Thereby, the idle time and overtime decreases for Internist B. A negative consequence of this rule is that the access time to Internist B increases and the overtime of the Nurse Specialist increases (when referral procedures are upgraded). The first can be reduced when the capacity of Internist B is increased, for example by adding a timeslot to the clinic session or increasing the amount of production weeks. Supplementary we advice Internist A and Endocrine Surgery to take on the CBG rule as this results in lower access time to Internist A and lower waiting time at both outpatient clinics. The drawback is that this rule may result in more overtime for Endocrine Surgery. For the Nurse Specialist no appointment system outperforms the current system and for the Genetic Counselor no adaptations to the appointment system are investigated.

8.2 Recommendations

This section presents recommendations for implementation and further research. The recommendations to outpatient clinic Endocrine Oncology are to: 1) implement the (small) adaptations to the appointment system, 2) to improve the procedures at the department and 3) to further improve the appointment systems of the specialists. Furthermore, we present: 4) general recommendations and 5) recommendations for further research.

1) Adaptations to the appointment system

- The patient types of the Internists should be rearranged. Currently several different patient types are used: new, check-up, check-up MEN-1, check-up MEN-2, check-up VHL, with all different appointment durations. We advice to change this system to two types: new and check-up, with a duration of respectively 40 and 20 minutes. The agenda of Internist B should subsequently be changed to timeslots with a length of 20 minutes.
- The agenda of Internist A and Endocrine Surgery should be changed according to the CBG rule: 2 appointment slots for combination patients in the beginning of the consultation session. This means that Internist A may have to start his consultation hour 30 minutes earlier than at the moment.

2) Improvements of the procedures

- The patients who need a consultation of supporting specialists, i.e. of the Nurse Specialist or Genetic Counselor, need to be identified. When these patients are identified, they can be grouped by their characteristics. These characteristics should be clear for all specialists involved and well communicated. Presumably this shall result in an increase of the (referred) walk-in patients of the Nurse Specialist and Genetic Counselor.
- The same goes for combination patient which require a consultation by both Internist A and the Endocrine Surgeon at the same time. Patients who require such an appointment are rare, but at the same time the patients who do require such an appointment, need instantly specialized care as their tumors are not common, vary between patients and may be aggressive. This means that it is desirable to save dedicated slots for combination patients, but the procedures need to be refreshed to identify combination patients more often and increase the utilization of these slots.
- The scheduling of combination patients should be simplified by giving the receptionists of both departments access to schedule patients in each other’s agenda and providing the patients a confirmation of the combination appointment with only

one location on it. These improvements should be provided by data managers. Thereafter the scheduling procedures should be improved and communicated to the receptionist to avoid incorrect bookings.

In response to the implemented procedures, the appointment systems of the specialists can further be improved.

3) Further improvements the appointment systems of the specialists

- The patients can be scheduled in the agenda's of the Internists according to the categorization for the referral patients to the supporting specialists. For example the new procedure is to always refer MEN-1 patients to the Nurse Specialist. Not taking this into account when scheduling the appointments of the Internist can result in a high amount of MEN-1 patients at the end of the clinic session. Consequently the Internists refer simultaneously patients to the Nurse Specialist resulting in high waiting times for the patients an overtime for the Nurse Specialist. By introducing sequencing rules in the agendas of the Internists, the walk-in arrival rate to the supporting specialists can be regulated.

4) General recommendations

- We advice outpatient clinic Endocrinology to provide at least 42 weeks with consultation sessions. Currently it can occur that the specialists have less production weeks, resulting in high access times. We recommend specialists to plan their holidays and days off a year ahead (or at least half a year). This should result in less rescheduled appointments.
- We recommend Outpatient clinic Endocrine Surgery to reconsider the overbooking of the appointment system. This system is highly depended on the presence of the Resident Doctor and demand of the patients. When the scheduling of the clinic session has a limit, the utilization of the clinic session and therefore the waiting time and overtime have an upper bound as well.

5) Recommendations for further research

- To make the study useful for a broad ranch of outpatient clinics, we recommend applying the research to a larger outpatient clinic. In an outpatient clinic where few specialists and patients are involved it is hard to identify characteristics for example the referral of patients to supporting specialists. The major advantage of a small clinic is the close communication resulting in fast problem solving. This also has disadvantage as the specialists quickly fall into "fire fighting": solving problems at the operational level. This makes it hard to emphasize the necessity of improvements on a tactical or strategic level.

- We recommend conducting further research in an outpatient clinic which provides primary care. In an outpatient clinic which provide care to rare diseases it is hard to categorize the patients. As the tumors of Endocrine patients vary a lot, almost all patients are seen as an exception. This makes it hard to draw conclusions about patient streams through the outpatient clinic and therefore to decide on the input parameters of the model.
- More data should be collected to derive the performance of the current system. Because the outpatient clinic of our research existed in the same formation for just a year, it was not possible to take on season variations and to collect a significant data sample.
- In this study we made the assumptions that the arrival pattern is the same throughout the year and holidays and canceled clinic sessions are not taken into account. In reality, seasonal trends may occur in the arrival rate, where the use of temporary extra capacity may be preferred.
- In this study the preferences of patients are scheduled at the earliest possibility. In reality patients may prefer a certain appointment time, or the specialist may request the patient to return on a certain moment. For a further study we advice to consider these preferences.

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Appendix A

Endocrine Tumors begin in the parts of the body that produce and release hormones. This tumor may produces hormones as is originated from hormone producing cells. NETs are not only located in the endocrine glands that produce hormones, but can occur in all body tissues. These tumors are made up of both endocrine cells and nerve cells and produce in some cases hormone-like substances (functioning NET), which can deregulate the hormonal system (Maag Lever Darm Stichting, 2015).

Endocrine tumors can be divided into slow-growing tumors (stage 1 and 2) and fast-growing tumors (stage 3), which are respectively named NET (Neuro-Endocrine Tumors) and NEC (Neuro-Endocrine Carcinoma). Because in a NEC the cells divide more rapidly, the risk of metastasis increases and therefore the prognosis is worse than in case of a NET (UMC Utrecht Cancer Center, 2015). Many Endocrine tumors are slow-growing, the so-called benignant tumors, while some are fast-growing, the malignant tumors.

NET can occur in all body tissues, but in most cases the tumor is located in: the small intestine, lungs, pancreas, stomach and thyroid. As a consequence of a functioning NET, the hormone production can be disrupted. For example: a tumor in the pancreas can lead to an excessive secretion of the hormone Insulin, Glucagon or Gastrin, which leads either to a too low blood sugar, a too high blood sugar or an abundant production of stomach acid (Zollinger Ellison). A functioning tumor is named after the hormone-like substance it is producing. For example: an Insulinoma, Gastrinoma and Glucagonoma. Non-functioning tumors can as well cause symptoms as a result of the size of the tumor like pain and weight loss (Maag Lever Darm Stichting, 2015).

Endocrine tumors are rare. This complex type of cancer is yearly diagnosed at approximately 700 patients. In some of these cases genetic disorders are the cause of these tumors. For example, in case of Multiple Endocrine Neoplasia type 1 (MEN-1 syndrome). In most cases of MEN-1, the NET occurs in the parathyroid (78-90% of the patients), pancreas (46%) or pituitary (38%) (Stichting Opsporing Erfelijke Tumoren, 2010). Another genetic cause can be Multiple Endocrine Neoplasia type 2, called MEN-2, which can be subdivided into three types: MEN-2a, MEN-2b and FMC (Familial Medullar Thyroid Carcinoma). These types are characterized by tumors in the thyroid (all types >90%), adrenals (>50% for type a and b) and parathyroid's (20-30% for type a). It is estimated that there are in the Netherlands about 350-400 MEN-1 and about 400 MEN-2 patients. Because genetic disorders are not curable, a patient diagnosed with MEN-1 or MEN-2 will be the rest of his life under treatment of the Internist Endocrinologist.

Appendix B

Patient classification

To assign the patient to a service time, patient codes are introduced. These codes mostly depend on the type of appointment instead of the type of disease. See Table B-1, Table B-2 and Table B-3 for the patient types corresponding to the specialists.

Table B-1: Patient types in agenda of Endocrine surgery

Endocrine surgery

Code	Characteristics	Service time (min)
N	New patient	20
CNO	Checkup after surgery	15
C	Checkup consult	15
TC	Telephone consult	5
ECO	E-consult	5
NCHIEND	New consult by surgeon and endocrinologist	15
CCHIEND	Checkup consult by surgeon and endocrinologist	15

* Remaining like second opinion (SO; 20 min), checkup after SEH (SEH; 15min), consultation elsewhere (CEL; 15 min)

The Internist Endocrinologist does make use of patient codes indicating specific diseases: CM1, CM2, CVHL (Table B-2Table). The corresponding service times for these diseases are based on experience. The use of these patient codes requires dedication of the secretary.

Table B-2 Patient types in agenda of Internist of Endocrine Oncology

Endocrinology outpatient clinic (MEN) - Internist Endocrinologist

Code	Characteristics	Service time (min)
N	New patient	45
CM1	Checkup consult MEN-1 patient	20
CM2	Checkup consult MEN-2 patient	20
CVHL	Checkup consult Von Hippel-Lindau patient	20 - 30
C	Checkup consult	15
TC	Telephone consult	5
NENDCHI	New consult by surgeon and endocrinologist	15
CENDCHI	Checkup consult by surgeon and endocrinologist	15

* Remaining like second opinion (SO; 45min), new old consult (NO; 30min) and inspection (KE 45min).

The Nurse specialist uses only two patient types (Table B-3). It is less important to make distinction between patients, because the patients of the Nurse specialist are mostly planned during the clinic session; dynamically.

Table B-3 Patient types in agenda of Nurse Specialist of Endocrine Oncology

Endocrinology outpatient clinic (MEN) - Nurse specialist		
Code	**Characteristics**	**Service time (min)**
CVPS	Checkup consult Nurse specialist	30
TCVPS	Telephone consult Nurse specialist	10

The Genetic Counselor has only one type of patients named: MGT ONC. The planned duration of appointments for these patients is 30 minutes.

