May 2016

MASTER THESIS

REDUCING WAITING TIMES IN THE PRE-ANAESTHETIC CLINIC OF VU UNIVERSITY MEDICAL CENTER

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Management summary

Like many hospitals in the Netherlands, VU university medical center organizes the pre-operative screening of patient at an outpatient clinic. Within such a screening, the health of the patient is checked by an anaesthetist and the patient is informed about the surgery. Patients for elective surgeries from different speciality departments are redirected to the pre-anaesthetic clinic (PAC). So most of the patients of the PAC are walk-in patients without an appointment.

With the current design, long waiting times occur. During our initial investigation we have found that 25% of the patients have to wait longer than 60 minutes. The waiting times arises at two places, at the arrival at the PAC and between the pre-operative processes. So planning and control rules are formulated to reduces both kind of waiting times.

During the day peak moments can be observed, since most of the patients visit the PAC by the walk-in principle. On average four patients per hour visit the PAC and this can rise to ten patients per hour. These peaks result in longer waiting times at the PAC and increase the workload of the staff. Therefore, a redesign of the PAC is needed. The redesign includes the introduction of the so-called carrousel, which means that within one series of appointments a patients sees the nurse, a member of the medication team and the anaesthetist.

The main research questions in this study is defined as:

What causes the current waiting times at the pre-operative department? And how can the waiting times be decreased with the use of planning and control rules?

In order to answer the research questions, we translated the planning and control rules into three PAC design factors:

- The dimensioning of the capacity, defining the capacity of the staff per day;
- The appointment schedule, allocating time slots for appointments;
- The routing rules, prioritizing the patients in the waiting room.

The factors are analysed with the use of two quantitative models. First, a queuing model is introduced to determine the capacity of the department, followed by the introduction of a simulation model, which allows us to model in more details. Next, a heuristic approach is built to construct an appointment schedule. The schedule defines which time slot of the blueprint can be used for appointments.

Results

For the capacity dimensioning, three service levels are set, the maximum waiting time for the first process is 30 minutes, the maximum waiting time between the processes is 10 minutes and the utilization rate has as maximum of 80% due to additional administration tasks. Currently the capacity is the same for all weekdays, but seen the fluctuation in the arrival of the patients we advise a capacity setting that differs daily, see Table 0.1.

Table 0.1: Number of staff per weekday.

	Mon	Tue	Wed	Thu	Fri
Secretary desk	1	1	1	1	1
Nurse	2	3	3	3	2
Medication team	2	2	2	2	1
Anaesthetist	2	3	3	3	2

The routing rules can be seen as a work agreement to serve the patients between the pre-operative processes. Five rules are tested and the biggest difference is the differentiation of the patients with an appointment and the walk-in appointments. When no differentiation is made, we recommend the First Come, First Served rule, which serves the patients in the order they arrive. However, we advise to prioritize on the appointment patients with the rule Arrival on Earliest Appointment Time, which serves the patients according to their appointment time.

The appointment schedule defines the time slots of the blueprint which can be used for appointments. Introducing an appointment schedule reduces the maximum waiting time for all patients by 42%. Table 0.2 shows the the distinction in the performance of the walk-in patients and the appointment patients. The reduction is reached since the appointment scheduling decreases the long waiting times during the afternoon, as shown in Figure 0.1. A characteristic of the appointment schedule are the scheduled appointments at the beginning and the end of a day. Moreover, time slots are used with a small appointment interval, which defines the time between two time slots.

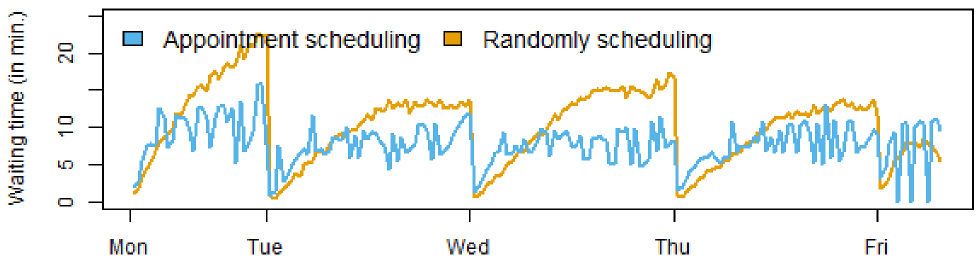


Figure 0.1: Average waiting time per time slot for randomly scheduling and appointment scheduling.