Appendix C

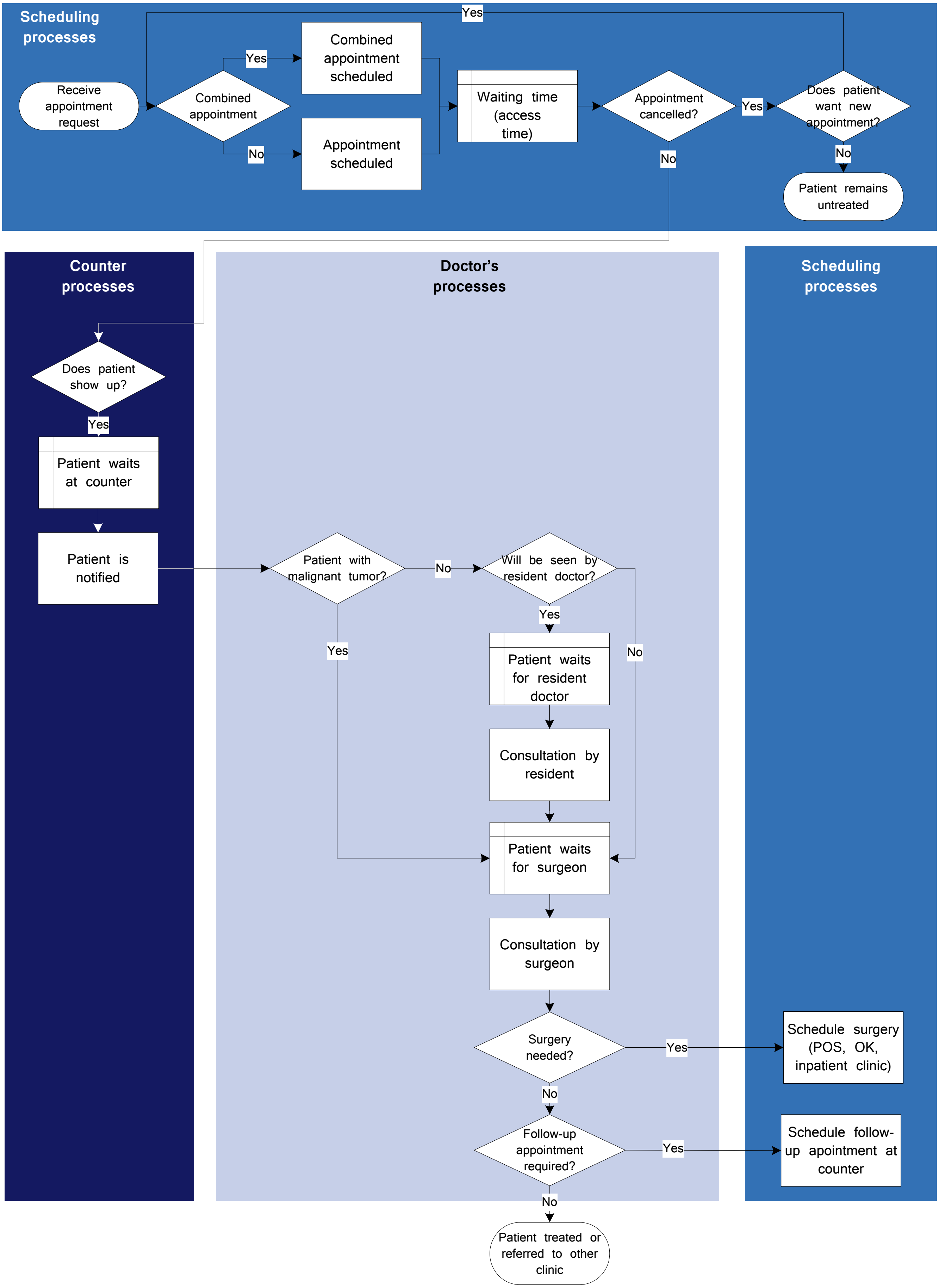


Figure C-1: Flowchart of processes at Endocrine Surgery

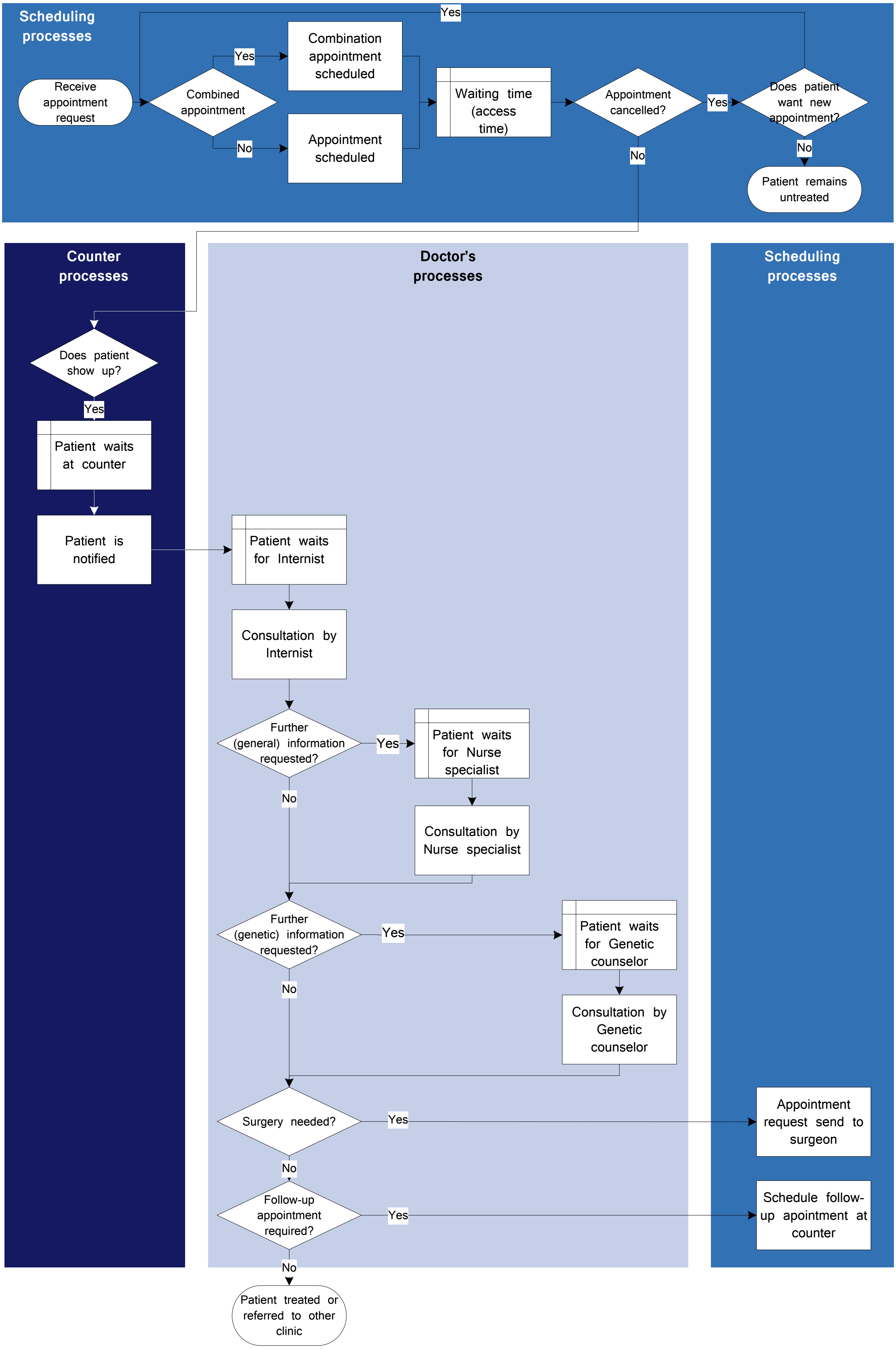


Figure C-2: Flowchart of processes at Endocrine Oncology

Appendix D

Counter processes

All patients with an appointment in the outpatient clinic have to report their arrival at the counter. The counter personnel verifies the address and insurance information of the patient and labels the patient as “present”. In case a new patient arrives at the counter more information of the patient is required and a new medical status record is created. This may take some minutes. As mentioned above, at the Endocrine Oncology, the return rate is high, which means that more return patients than new patients arrive at the counter.

After the consultation the patient may come back at the receptionist to schedule diagnostic appointments, an appointment with another specialist a follow-up appointment or a telephone appointment.

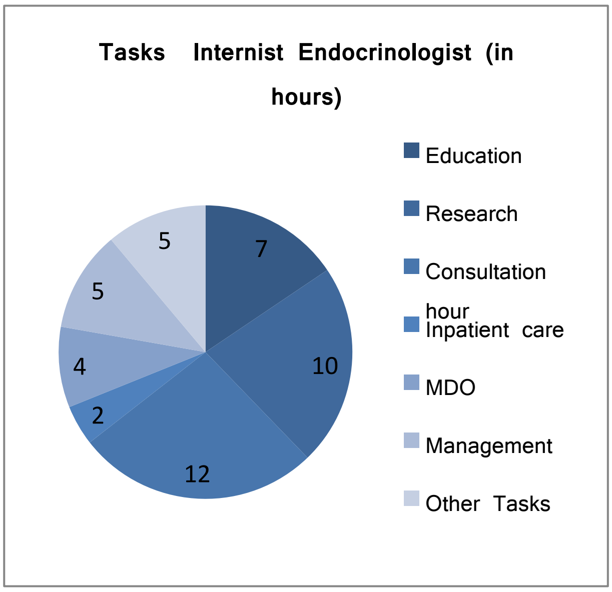
At Endocrine Surgery, the counter personnel and doctors are supported by a nurse. This nurse partially has the function of a Nurse Specialist, i.e. supporting patients and performing minor medical treatments (removing stitches) and partially the function of a receptionist, i.e. scheduling appointments at other divisions and keeping an eye on the care process of the patients.

Doctor’s processes

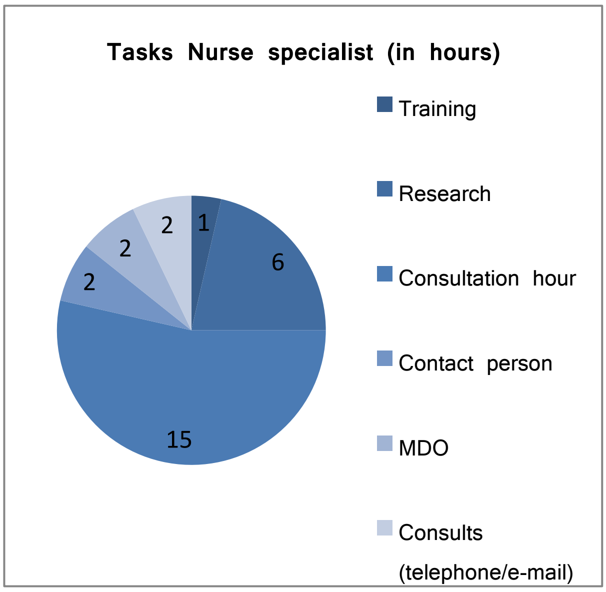
The Doctor’s processes will be separately discussed for Endocrine Oncology and Endocrine Surgery.

Endocrine Oncology

The Internist Endocrinologist is the primary practitioner of the patient. This means that the ultimate responsibility of the care process is in hands of the Internist. In case (new) tumors are suspected, the Internist is the communicator with the general practitioner and other involved disciplines. During the consultation hour the Internist decides, in cooperation with the other specialists, whether patients require extra information of the Nurse Specialist or Genetic Counselor (Figure 11). The patient has the final decide in the necessity of these additional appointments.



Next to being a doctor, i.e. giving consultations, the Internist Endocrinologist also is a professor. This means that he provides education for university students and leads research projects.



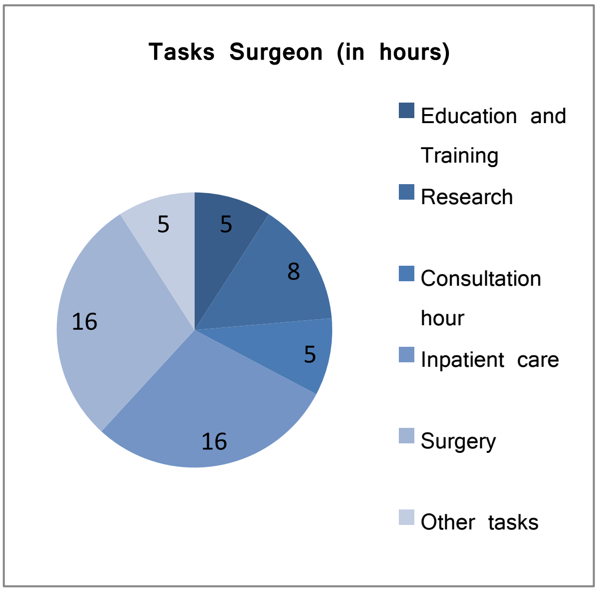
The Nurse Specialist is the first point of call; the case manager of the patients. He refers the patient to the right care giver. If a patient is referred to the Nurse Specialist (by the internist), he gives psychological assistance to a (newly diagnosed) patient. Thereby information about treatment and coping with the disease is given. Additionally to the tasks during the consultation hour, the Nurse Specialist has an important task in guiding and coordinating the care processes, e.g. the Nurse Specialist had a great role in the documentation and implementation of the care pathways.

If the patient has (a suspicion on) a genetic disorder, the patient is referred to the Genetic Counselor. The Genetic Counselor will inform the patient and family about the (physical as well as mental) consequences of carrying a genetic disorder. In case of a type 3 patient, an advice on whether to conduct a DNA investigation or not, is given.

In case a surgery indication is given, the patient is referred to Endocrine Surgery.

Endocrine Surgery

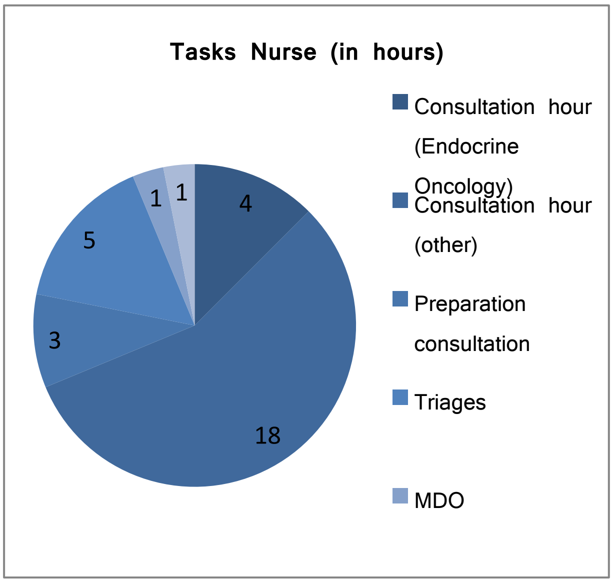
The primary task of the surgeon is performing surgery. In our case, the surgeon is specialized in Endocrine surgery: surgery to the adrenals, pancreas, thyroid and parathyroid. In addition to surgery, the surgeon gives consultations and does visitations. Next to patient care, the surgeon is a professor of Endocrine Oncologic Surgery, so the surgeon has to give lectures about Endocrine Oncologic Surgery. During the consultations, the surgeon informs new patients about the surgery possibilities and comes with a treatments plan. After surgery the surgeon visits the patient to talk about the

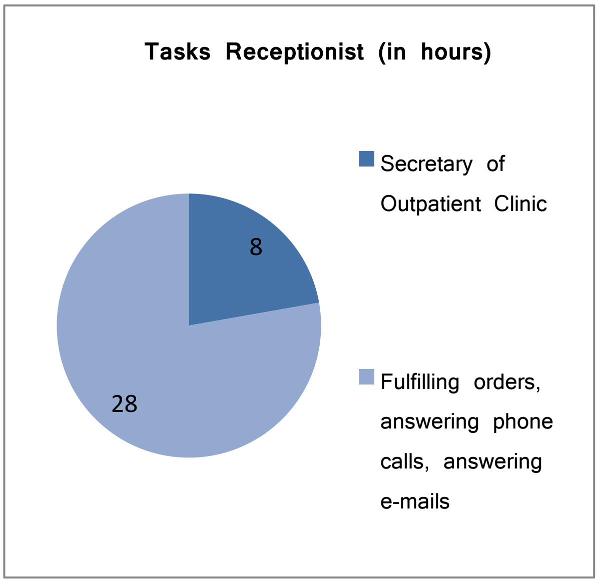


course of the operation and answers questions. As well part of the follow-up of a patient who got surgery is in the hands of the surgeon. As mentioned in Section 2.1.2 Care pathway of Endocrinology patients, patients with rare tumors (i.e. malignant tumors, so patients of type 2) are assigned to the surgeon and patients with benignant tumors may receive a consultation by either the surgeon or the resident doctor. The Surgeon prefers check-up (after surgery) patients, as he can give deeper insight about the course of the surgery.

The Resident Doctor at Endocrine Surgery has a medical degree (M.D.), but is not specialized (yet). In most cases the Resident Doctor stays for a limited period of time at the outpatient clinic, after which a successor for the Resident Doctor needs to be selected and inducted. As the Resident Doctor is not specialized yet, the rare and complex tumors are assessed by the Surgeon and not by the Resident Doctor. As well, (benignant) patients who receive a consultation by the Resident Doctor receive in most cases afterwards a short consultation by the Surgeon (supervision).

Next to the contact with patients, the Internist Endocrinologist, Nurse Specialist and Surgeon at UMC Utrecht Cancer Center have a leading role in research about the MEN-1 syndrome. As well the specialists do laboratory research on the development of (in particular Neuro-Endocrine) tumors.