The implementation of the appointment schedule requires dedicated time slots in the agenda of the PAC. This restricts the scheduling freedom of the scheduler but avoids scheduling mistakes. Another way to define the appointment slots is by the use of an appointment rule. This defines how the scheduler schedules the appointment during the day by means of a working agreement. Three rules are tested and it resulted that the best rule is rule 2 which allows the scheduler to use two out of three time slots for appointment and schedule no appointments between 11 and 1 o'clock. The performances of the rule are shown in Table 0.2.

Table 0.2: Summary of the performance of an appointment schedule.

Performance	Flows	Random scheduling	Appointment scheduling	Appointment rule 2
Average waiting time	Total	14.6	8.5	9.2
	Walk-in	24.7	12.1	13.1
	Appointment	8.4	6.2	6.6
Maximum waiting time	Total	63.6	35.7	39.4
	Walk-in	90.4	48.6	55.7
	Appointment	31.8	26.6	27.6

Conclusions and recommendations

In this research we analysed planning and control rules to decrease the waiting time of the patients. First we proposed a capacity setting per weekday when implementing the carrousel for the PAC. As routing rule, we advise the Arrival on Earliest Appointment time. This rule is easy to implement and most of all it is fair to the patients. We recommend to dedicate time slots for appointments in the PAC agenda. For the dedication of the appointments, the heuristic of this thesis can be used. It is also possible to implement the routing rules within the PAC agenda. Which schedule to implement depends on the accuracy of the input, like the collected data and the blueprint. It is up to the management of the hospital to make this decision.

Management samenvatting

Zoals vele andere ziekenhuizen in Nederland, organiseert VU universitair medisch centrum de pre-operatieve screening van patiënten op een polikliniek. Tijdens de screening wordt de gezondheid van de patiënt gecontroleerd door een anesthesioloog en wordt de patiënt genformeerd over de operatie. Patinten voor electieve operaties worden van diverse poliklinische afdelingen doorgestuurd naar de pre-operatieve screening (POS), wat resulteert in het feit dat de meeste patiënten van de POS inloop patiënten zijn zonder een afspraak.

In het huidige ontwerp, ontstaan lange wachttijden. Tijdens ons onderzoek, hebben we ontdekt dat 25% van de patiënten langer wacht dan 60 minuten. De wachttijden ontstaan op twee plekken, bij de aankomst van patiënten op de POS en tussen de pre-operatieve processen in. Planning en control regels worden geformuleerd om beide soorten van wachttijden te verminderen.

Aangezien de meeste patiënten de POS bezoeken via het inloop principe, ontstaan gedurende de dag piekmomenten in de aankomst van patiënten. Gemiddeld bezoeken 4 patiënten per uur de POS en dit loopt tijdens de piekmomenten op tot meer dan tien patiënten per uur. De pieken leiden tot langere wachttijden bij de POS en verhogen de werkdruk van het personeel. Daarom is een herontwerp van de processen op de POS nodig. Het herontwerp omvat de introductie van een zogenoemde carrousel. In de carrousel heeft de patiënt achtereenvolgens een gesprek met een verpleegkundige, een lid uit het medicatie team en een anesthesioloog.

De hoofdvragen voor dit onderzoek zijn als volgt gedefinieerd:

Wat is de oorzaak van de huidige wachttijden bij de pre-operatieve afdeling? En hoe kunnen de wachttijden worden verminderd met het gebruik van planning en control regels?

Om de onderzoeksvragen te beantwoorden, onderzoeken we drie POS design factoren:

- De dimensionering van de capaciteit, bepaald de capaciteit van het personeel per dag;
- Het afsprakenschema, bepaald de tijdsloten voor de afspraken;
- De prioriseringsregel, bepaald de volgorde van de patiënten in de wachtkamer.

De factoren zijn geanalyseerd met behulp van twee kwantitatieve modellen. Als eerste wordt er een wachtrijmodel gentroduceerd om de capaciteit van de POS te bepalen. Gevolgd door de introductie van een simulatie model, waarin meer detail gemodelleerd kan worden. Daarna is een heuristiek gebouwd om een afsprakenschema te construeren. Het schema definieert welke tijdsloten van de blauwdruk worden gebruikt voor afspraken.

Resultaten

Voor de capaciteit bepaling, zijn drie service levels gedefinieerd. De maximale wachttijd voor het eerste proces van 30 minuten, een maximale wachttijd tussen de processen van 10 minuten en een maximale bezettingsgraad van 80%. Momenteel is de capaciteit voor iedere dag gelijk, maar gezien de fluctuaties in de aankomst van de patiënten adviseren wij de capaciteit per dag aan te passen, zie Tabel 0.3.

Table 0.3: Aantal medewerkers per dag.