Appendix E

Table E-1: Number of appointment slots per clinic session

Specialist	Day	Patientcode	Number of slots
Surgeon	Monday	C, CNO, (CEL, SEH).	4
		N, (SO).	4
		NCHIEND, CCHIEND	4
		TC	2
Internist Endocrinologists	Monday	All	6 + 5
		NENDCHI, CENDCHI	4
		TC	4
	Wednesday	All	6
		TC	4
	Thursday	All	6
		TC	4
Nurse specialist	Monday	CVPS	7
	Wednesday	CVPS	7
		TCVPS	3
Genetic Counselor	Monday	MGT ONC	2

Appendix F

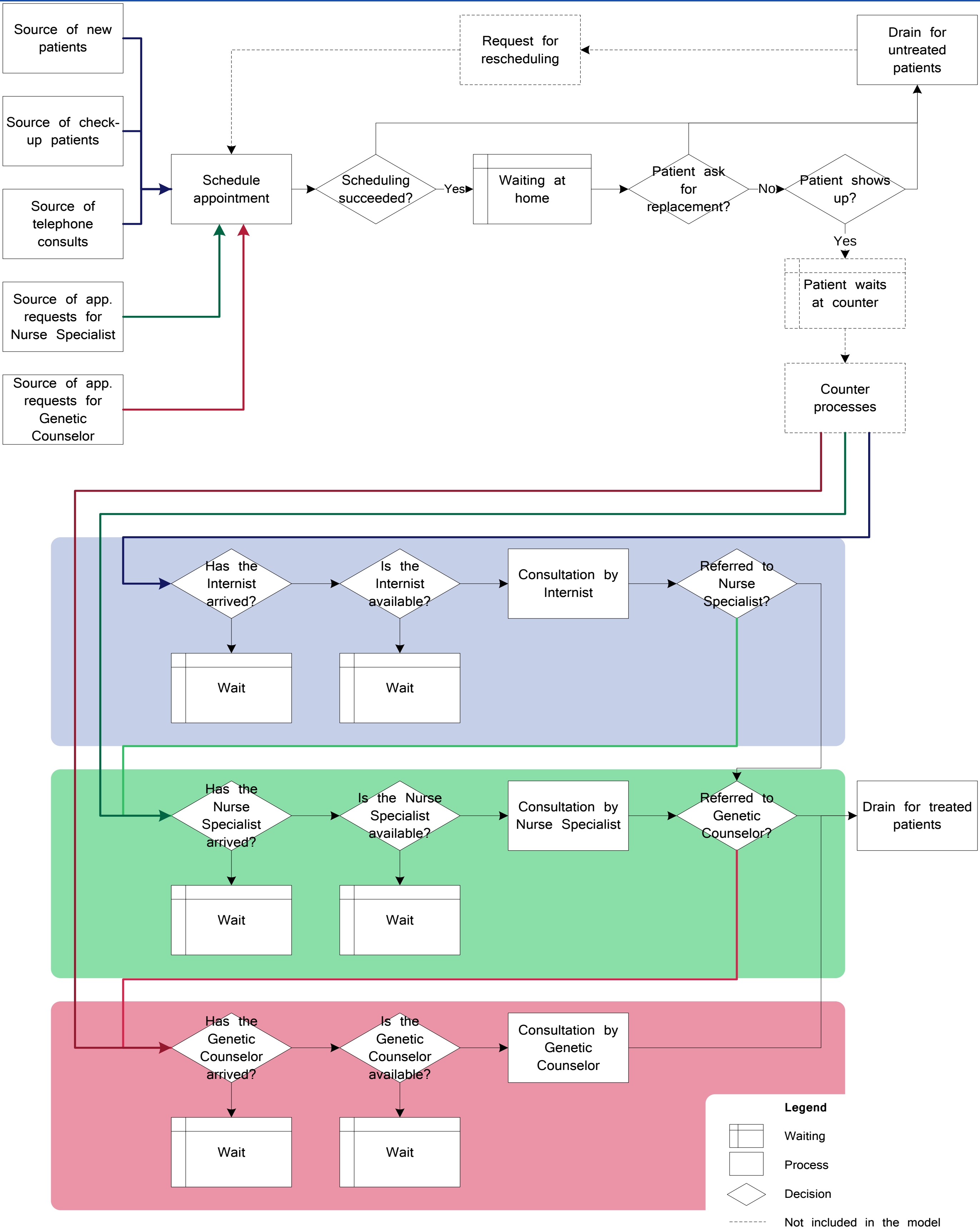


Figure F-1 Process flow of patients at Endocrinology

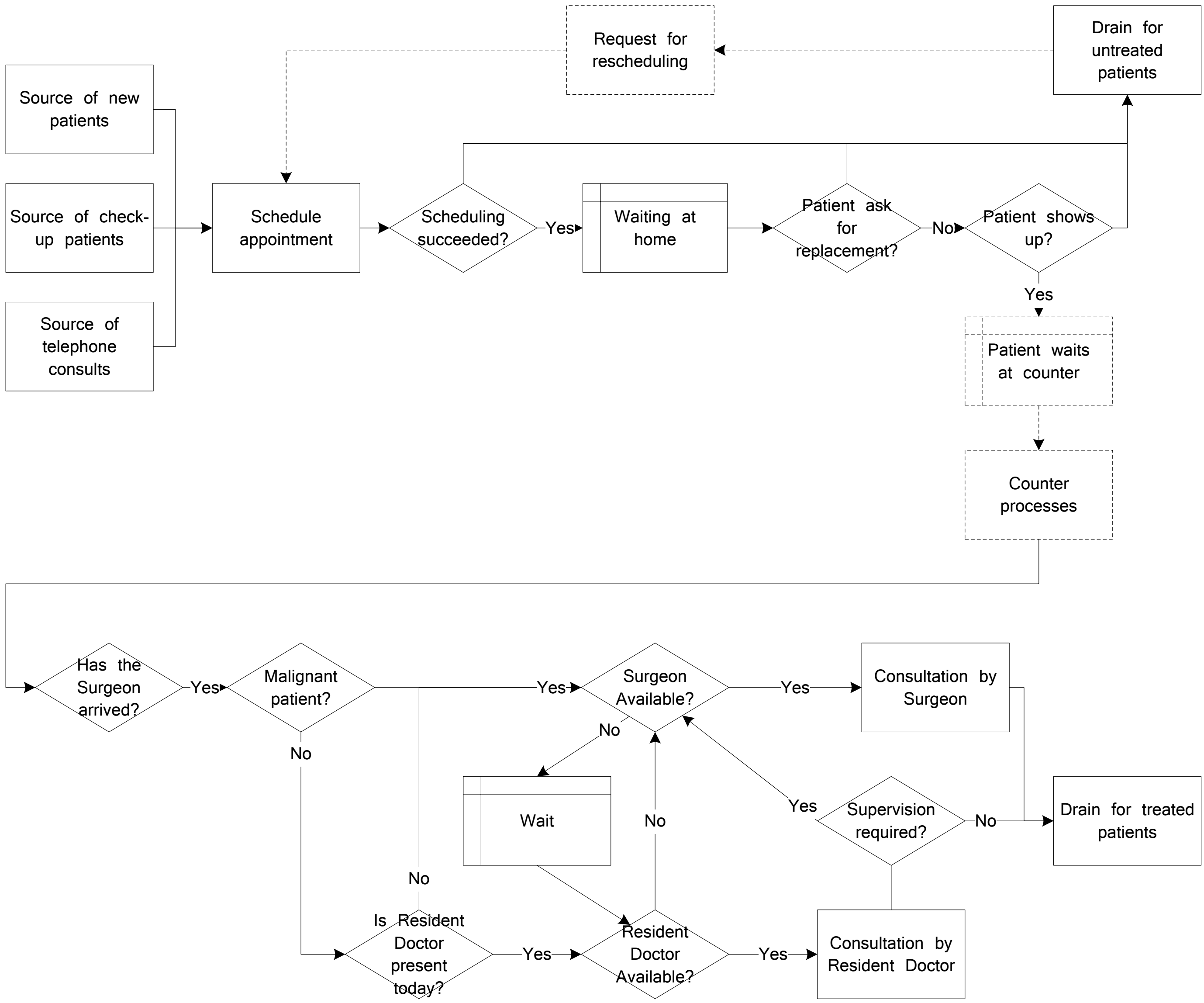


Figure F-2: Process flow of patients at Endocrine Surgery

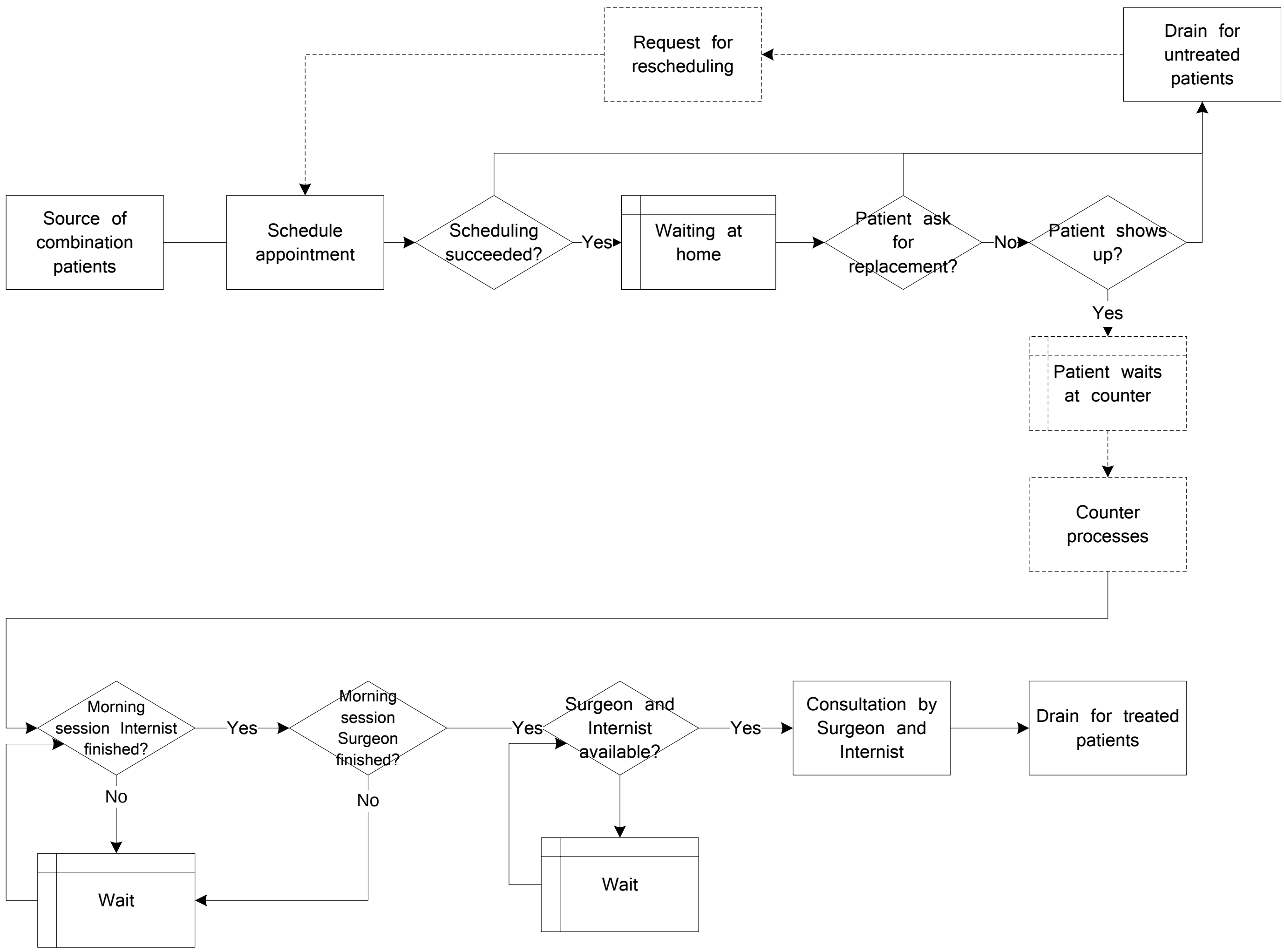


Figure F-3: Process flow of combination patients

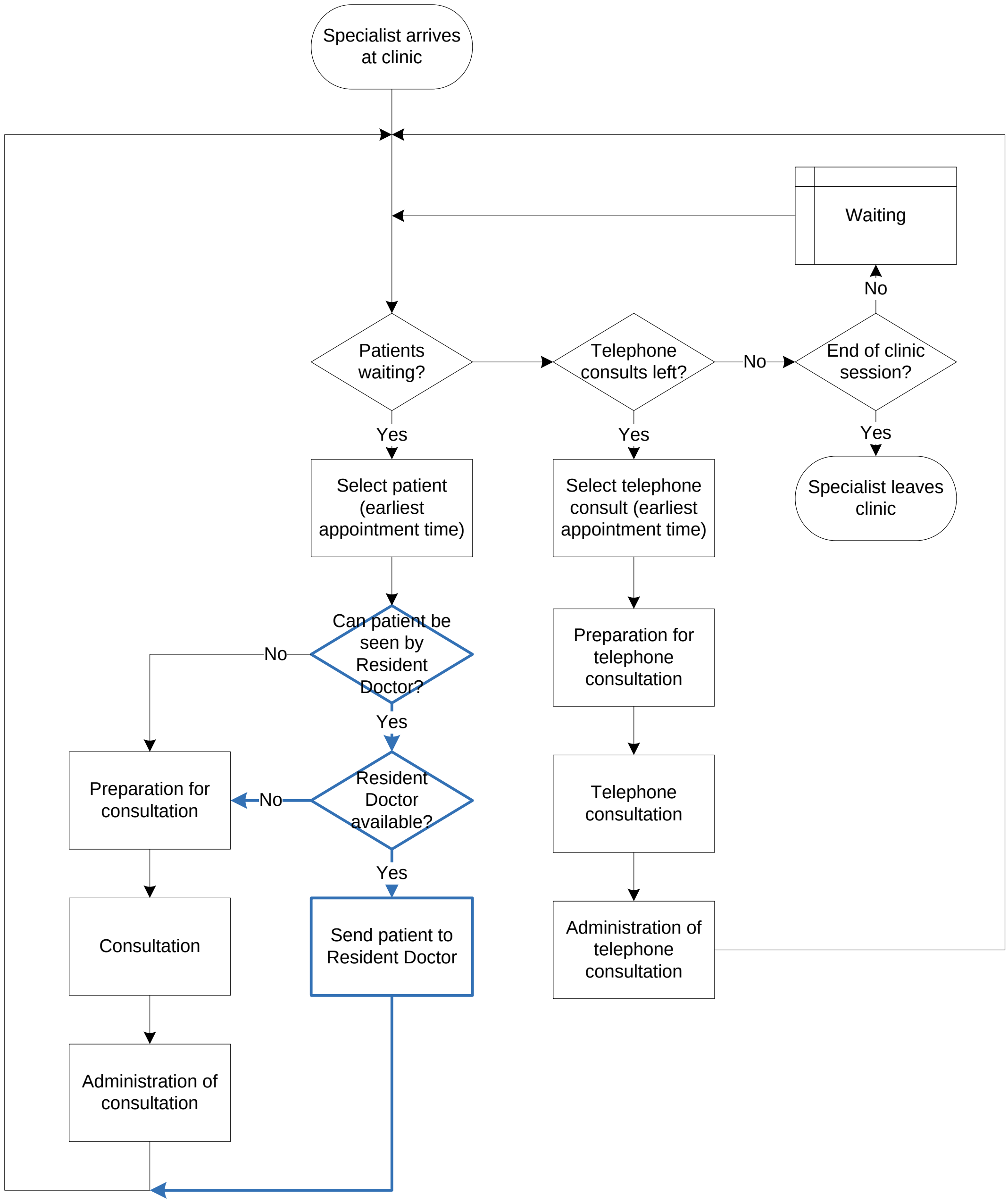


Figure F-4: Process flow of specialists at Endocrinology and Endocrine Surgery

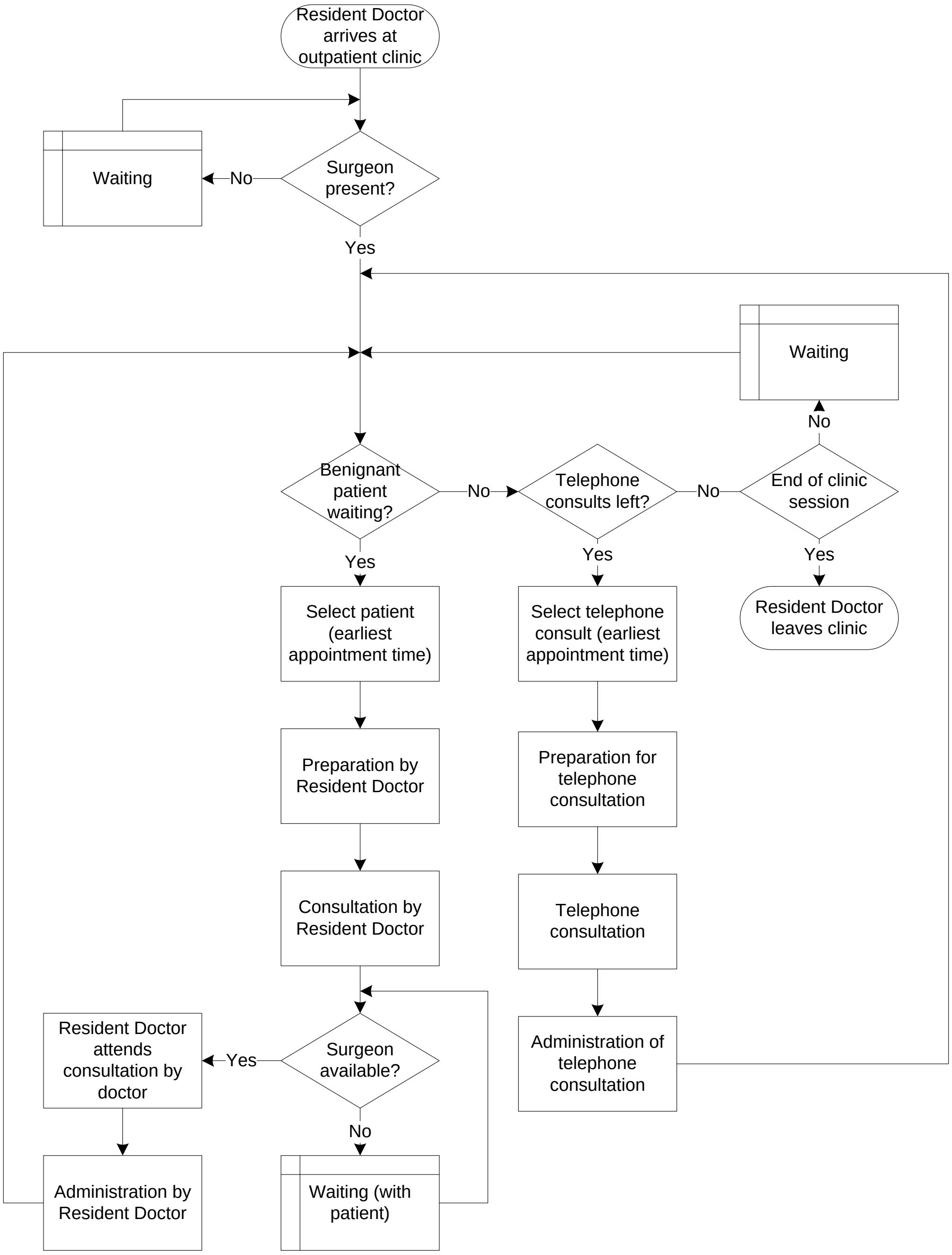


Figure F-5: Process flow of Resident Doctor at Endocrine Surgery

Appendix G

Table G-1: Distribution of patient types over the specialists

	New patients				Check-up patients			
	Internist A		Internist B		Internist A		Internist B	
Diagnosis	#	%	#	%	#	%	#	%
MEN-1 syndrome	6	29%	8	9%	98	44%	24	15%
MEN-2 syndrome	2	10%	0	0%	74	33%	17	10%
Carcinoïd syndrome, NET	4	19%	17	20%	11	5%	17	10%
Pheochromocytoma	0	0%	7	8%	0	0%	6	4%
Paraganglioma	0	0%	9	10%	1	0%	6	4%
Von Hippel-Lindau	0	0%	4	5%	1	0%	7	4%
Thyroid Carcinoma	2	10%	9	10%	6	3%	36	22%
Screening on MEN syndrome, NET	1	5%	10	12%	0	0%	5	3%
Carcinoma other	0	0%	3	3%	2	1%	5	3%
Other	6	29%	19	22%	29	5%	41	25%
Total	21		86		222		164	

Appendix H

Table H-1: Interarrival rate per working day (from January 2015 to November 2015, N=220, source is EZIS)

			Arrival amount			Arrival rate (λ)	p
Internist A					*1%*	*99%*	
	New				2	0.06	0.84
					2%	*98%*	
	Check-up	Clinic hours			11	3.82	0.16
					1%	*99%*	
		Other days			4	0.36	0.13
	Telephone	Clinic hours				3.98	0.37
			39%			*61%*	
		Other days	0			0.89	0.06
Internist B					*2%*	*98%*	
	New				4	0.34	0.62
	Check-up	Clinic hours				1.94	0.22
			16%		*1%*	*83%*	
		Other days	0		7	0.98	0.05
	Telephone	Clinic hours				4.88	0.04
						85%	
		Other days				1.06	0.13
						15%	
		Other days				6.04	0.66
Nurse Specialist	All					0.14	0.99
	Telephone	Clinic hours				1.36	0.37
		Other days				0.43	0.31
Genetic Counselor	All					0.30	0.42
Endocrine Surgery	New					0.92	0.40
	Check-up	Clinic hours				1.35	0.07