	Ma	Di	Woe	Do	Vrij
Baliemedewerker	1	1	1	1	1
Verpleegkundige	2	3	3	3	2
Medicatie team	2	2	2	2	1
Anesthesioloog	2	3	3	3	2

De prioriseringsregels bepaald de volgorde waarin patiënten opgeroepen worden vanuit de wachtkamer. Vijf regels zijn getest en het grootste onderscheid tussen de regels is de differentiatie van de patiënten met een afspraak en de inloop patiënten. Indien er gekozen wordt om geen onderscheid te maken, raden we een First Come, First Served regel aan, die de patiënten in volgorde van binnenkomst oproept. Wij adviseren om onderscheid te maken tussen afspraak patiënten en inloop patiënten. Dit doet de regel Arrival on Earliest Appointment Time het beste. De regel (AEAT) bepaald de volgorde van de patiënten op basis van hun gegeven afspraken tijd.

Het afsprakenschema bepaald welke tijdsloten gebruikt worden voor afspraken. De invoering van een afsprakenschema reduceert de maximale wachttijd voor alle patiënten met 42%. Tabel 0.4 laat hierin het onderscheid van de inloop patiënten en patiënten met een afspraak zien. De afname wordt bereikt doordat het afsprakenschema de lange wachttijden in de namiddag vermindert, zie Figuur 0.2. Kenmerken van het afsprakenschema zijn dat de afspraken worden gepland in het begin en aan het einde van de dag. Daarnaast worden tijdsloten gebruikt die elkaar snel opvolgen.

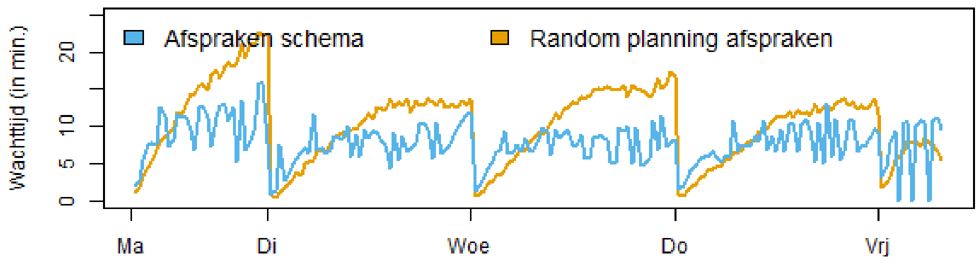


Figure 0.2: Gemiddelde wachttijd per tijdslot.

De implementatie van het afsprakenschema vereist een toewijzing van de tijdsloten in de POS agenda. Dit beperkt de planningsvrijheid van de planner, maar vermijdt fouten tijdens het plannen. Een andere aanpak is door middel van een planningsrichtlijn, die voorschrijft op welke tijdsloten een planner afspraken mag plannen. Drie richtlijnen zijn getest. Het beste resultaat levert de richtlijn die voorschrijft dat twee van de drie tijdsloten gebruikt mogen worden voor afspraken. Geen afspraken worden gepland tussen 11 en 1 uur. De prestaties van de richtlijn worden weergegeven in Tabel 0.4.

Table 0.4: Samenvatting van de prestatie van het afsprakenschema.

Prestatie	**Stroom**	**Random planning**	**Afspraken schedule**	**Plannings-richtlijn 2**
Gemiddelde Wacht-tijd	Totaal	14.6	8.5	9.2
	Inloop	24.7	12.1	13.1
	Afspraak	8.4	6.2	6.6
Maximale Wacht-tijd	Totaal	63.6	35.7	39.4
	Inloop	90.4	48.6	55.7
	Afspraak	31.8	26.6	27.6

Conclusies en aanbevelingen

In dit onderzoek zijn drie POS design factoren geanalyseerd, met als doel het terugdringen van de wachttijden. Allereerst is de personele capaciteit bepaald per dag. Als prioriseringsregel raden wij de Arrival on Earliest Appointment Time aan. De regel is eenvoudig te implementeren en ook tegenover de patiënt is het eerlijk. We adviseren daarnaast om in de POS agenda tijdsloten toe te wijzen aan afspraak patiënten. Om de toewijzing van de afspraken te vinden kan de heuristiek van dit verslag worden gebruikt. Het is ook mogelijk om de planningsrichtlijnen in de POS agenda te gebruiken. Het besluit welk schema te implementeren is afhankelijk van de nauwkeurigheid van de input, zoals de informatieverzameling en de blauwdruk. Het is aan het management van het ziekenhuis om deze beslissing te maken.