			20%			*80%*	
		Other days	0			0.64	0.14
	Check-up		*11%*	*3%*	*1%*	*85%*	
	after Surgery		0	4	5	0.70	0.06
	Telephone	Clinic hours				2.25	0.67
		Other days				0.27	0.84

Appendix I

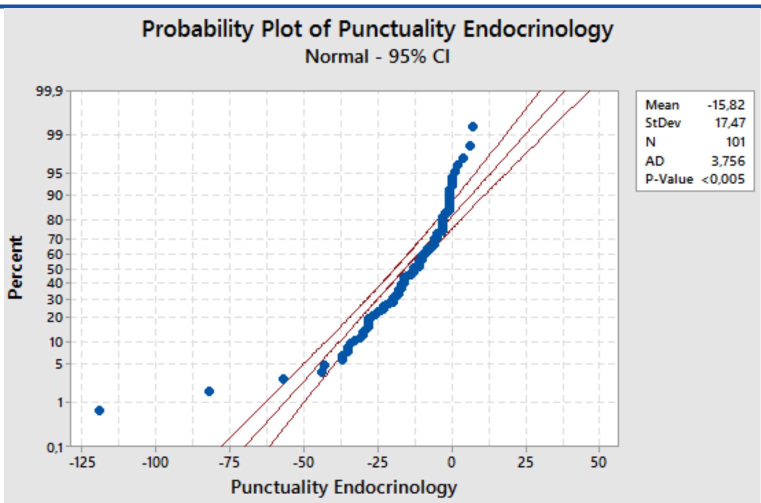


Figure I-1: Normality test of punctuality data of Endocrinology (from 21 September 2015 to 9 November 2015, N=101)

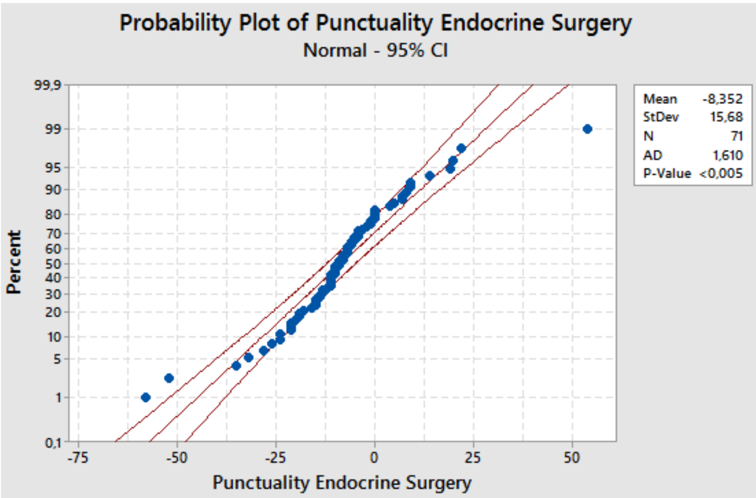


Figure I-2: Normality test of punctuality data of Endocrine Surgery (from 21 September 2015 to 9 November 2015, N=101)

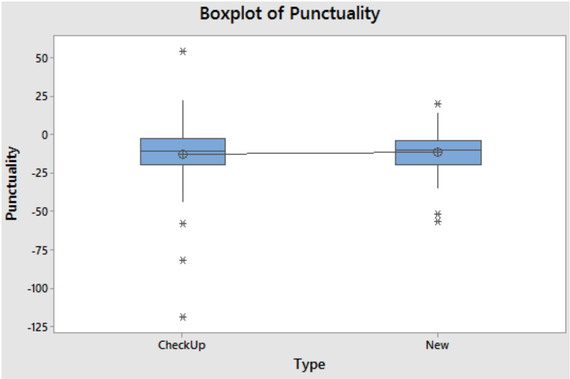


Figure I-3: Boxplot to analyze difference in mean in the punctuality of New and Check-up patients (21 September 2015 to 9 November 2015, N=172)

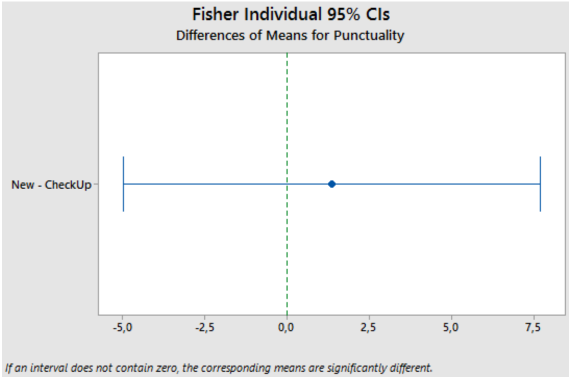


Figure I-4: Equal mean test of the punctuality of New and Check-up patients (21 September 2015 to 9 November 2015, N=172)

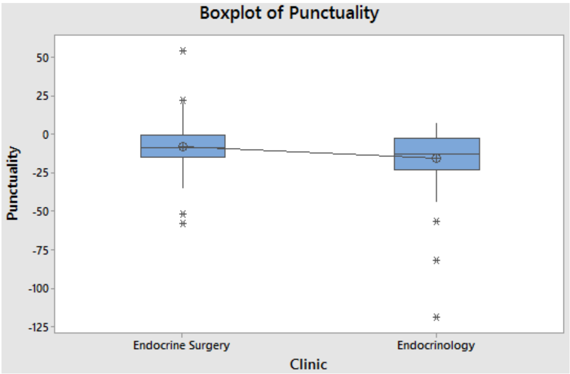


Figure I-5: Boxplot to analyze difference in mean in the punctuality of patients of Endocrinology and Endocrine Surgery (21 September 2015 to 9 November 2015, N=172)

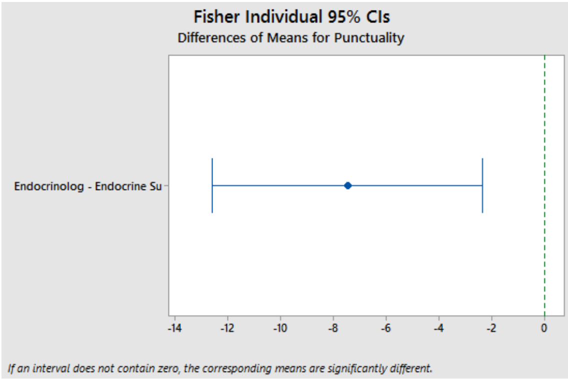


Figure I-6: Equal mean test of the punctuality of patients of Endocrinology and Endocrine Surgery (21 September 2015 to 9 November 2015, N=172)

Appendix J

Table J-1: Reasons for replacements of the appointment at Endocrinology (January 2015 to December 2015 from EZIS)

	Endocrinology							
	Internist A (N=72)		Internist B (N=84)		Nurse Specialist (N=17)		Genetic Counselor (N=15)	
Request of patient	33	(45.8%)	37	(44.0%)	1	(5.9%)	9	(60.0%)
Request of practitioner	29	(40.3%)	27	(32.1%)	4	(23.5%)	5	(33.3%)
Incorrect booking	3	(4.2%)	2	(2.4%)	6	(35.3%)	1	(6.7%)
Patient did not show up	2	(2.8%)	3	(3.6%)				
Cancelation on appointmentday			3	(3.6%)	1	(5.9%)		
Other	5	(6.9%)	12	(36.6%)	5	(29.4%)		

Table JI-2: Reasons for replacements of the appointment at Endocrine Surgery (January 2015 to December 2015 from EZIS)

	Endocrine Surgery	
Request of patient	37	(61.7%)
Request of practitioner	9	(15.0%)
Incorrect booking	8	(13.3%)
Patient did not show up	2	(3.3%)
Other	4	(6.7%)

Appendix K

Table K-1: Descriptive statistics of the net consultation times of Endocrinology

Net consultation times Endocrinology

Internists	N	CM1/CM2/CVHL	C	Combi	Cluster C
Count	10	38	32	4	70
Mean	35.3	19.7	19.4	21.3	19.6
StDev	7.7	6.6	9.1	11.6	7.8
Shape	23.9	10.2	5.6	4.8	7.4
Scale	1.5	1.9	3.5	4.4	2.6