List of abbreviations

AEAT	Arrival on Earliest Appointment Time (Routing rule)
ASA score	A physical status classification system for assessing a patients before surgery, established in 1963 by the American Society of Anaesthesiologists (ASA)
CPM	Cardiopulmonary Measurements, containing an ECG or lung test
EAT	Earliest Appointment Time (Routing rule)
ECG	Electrocardiogram
FCFS	First Come, First Served (Routing rule)
LWTF	Longest Waiting Time First (Routing rule)
MSBI	Management System Business Intelligence, data registration system of the hospital
OQN	Open Queuing Network
PAC	Pre-anaesthetic clinic (in Dutch: Pre-Operatieve Screening, POS)
SEPT	Shortest Estimated Processing Time (Routing rule)
VUmc	VU University Medical Center

List of symbols

Symbol	**Definition**
c_i	Number of servers at station i
C_{ai}^2	Squared coefficient of variation of the arrivals at station i
C_{air}^2	Squared coefficient of variation of the arrivals of patient class r at station i
C_{di}^2	Squared coefficient of variation of the departure process at station i
C_{si}^2	Squared coefficient of variation of the service time at station i
C_{sir}^2	Squared coefficient of variation of the service time of patient class r at station i
EL	Mean number of patients present in the system
EL_i	Mean number of patients at station i
EL_{Qi}	Mean number of patient in the queue at station i
ES_i	Mean average service time at station i
ES_{ir}	Mean average service time of patient class r at station i
EW_{Qi}	Mean waiting time at station i
EW_r	Mean length of stay at the system for patient class r
G_i	Normalization constant for station i
λ_{ir}	Arrival rate of patient class r at station i
λ_i	Aggregated arrival rate at station i
P_{ij}	Fraction of patients at station i flowing to station j
Q_{ir}	Portion of arrival flow into station i originating from arrival flow patient class r
ρ_i	Aggregated utilization rate per server at station i
ρ_{ir}	Utilization rate for patient class r per server at station i
$t_{n-1,1-\alpha/2}$	Student t-value for $(n-1)$ degrees of freedom and confidence level $(1-\alpha)$
$\overline{X}_n$	Average of n simulation replications
S_n^2	Variance of n simulation replications
γ	Relative error
γ'	Corrected relative error

Preface

Around six and a half years ago, I started the bachelor Applied Mathematics, and four years later I continued with the master Industrial Engineering and Management. During my study time, I have developed myself in several areas. With the combination of studies, I was able to develop both my analytical and management skills and I have improved my social skills during my experiences as a teacher in mathematics and as a board member of the student sailing association Euros. With the combination of all skills, I was ready for my last challenge of my master study, my graduation thesis, which is lying in front of you.

Prior to this research, I contacted Vreelandgroep and together we looked for a master assignment. Herre van Kaam introduced me to Christine van Hartingsveldt of VUmc. With a lot of energy and enthusiasm, she told me about the project of redesigning the pre-operative department and the planning issues they were facing. This sounded like the perfect subject for my master thesis since I would be able to use my analytical skills to help people! To make the research even more interesting, the combination between VUmc and Vreelandgroep was made, allowing me to discover more about the organisation of a hospital and the ins and outs of consulting.

At VUmc, I was introduced to the work group of the redesign project by Christine. They warmly welcomed me and taught me a lot about the pre-operative processes. I thank Christine for initializing this research to me and for her motivational support during the formulation of the problem, which was one of my biggest struggles of this research. Unfortunately for me, she found a great job somewhere else, so Suzanne Smit became my new daily supervisor. I also thank Suzanne for her great supervision and especially for all the help with the data collection.

I have experienced the support from Vreelandgroup as very pleasant and useful. Their motivation words in combination with the nice work environment have kept me going. In particular I thank Herre van Kaam, who helped me finding this challenging research and taught me a lot more about the health care sector in general.

From the university, a lot of help was provided by Erwin Hans. I would like to thank him for the critical point of view at the beginning of the research. Together with you motivation words, this increased my confidence in the project and my abilities. Ingrid Vliegen has provided constructive feedback which allowed me to improve my thesis, so thank you!

Last but not least, I thank my friends and family for their support and belief in me. I hope you will enjoy reading my master thesis since a lot of effort and joy is put into it.

May 2016, Bilthoven
Denise van Brenk

Contents

Chapter 1

Introduction

Like many hospitals in the Netherlands, VU University Medical Center organizes the pre-operative screening of patients at an outpatient clinic. Patients for elective surgeries from different specialty departments are redirected to the pre-operative department for the screening, which results in the fact that most of the patients are walk-in patients. Peak hours of walk-in patients during the day increases the waiting times of the patients and the workload of the staff, demanding a redesign of the pre-operative processes. With the use of research techniques, we analyse the pre-operative processes, leading to recommendations for the planning and control design of the processes.

This chapter provides background information about VUmc and the pre-operative processes in Section 1.1 and continues with the scope of the research (Section 1.2), the problem definition (Section 1.3) and the research goal (Section 1.4). The chapter concludes by presenting the research questions in Section 1.5.