Nurse Specialist	CVSP/Voorl
Count	17
Mean	27.4
StDev	15.2
Shape	3.4
Scale	8.1

Genetic Counselor	MGT ONC
Count	7
Mean	25.7
StDev	8.5
Shape	6.5
Scale	4.0

Table K-2: Descriptive statistics of the net consultation times of Endocrine Surgery

Net consultation times Endocrine Surgery

Surgeon	C	CNO	N	SUP	Cluster C
N	13	13	12	16	26
Mean	11.0	10.6	18.2	8.2	10.8
StDev	7.8	7.1	10.6	7.2	7.3
Shape	3.2	2.8	3.9	1.8	10.8
Scale	3.4	3.7	4.6	4.6	7.3

Resident Doctor	C	CNO	N
N	7	9	15
Mean	9.6	19.8	22.1
StDev	7.6	14.8	10.8
Shape	1.6	1.9	4.4
Scale	5.9	10.2	5.0

Table K-3: Descriptive statistics of the gross consultation times of Endocrinology

Gross consultation times Endocrinology

Internists	N	CM1/CM2/CVHL	C	Combi
Count	10	38	32	4
Mean	39,8	22,9	20,2	32,0
StDev	11,6	8,4	9,3	9,9
Shape	13,7	8,1	5,7	15,3
Scale	2,9	2,8	3,5	2,1

Nurse Specialist	CVSP/Voorl
Count	17
Mean	32,1
StDev	16,9
Shape	3,7
Scale	8,7

Genetic Counselor	MGT ONC
Count	7
Mean	29,0
StDev	12,1
Shape	4,8
Scale	6,1

Table K-4: Descriptive statistics of the gross consultation times of Endocrine Surgery

Gross consultation times Endocrine Surgery

Surgeon	C	CNO	N	SUP
N	13	13	12	13
Mean	13,9	12,2	21,9	12,4
StDev	9,3	7,0	12,0	9,6
Shape	2,8	3,5	3,7	2,0
Scale	5,0	3,4	5,9	6,2

Resident Doctor	C	CNO	N
N	7	9	15
Mean	10,6	23,3	27,6
StDev	8,8	17,0	11,2
Shape	1,5	2,0	7,1
Scale	7,2	11,5	3,9

Appendix L

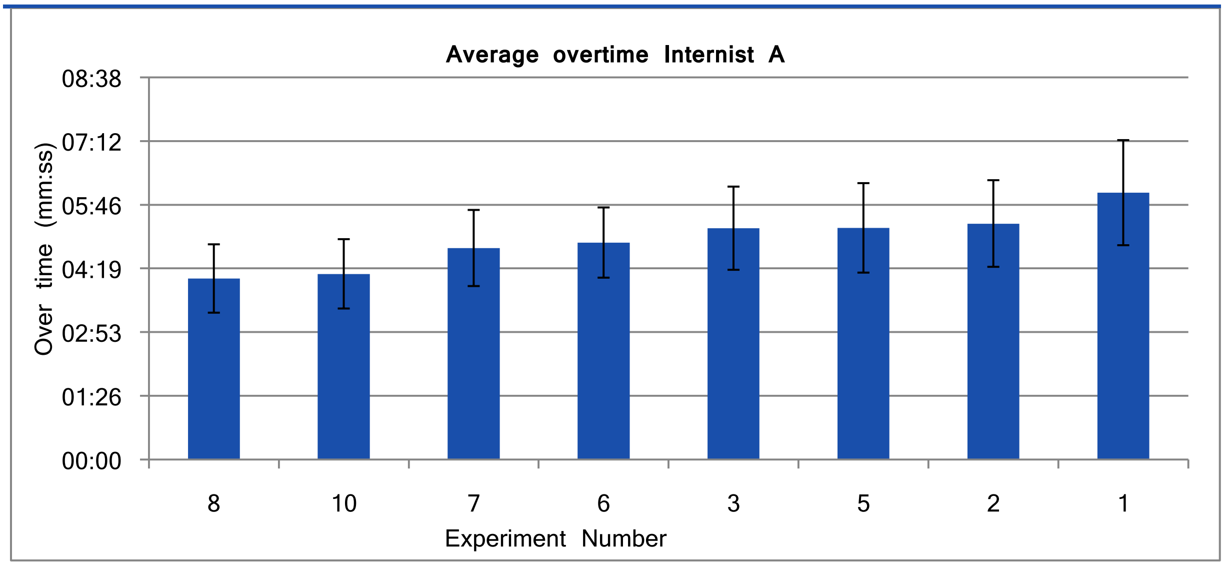
Table L-1: Current demand versus capacity Internist A

Patient type	**Arrival rate (λ_{day})**	**Arrival rate (λ_{week}) = λ_{day} · days per week**	Demand = λ_{week} · duration (min)	Clinic days	Capacity = clinic days · daily capacity
New	0.06	0.06 · 5 = 0.30	0.30 · 45 = 13.5	Monday (1 per week)	1 · 120 = 120
Check-up (clinic days)	3.82	3.82 · 1.5 = 5.73	5.73 · 20 = 114.6	Wednesday (0.5 per week)	0.5 · 140 = 70
Check-up (other days)	0.36	0.36 · 3.5 = 1.26	1.26 · 20 = 25.2		
			153.3 (min per week)		**190** (min per week)

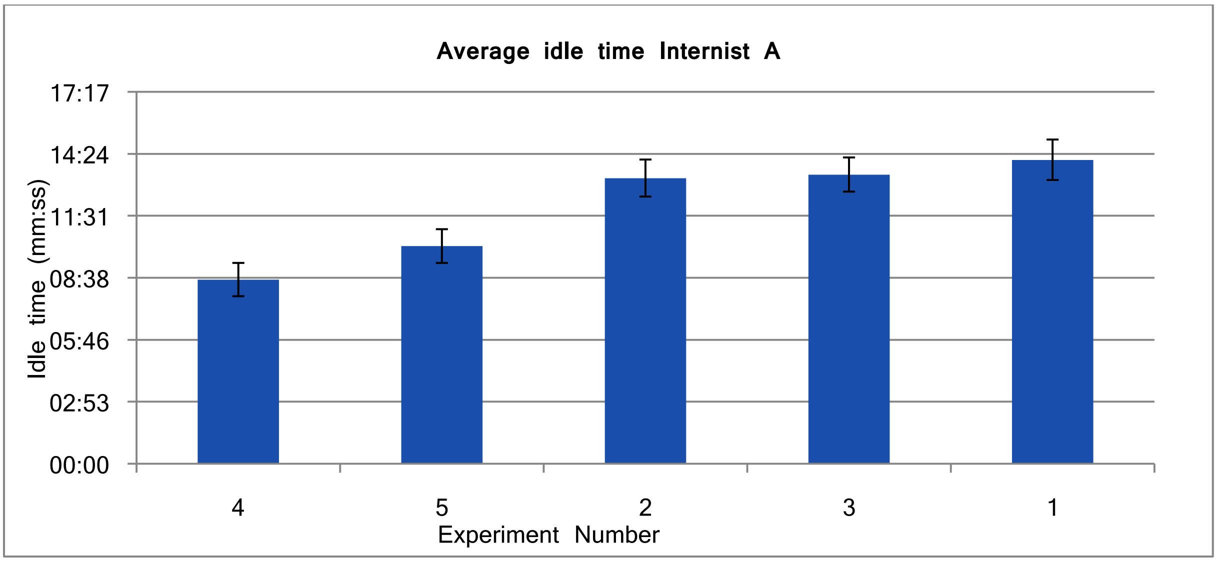
Table L-2: Current demand versus capacity Internist B

Patient type	**Arrival rate (λ_{day})**	**Arrival rate (λ_{week}) = λ_{day} · days per week**	Demand = λ_{week} · duration (min)	Clinic days	Capacity = clinic days · daily capacity
New	0.34	0.34 · 5 = 1.70	1.70 · 45 = 76.5	Monday (1 per week)	1 · 90 = 90
Check-up (clinic days)	1.94	1.94 · 2 = 3.88	3.88 · 15 = 58.2	Thursday (1 per week)	1 · 150 = 150
Check-up (other days)	0.98	0.98 · 3 = 2.94	2.94 · 15 = 44.1		
			178.8 (min per week)		**240** (min per week)

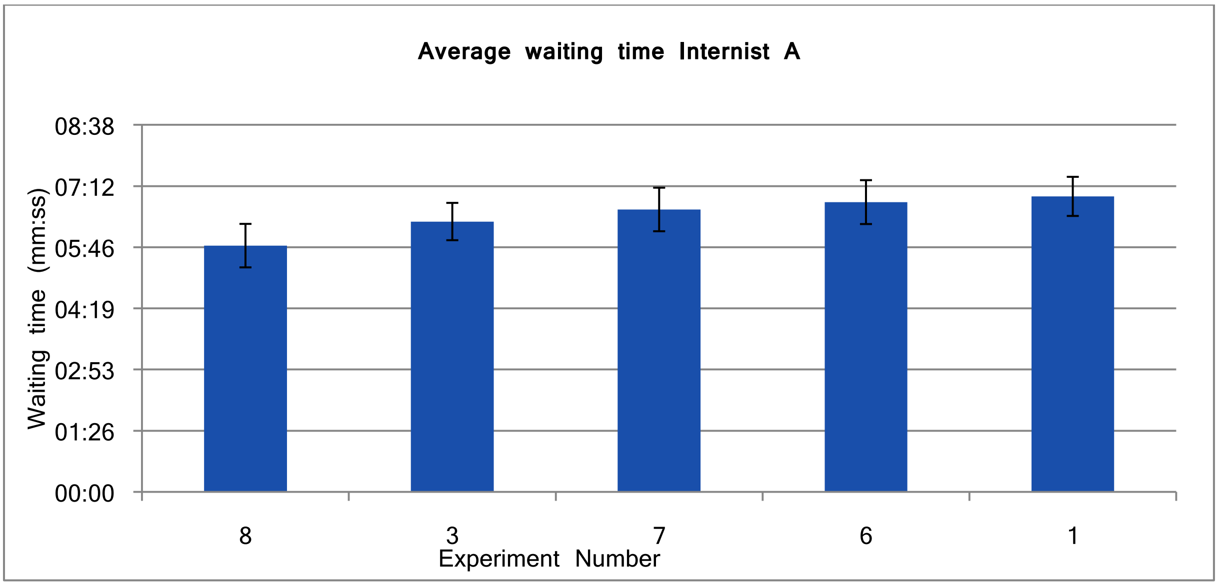
Appendix M



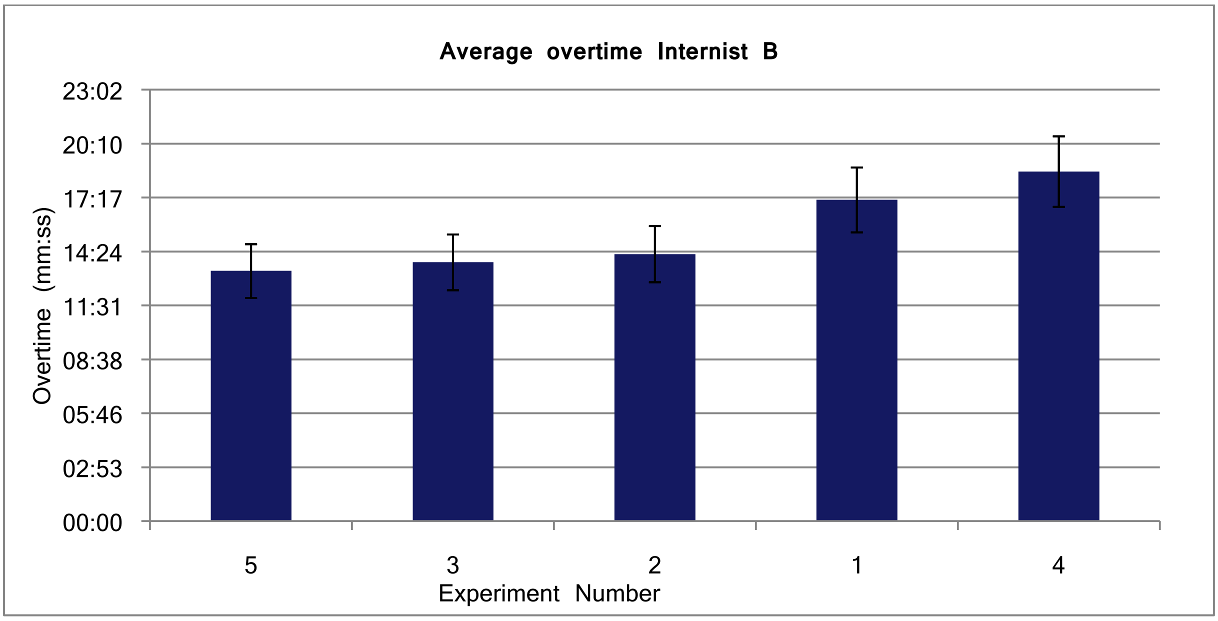
Average overtime Internist A
Over time (mm:ss)
08:38
07:12
05:46
04:19
02:53
01:26
00:00
8
10
7
6
3
5
2
1
Experiment Number