1.1 Background

The research was initiated by VU University Medical Center (VUmc) in Amsterdam. VUmc organizes the pre-operative screening of patients for elective surgeries at an outpatient clinic. Within such a screening the health of the patient is checked by an anaesthetist and the patient is informed about the surgery. At the moment patients are not optimally informed about the surgery. First of all, this is undesirable for the patients, but it could also lead to delayed or cancelled surgeries, for example when the patient is not fasting on the day of surgery. In combination with the long waiting times for the walk-in patients at the clinic, this is enough evidence for a redesign of the pre-operative department. This section introduces VUmc and it explains the pre-operative processes with the use of an example.

1.1.1 VUmc

VUmc is one out of eight university medical centers in the Netherlands. In 1964, the hospital opened the doors as an academic hospital, which became VUmc by merging the medical faculty and the hospital in 2001. The core functions of the hospital are distinctive patient care, ground-breaking research and excellence in higher education. In practical this means that despite time for the patient, there is also time made for education. Daily these functions are conducted by 7.200 employees (6.000 FTE) at more than 700 beds. VUmc treats yearly 32.000 emergency patients and almost 30.000 day-care patients (VUumc, 2014a), which makes VUmc a medium-sized hospital.

1.1.2 The pre-operative processes

With an example, we now explain the current pre-operative processes and place them in a broader hospital perspective. Figure 1.1 presents an overview of the possible patient paths through the hospital. Imagine a patient that visits the specialist at an outpatient department in the morning. When it is clear that the patient needs surgery, the patient is sent directly to the pre-operative department, according to the one-stop shop principle of the hospital, which means that a patient visits the departments needed as much as possible on the same day. This patient is what we call a walk-in patient. When there are long waiting times, the patient can decide to make an appointment for the PAC. At the pre-operative department, the health of the patient is checked and the patient will be informed about the surgery. During the screening, the patient is seen by an anaesthetist and some additional tests may be performed, if needed. The screening is valid for half a year, which means that surgery should be performed within this time frame. Before surgery, the patient is hospitalized at the ward, where the nurse performs anamnesis and the patient is visited by a member of the medication team to check the medication list of the patient. Just before surgery, the patient sees an anaesthetist again to check whether the health of the patient is changed.

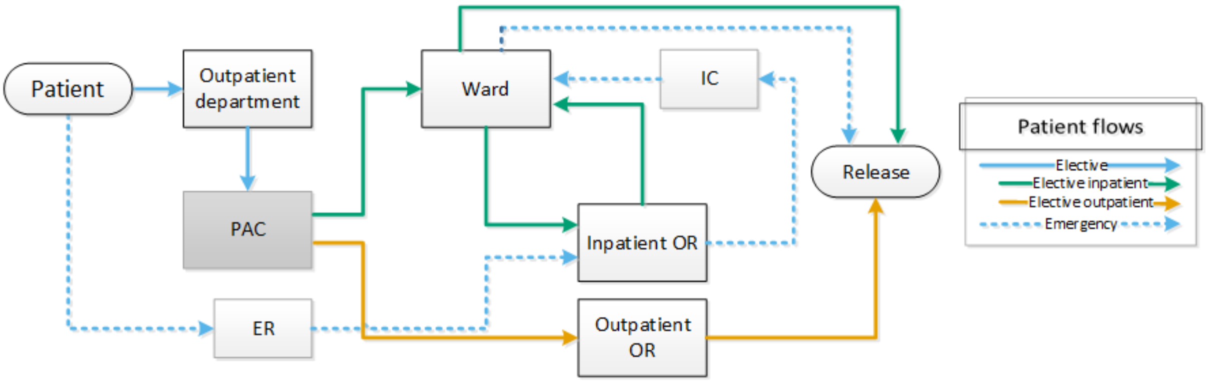


Figure 1.1: Patient flows through the hospital.

1.2 Scope of the research

The scope of the research is limited to the pre-operative department, also called the pre-anaesthetic clinic (PAC), as shown in Figure 1.1. We define the PAC as the processes between the referral from the specialist at an outpatient department until the consent of the pre-operative screening. The day of surgery is not a part of the scope of this project. The focus of the research is on the planning and control of the PAC, including the case mix planning and appointment scheduling, but excludes medical planning, like the content of the questionnaires used at the PAC.

1.3 Problem definition

In 2007, the Inspection of Healthcare (IGZ) published a report describing the findings of the information flows at PACs in Dutch hospitals. Their conclusions were clear. There is a huge opportunity to improve the transfer and provision of information (IGZ, 2007). After the development of guidelines in 2010, a lot has improved. Unfortunately, the provision and transfer of information at VUmc can still be improved, since the pre-operative processes are not performing optimally. We determine three categories of causes, (1) there are flaws in the patient information provision, (2) there is room for improvement in the transfer of information and the communication between the care providers, and (3) there are long waiting times at the PAC for the patients. The causes will be discussed next, but first, the main problem is formulated as:

Deteriorating performance of the pre-operative processes leads to patient dissatisfaction since patients are not well informed and there are long waiting times at the pre-operative department.

(1) Information provision
During a visit at the PAC, the patient is informed about several important topics, like the way of narcosis or the medication of the patient around the surgery. Currently, complaints arise that patients are not informed well enough about the surgery. For the patient this is unpleasant, but it could even lead to surgery delay or cancellation, for instance when the patient is not fasting the day of surgery.

(2) Information transfer and communication between care providers
From the hospital perspective, the activities of the pre-operative screening are divided between different disciplines, like anaesthesiology, nursing and admissions planning. To perform the screening well, it is important that the transfer of information is efficient and that there is a good cooperation between the care providers. At the moment, there are too many opportunities for errors here, like missing medication lists before the surgery or anticoagulation forms which are not filled in. Such errors can be a threat to the safety and quality of the surgeries and increases the workload of the staff since they have to collect the missing information as quickly as possible. The missing information can lead to delay or cancellation of the surgery and unnecessary days of hospitalization for the patient. Because the processes of the pre-operative screening are separated as described before, there is a lot of overlap between the various forms and questionnaires, resulting in more work for the patients to fill in the questionnaires, but also results in inefficient work for the staff.

(3) Waiting times
Currently, enormous peaks in the arrival of walk-in patients result in waiting times. At those moments, the capacity is not able to serve all the demand, and therefore long waiting times arise. Another minor cause for the waiting times are the variabilities in the consult durations. Currently, the appointment system plans every patient in the same type of time slot, the variabilities of patient groups are not taken into account.

1.4 Research goal

To tackle the main problem, a redesign of the pre-operative processes is desirable. For the redesign several processes are brought together at the PAC, this happens in a so-called carrousel, where the patient sees within one appointment, a nurse, a member of the medication team, and an anaesthetist, see Figure 1.2. According to VUmc, one of the difficulties for the carrousel is the scheduling of appointments. We define the main goal of the research as:

To design and to test the redesign of the pre-operative process in a way that the patient satisfaction will increase.

Different settings will be tested with the use of quantitative models, where we obtain more insight in the pre-operative processes. The settings contain, on the strategic level, the definition of the patient flows, the determination of the capacity, and the specification of the case mix. Block scheduling and the allocation of the staff happens on the tactical level. The operational level contains appointment scheduling and workforce planning.

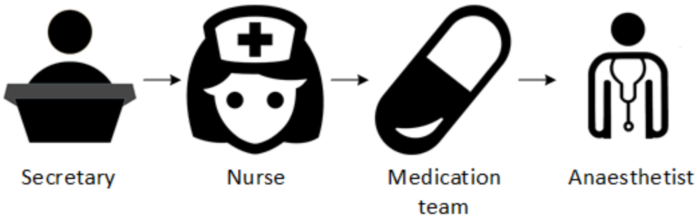


Figure 1.2: Appointments of the carrousel.

1.5 Research questions

The research goal is translated into the following main research questions:

What causes the current waiting times at the pre-operative department? And how can the waiting times be decreased with the use of planning and control rules?

To answer the main questions, five sub-questions are formulated:

1. *What is the current situation for the pre-operative screening, and what is the current performance?*

Describing the current situation and the performance will help us to determine the causes of the waiting times. Chapter 2 pays attention to this first research question, where the current situation will be described by looking into the demand and capacity of the pre-operative department. Information will be gathered from observations, interviews with the staff, and reports and data of the hospital. To be able to measure the performance of the current situation, performance indicators will be defined.

2. *What design and control rules can be developed for planning the carrousel?*

When the current situation is outlined, we review the literature to find suitable design and control rules for the situation of the PAC. This is done in Chapter 3. With the knowledge of the planning and control rules gathered from the literature, we develop designs that might improve the performance of the pre-operative processes.

3. *What quantitative modelling approaches are suitable for the analysis of the PAC?*

After defining the designs for the pre-operative department, we set up two quantitative models to test the designs. The models will be introduced, verified and validated in Chapter 4.

4. *What is the performance of the designs for the pre-operative department?*

In Chapter 5 the designs are tested with the use of the quantitative models. Not only the performance of the designs will be ranked according to the defined performance indicators, but we also explain the impact of the designs on the performance.