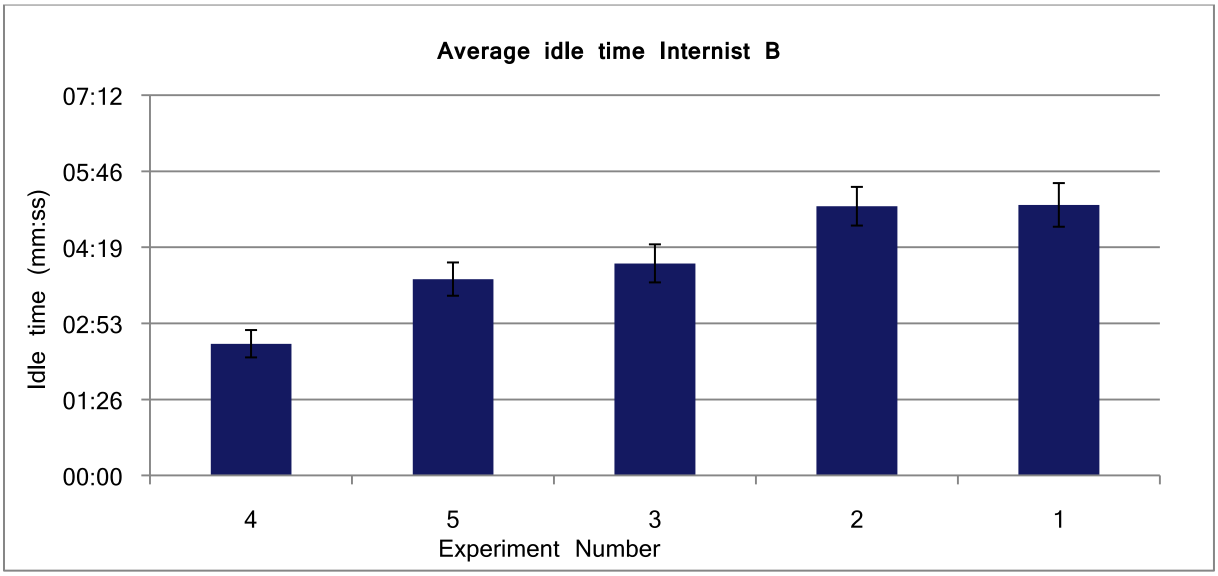


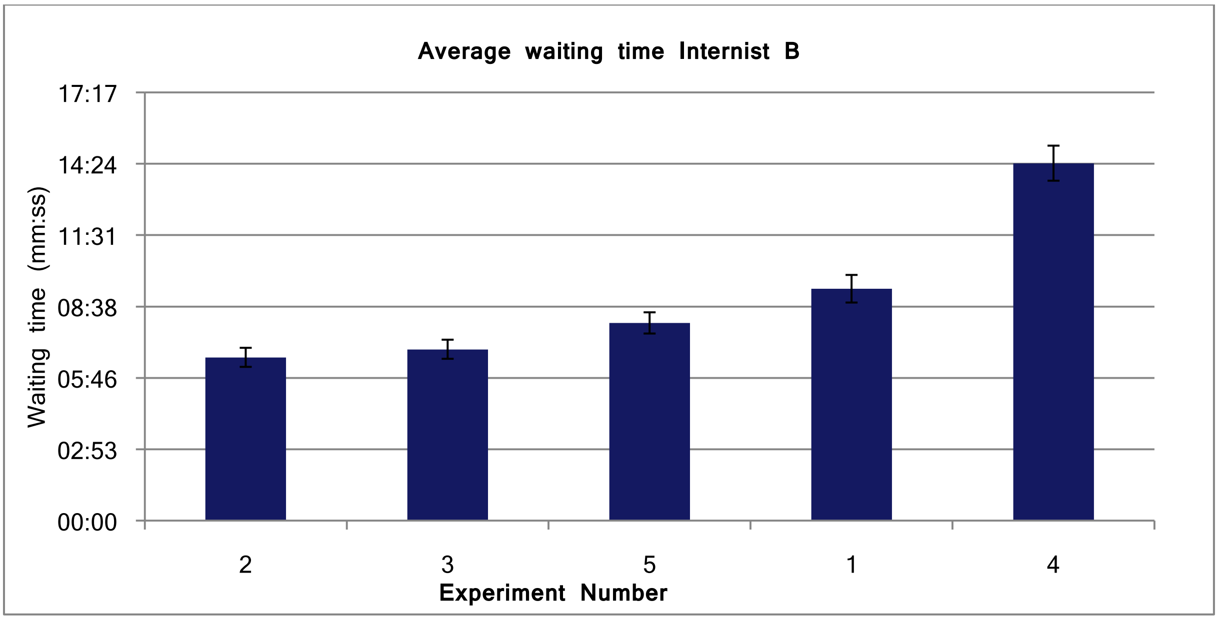
Average idle time Internist A
Idle time (mm:ss)
17:17
14:24
11:31
08:38
05:46
02:53
00:00
4
5
2
3
1
Experiment Number

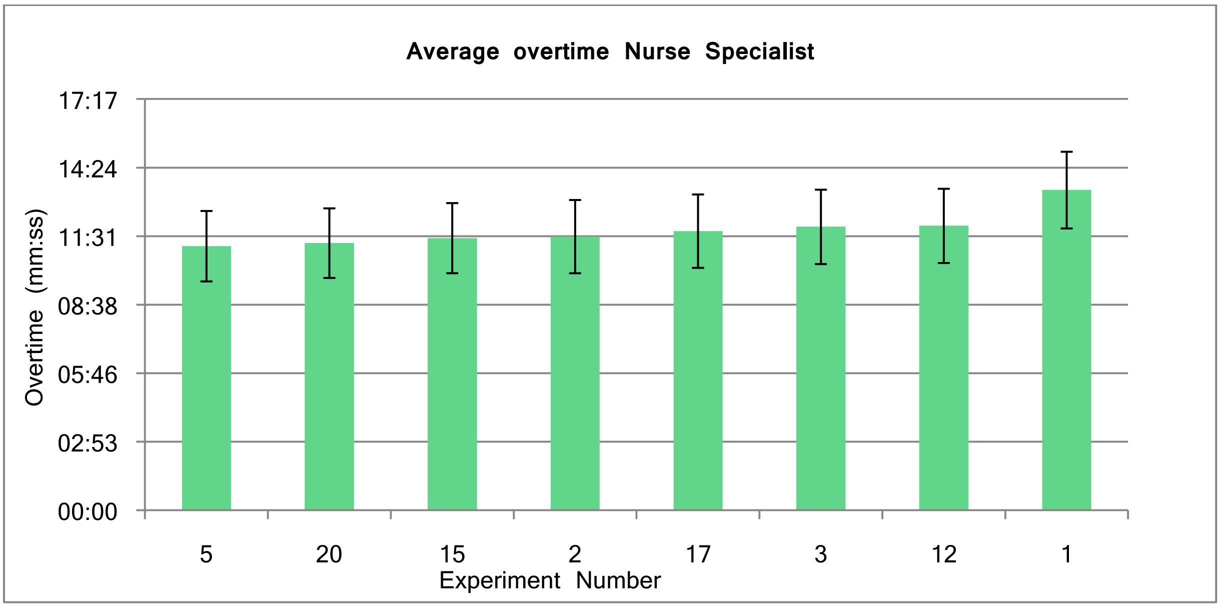


Average waiting time Internist A
Waiting time (mm:ss)
08:38
07:12
05:46
04:19
02:53
01:26
00:00
8
3
7
6
1
Experiment Number

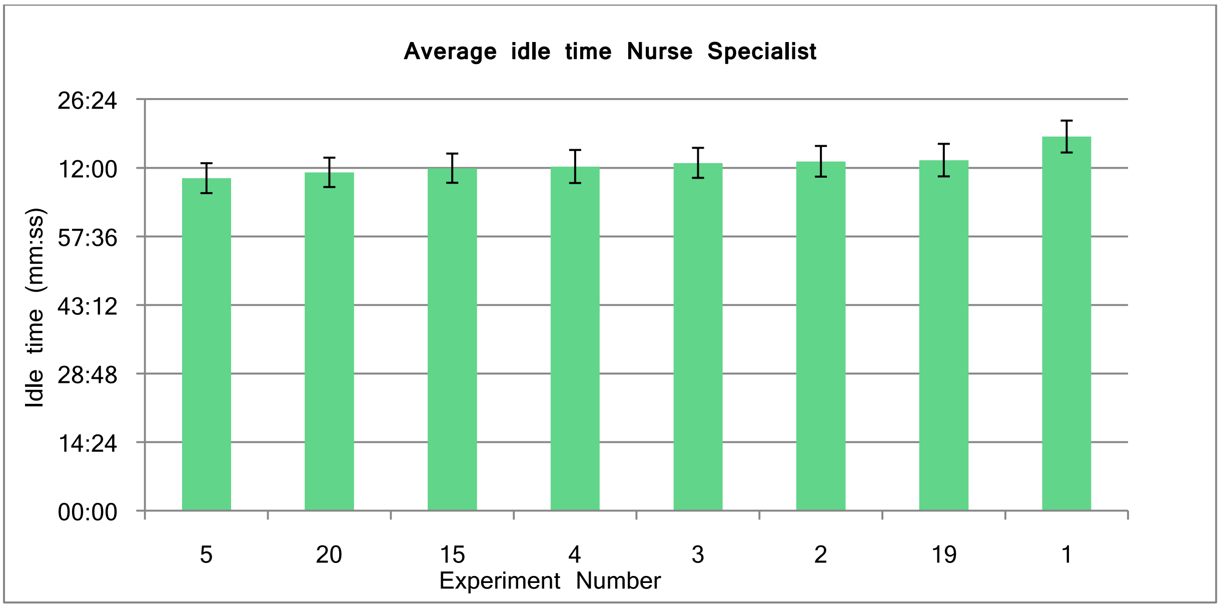

Average overtime Internist B
Overtime (mm:ss)
23:02
20:10
17:17
14:24
11:31
08:38
05:46
02:53
00:00
5
3
2
1
4
Experiment Number


Average idle time Internist B
Idle time (mm:ss)
07:12
05:46
04:19
02:53
01:26
00:00
4
5
3
2
1
Experiment Number

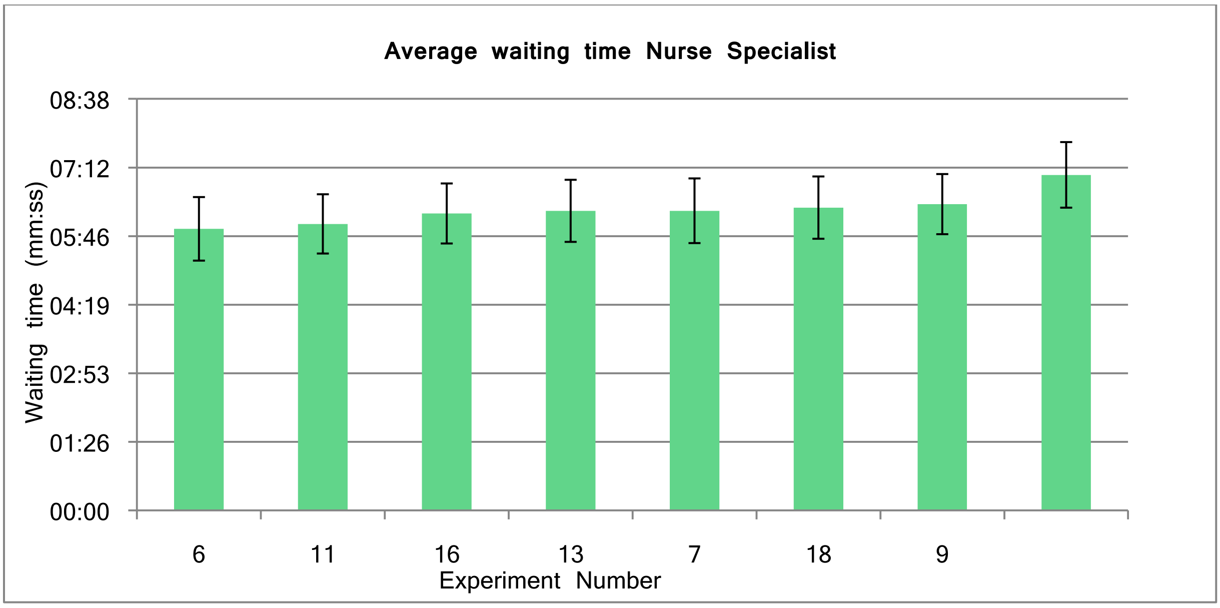

Average waiting time Internist B
Waiting time (mm:ss)
17:17
14:24
11:31
08:38
05:46
02:53
00:00
2
3
5
1
4
Experiment Number



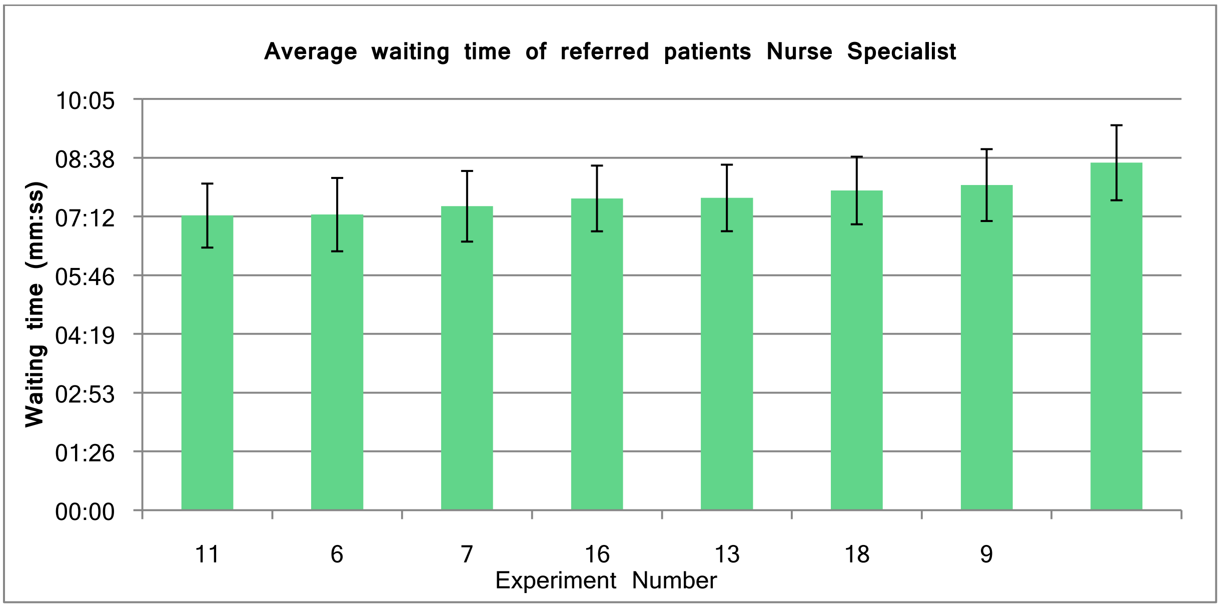
Average overtime Nurse Specialist
17:17
14:24
11:31
08:38
05:46
02:53
00:00
Overtime (mm:ss)
5
20
15
2
17
3
12
1
Experiment Number