5. *How can the developed situation be implemented?*

This last research question focuses on the practical implementation of the developed situations. Together with an analysis of the results, recommendations for the implementation are presented in Chapter 5.

The thesis ends with the conclusion, the recommendations to VUmc and the recommendations for further research. Additional information of the thesis is presented in the appendices.

Chapter 2

Current situation

In this chapter, we describe the current situation and the current performance of the pre-operative department of VUmc. The goal of this chapter is to obtain more insight in the current processes, which will support the problem analysis. We give an extensive description of the process in Section 2.1 and the control of the processes is presented in Section 2.2. In Section 2.3 performance indicators are defined and we outline strategic constraints for the new design in Section 2.4.

For this study, data has been collected in several ways. First of all, data from the registration system of the hospital (Management System Business Intelligence) is used, containing 16,000 consults from the period January 2014 to November 2015. However, this data did not cover all the requested information, so additional data collection was needed. During the first week of September a time registration form is used to collect information on all the patients (N=166) in the current situation, this involves waiting times and consult times. With those gathered data the current situation will be described.

2.1 Process description

The processes of the pre-operative department are described by the patient mix, the arrival process of the patients, the patient routing, the consultation times, and the capacity. In this order, we discuss the process description of the PAC at VUmc.

2.1.1 Patient mix

Figure 2.1 presents the number of patients visiting the PAC per week for the period January 2014 to November 2015. During this period on average 162 patients are visiting the PAC weekly, with 173 patients per week in 2014 and 149 patients per week in 2015. The shift in the health-care from clinical care to outpatient care declares the drop down in the number of patients. In both years, similar seasonal trends are observed, as the drop in the number of patients during the public holidays and during the summer period. This fluctuation in the number of patients makes it harder to match the demand to the supply. Only patients who undergo elective surgeries visit the PAC. In the year 2014, 15,421 surgeries are performed whereof 77.4% elective surgeries (VUumc, 2014b).

At the PAC, patients from different outpatient clinics are screened. To get an idea which patients needs to be screened, the number of patients per speciality are shown in Table 2.1. Departments which have less than 5% of the patients, like gastroenterology or rehabilitation are combined within other specialties.

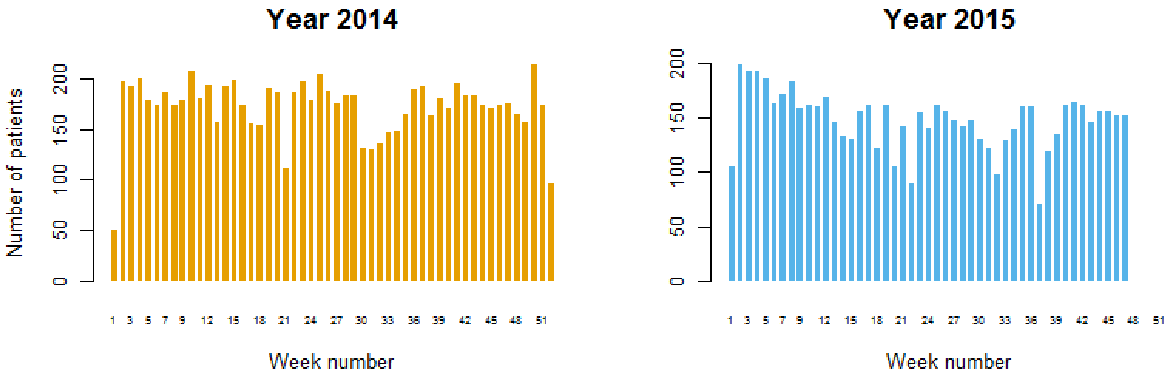


Figure 2.1: The number of patients visiting the PAC per week (Jan.2014-Nov.2015, MSBI).

Table 2.1: Patients per specialty (Jan.2014-May 2015, MSBI).

	Specialty	#	%
1.	General surgery	3,019	24%
2.	ENT	2,191	18%
3.	Gynaecology	1,361	11%
4.	Urology	955	8%
5.	Orthopaedics	853	7%
6.	Plastic surgery	713	6%
7.	Ophthalmology	695	6%
8.	Maxillofacial surgery	652	5%
9.	Neurosurgery	596	5%
10.	Paediatrics	583	5%
11.	Other	734	6%

An interesting factor is the ASA category of the patients since this can affect the consultation time of the patient. At the PAC of VUmc, four ASA categories are used, those are explained in Table 2.2. The division of the patients of the PAC into the ASA categories is presented in Figure 2.2. Severe comorbidities which restrict the patient of normal activities occurs at 15% of the patients. Observe that the ASA category of a patient is currently not known at the secretary desk, nor at the beginning of the screening.