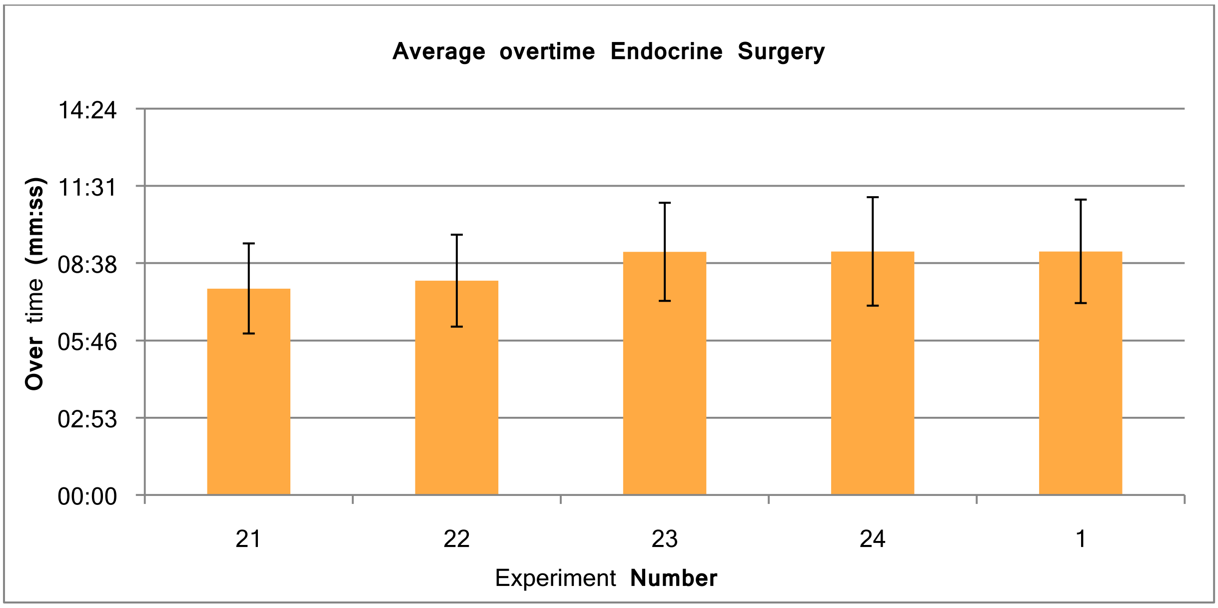


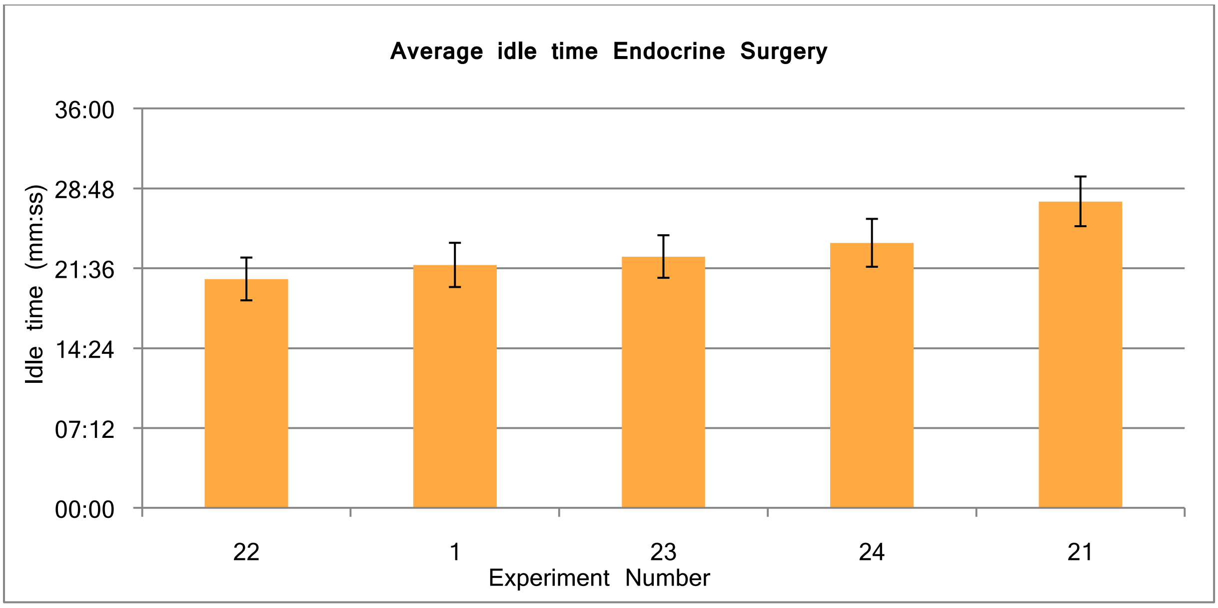
Average idle time Nurse Specialist
26:24
12:00
57:36
43:12
28:48
14:24
00:00
Idle time (mm:ss)
5
20
15
4
3
2
19
1
Experiment Number

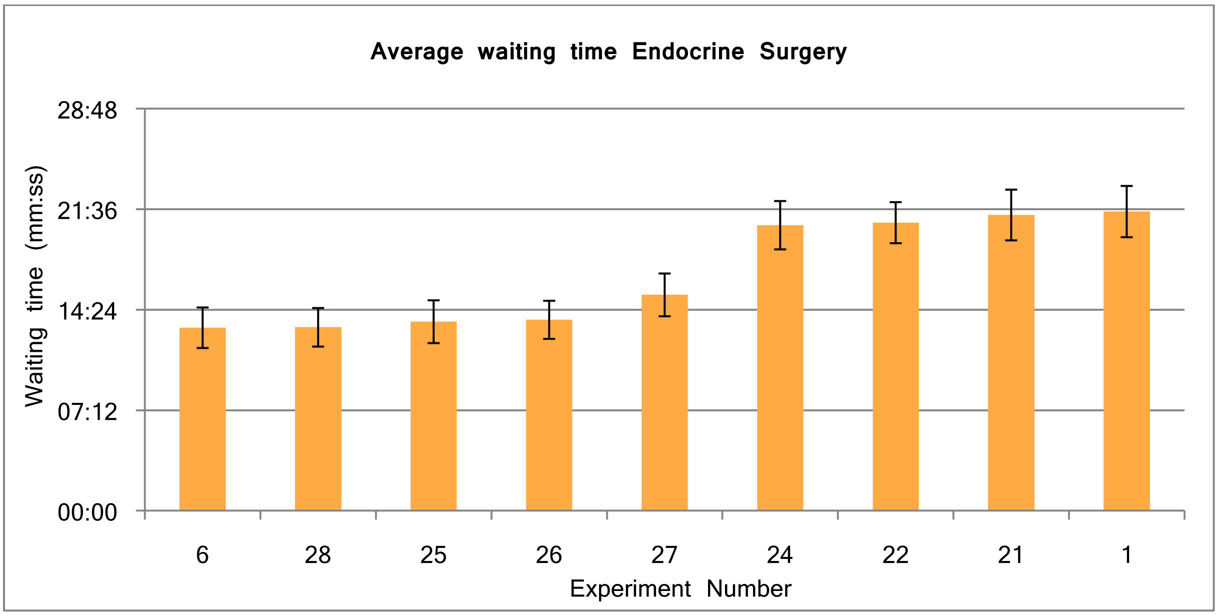


Average waiting time Nurse Specialist
08:38
07:12
05:46
04:19
02:53
01:26
00:00
Waiting time (mm:ss)
6
11
16
13
7
18
9
Experiment Number


Average waiting time of referred patients Nurse Specialist
Waiting time (mm:ss)
10:05
08:38
07:12
05:46
04:19
02:53
01:26
00:00
11
6
7
16
13
18
9
Experiment Number

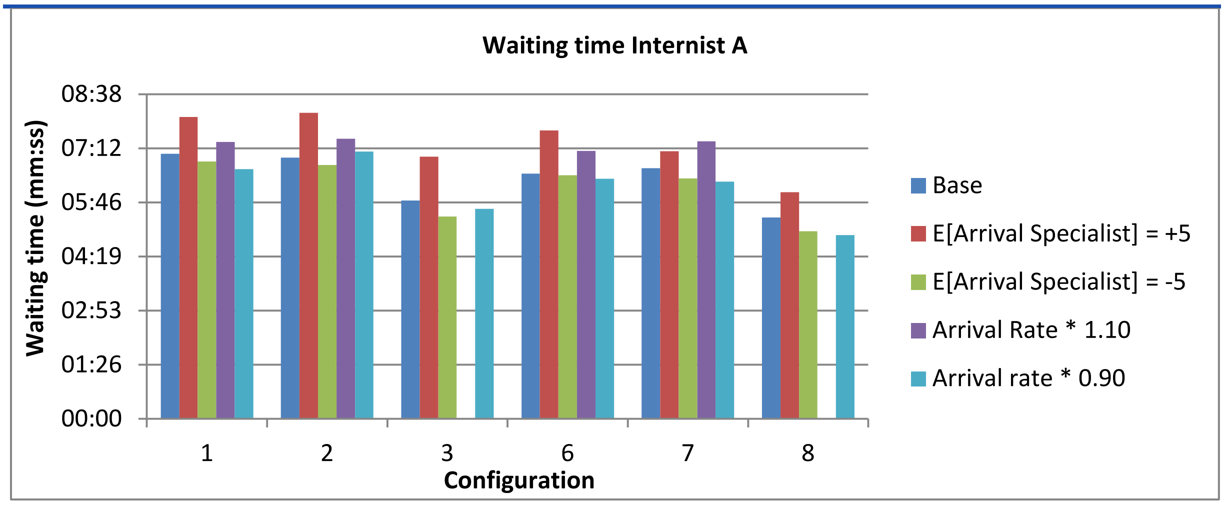

Average overtime Endocrine Surgery
Over time (mm:ss)
14:24
11:31
08:38
05:46
02:53
00:00
21
22
23
24
1
Experiment Number

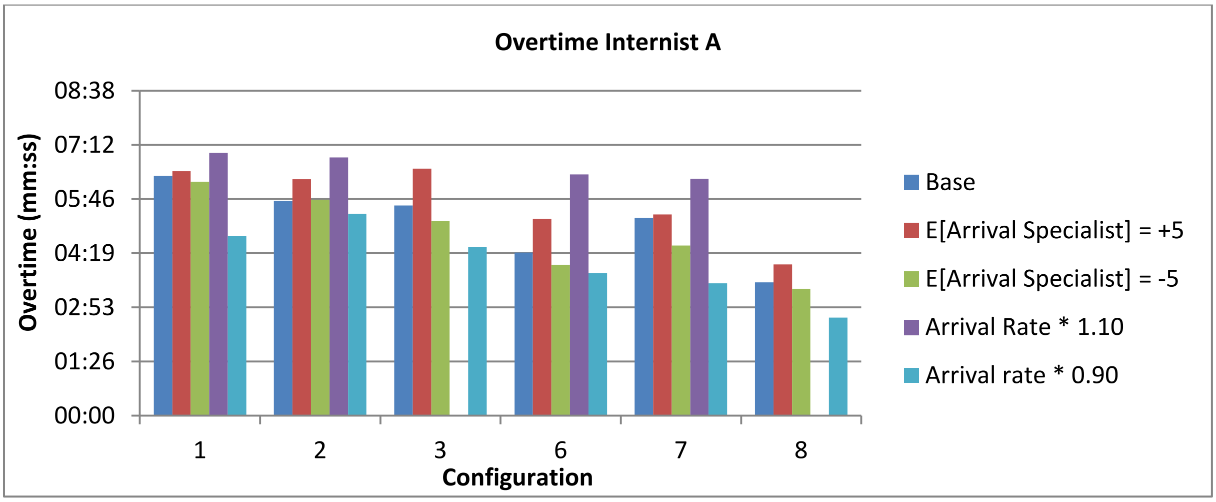

Average idle time Endocrine Surgery
Idle time (mm:ss)
36:00
28:48
21:36
14:24
07:12
00:00
22
1
23
24
21
Experiment Number

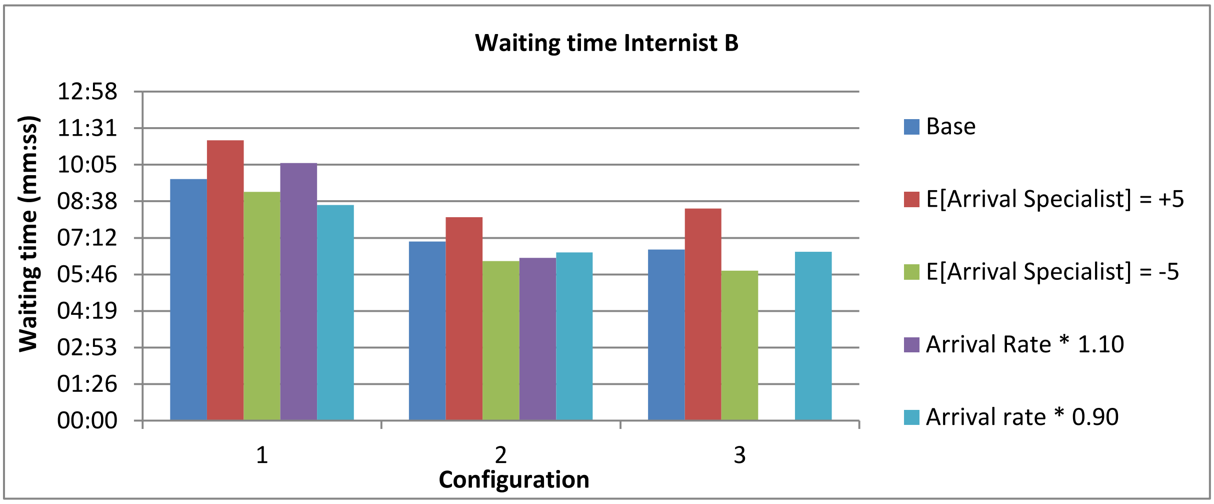


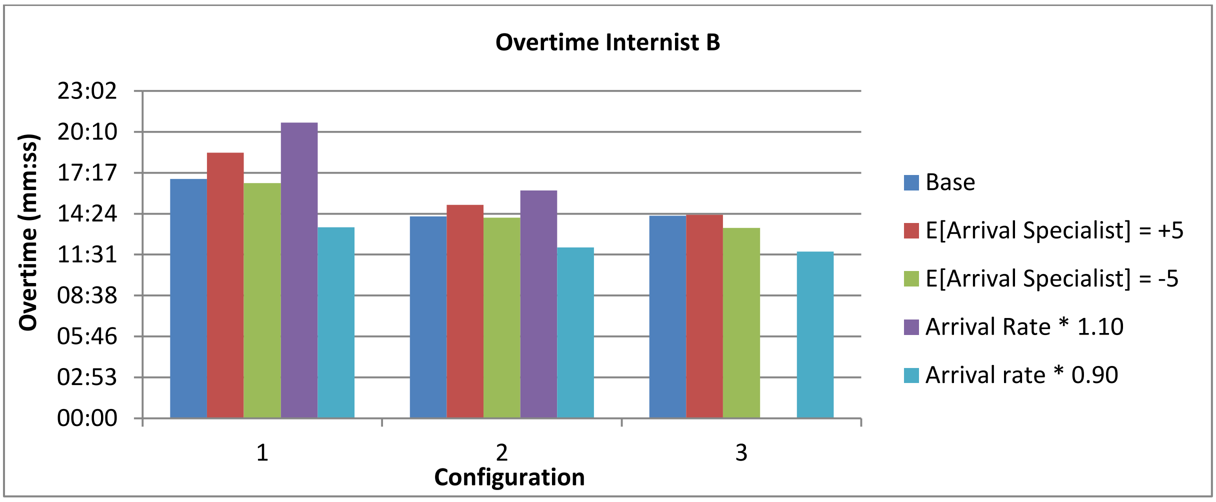
Average waiting time Endocrine Surgery
Waiting time (mm:ss)
28:48
21:36
14:24
07:12
00:00
6
28
25
26
27
24
22
21
1
Experiment Number

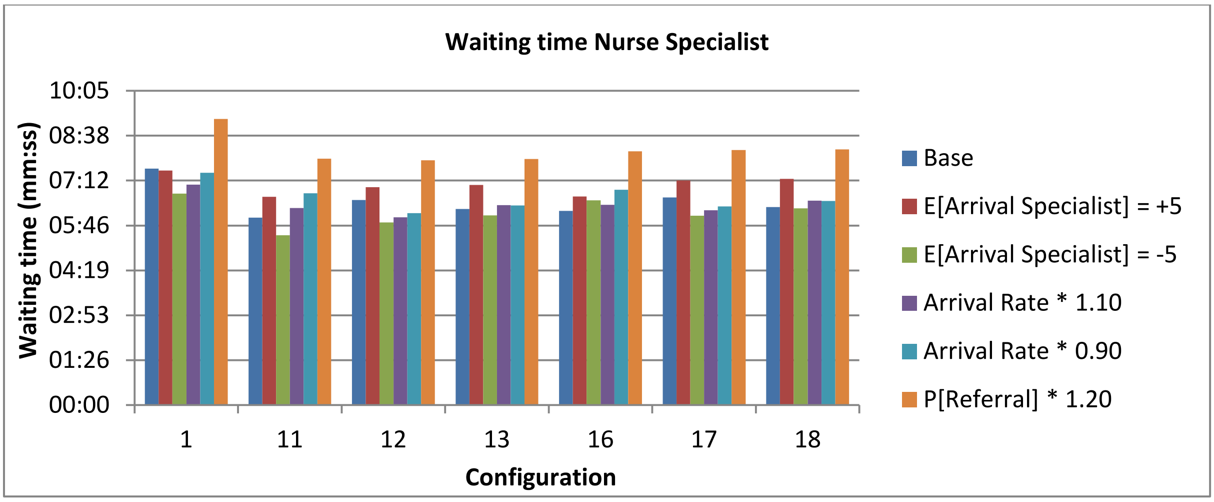
Appendix N

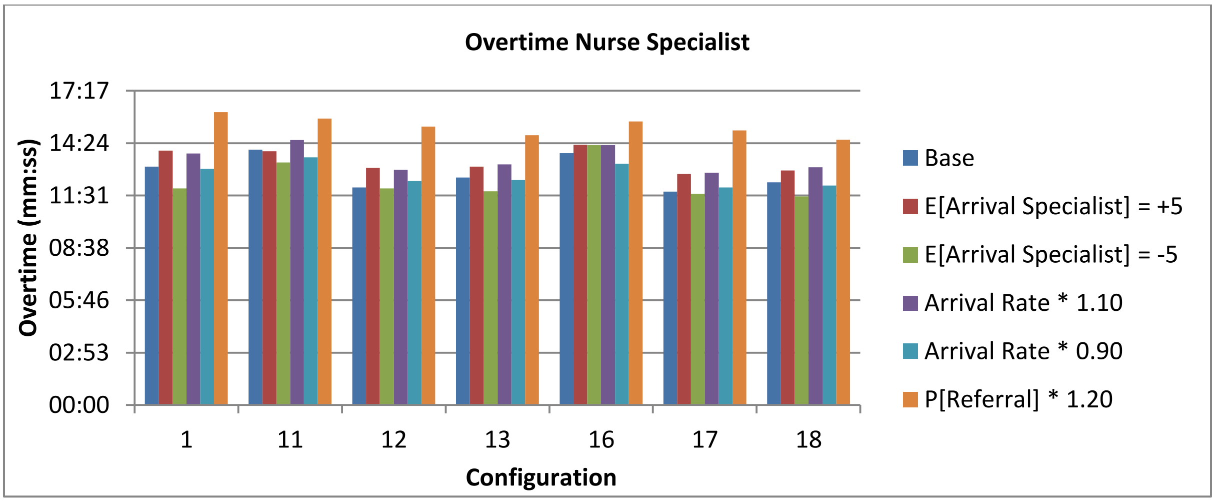

Waiting time Internist A
Waiting time (mm:ss)
08:38
07:12
05:46
04:19
02:53
01:26
00:00
1
2
3
6
7
8
Configuration
Base
E[Arrival Specialist] = +5
E[Arrival Specialist] = -5
Arrival Rate * 1.10
Arrival rate * 0.90

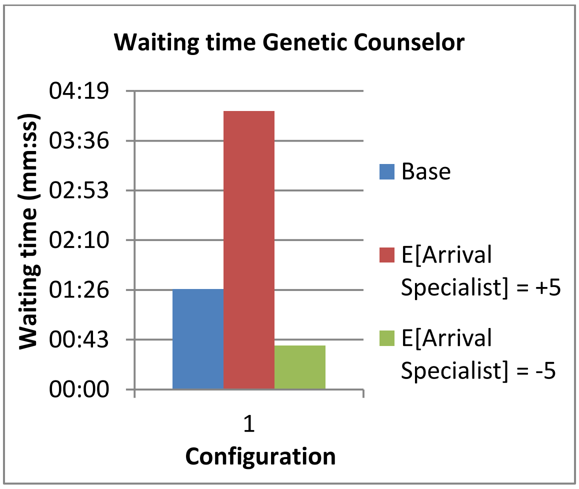

Overtime Internist A
Overtime (mm:ss)
08:38
07:12
05:46
04:19
02:53
01:26
00:00
1
2
3
6
7
8
Configuration
Base
E[Arrival Specialist] = +5
E[Arrival Specialist] = -5
Arrival Rate * 1.10
Arrival rate * 0.90

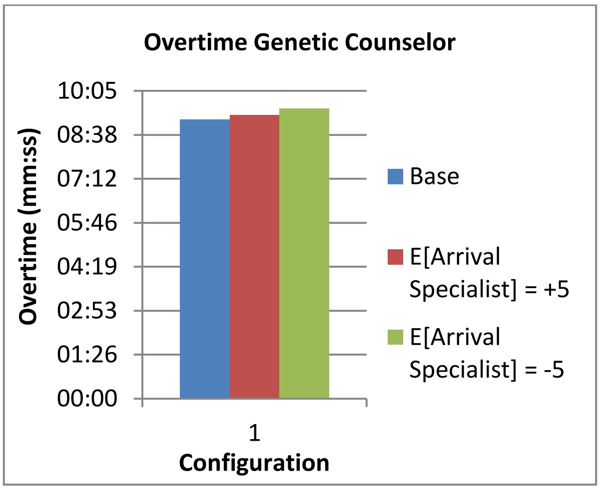

Waiting time Internist B
Waiting time (mm:ss)
12:58
11:31
10:05
08:38
07:12
05:46
04:19
02:53
01:26
00:00
1
2
3
Configuration
Base
E[Arrival Specialist] = +5
E[Arrival Specialist] = -5
Arrival Rate * 1.10
Arrival rate * 0.90

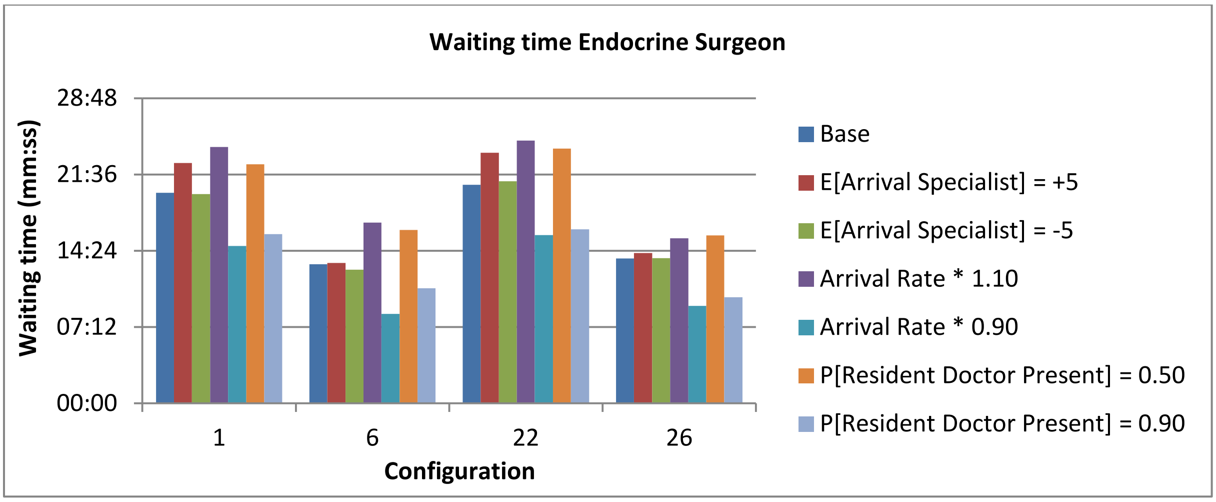

Overtime Internist B
23:02
20:10
17:17
14:24
11:31
08:38
05:46
02:53
00:00
Overtime (mm:ss)
1
2
3
Configuration
Base
E[Arrival Specialist] = +5
E[Arrival Specialist] = -5
Arrival Rate * 1.10
Arrival rate * 0.90

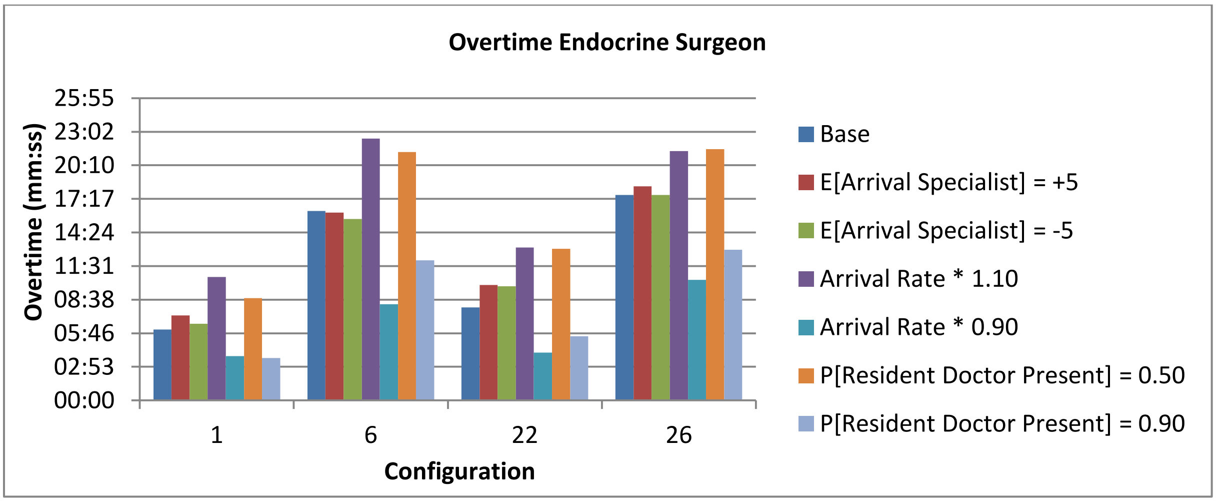

Waiting time Nurse Specialist
10:05
08:38
07:12
05:46
04:19
02:53
01:26
00:00
Waiting time (mm:ss)
1
11
12
13
16
17
18
Configuration
Base
E[Arrival Specialist] = +5
E[Arrival Specialist] = -5
Arrival Rate * 1.10
Arrival Rate * 0.90
P[Referral] * 1.20


Overtime Nurse Specialist
17:17
14:24
11:31
08:38
05:46
02:53
00:00
Overtime (mm:ss)
1
11
12
13
16
17
18
Configuration
Base
E[Arrival Specialist] = +5
E[Arrival Specialist] = -5
Arrival Rate * 1.10
Arrival Rate * 0.90
P[Referral] * 1.20


Waiting time Genetic Counselor
Waiting time (mm:ss)
04:19
03:36
02:53
02:10
01:26
00:43
00:00
1
Configuration
Base
E[Arrival Specialist] = +5
E[Arrival Specialist] = -5


Overtime Genetic Counselor
Overtime (mm:ss)
10:05
08:38
07:12
05:46
04:19
02:53
01:26
00:00
1
Configuration
Base
E[Arrival Specialist] = +5
E[Arrival Specialist] = -5


Waiting time Endocrine Surgeon
Waiting time (mm:ss)
28:48
21:36
14:24
07:12
00:00
1
6
22
26
Configuration
Base
E[Arrival Specialist] = +5
E[Arrival Specialist] = -5
Arrival Rate * 1.10
Arrival Rate * 0.90
P[Resident Doctor Present] = 0.50
P[Resident Doctor Present] = 0.90


Overtime Endocrine Surgeon
Overtime (mm:ss)
25:55
23:02
20:10
17:17
14:24
11:31
08:38
05:46
02:53
00:00
1
6
22
26
Configuration
Base
E[Arrival Specialist] = +5
E[Arrival Specialist] = -5
Arrival Rate * 1.10
Arrival Rate * 0.90
P[Resident Doctor Present] = 0.50
P[Resident Doctor Present] = 0.90