Category	**Definition**
ASA I	A normal healthy patient
ASA II	A patient with mild systemic disease
ASA III	A patient with severe systemic disease
ASA IV	A patient with severe systemic disease that is a constant threat to life

Table 2.2: Definition of ASA categories (ASA, 2015).

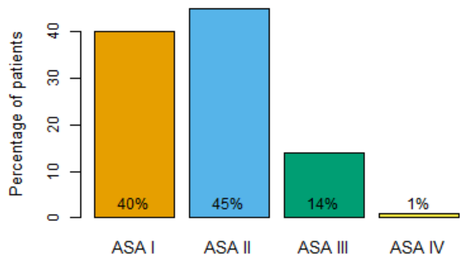


Figure 2.2: Division of patients into the ASA categories (Jan.2014-Nov.2015).

Another interesting characteristic of the patients is their age, which is shown in Figure 2.3 for the first week of September. As we would expect, a lot of patients (30%) is above the age of sixty, but there are also a lot of young patients, almost 35% below the age of 20.

We have also looked at the relationship between the age and the ASA category of the patients. Compared to the division of patients into the ASA categories, we see that less patients of ASA 1 (32%) and more patients of ASA category 3 (28%) visits the PAC in the first week of September. Therefore, we conclude that the data does not give a good representation of the total patient population.

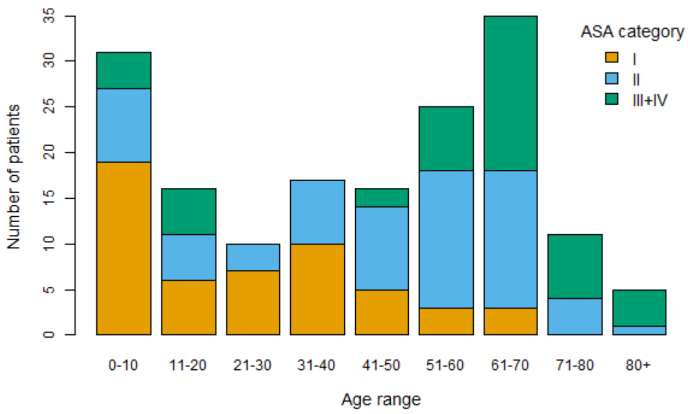


Figure 2.3: Number of patients per age range (N=166, week 36 2015).

2.1.2 Patient arrival

Currently, most of the patients visit the PAC according to the walk-in principle, which creates enormous peaks during the day, resulting in long waiting times at the PAC for the patients and a high workload for the staff. In this section, we analyse the arrival pattern in several steps. First, we look at the day of arrival and the hour of arrival.

The number of patients visiting the PAC fluctuates day by day. Figure 2.4 presents the number of patients per weekday. The average number of patients per day are respectively, 35 patients on Monday, 38 patients on Tuesday, 42 patients on Wednesday, 36 patients on Thursday, and 18 patients on Friday. The reason the number is so low on Fridays is that the PAC is only open in the morning, which is changed during the period, so that explains the outliers. We exclude telephonic consultations. Wednesday is by far the busiest day, which corresponds to the experience of the staff of the PAC.

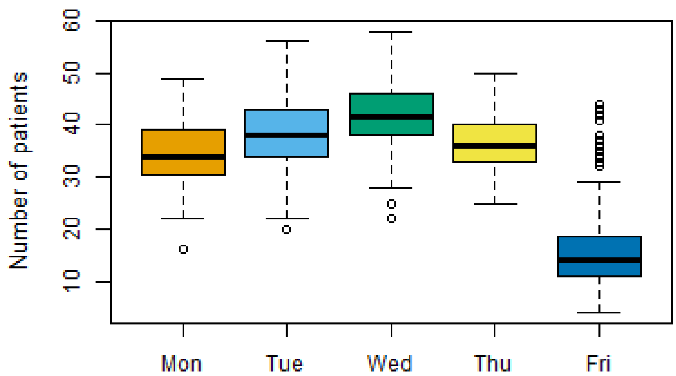


Figure 2.4: Number of patients per weekday (Jan.2014-Nov.2015, MSBI).

Taking a closer look at day level, we find an arrival pattern in the hour of arrival of patients. Most interesting here is the arrival of walk-in patients since this is harder to influence. Figure 2.5 shows the percentage of patients arriving per hour, which makes the distinction between walk-in patients and patients with an appointment. A peak arises in the morning between 10:00 and 12:00 hour and a smaller second peak arise in the afternoon between 14:00 and 15:00 hour. It is interesting to see that at those moments also peaks appear with appointment patients. During peak hours around seven patients arrives on average per hour, where outliers with more than ten patients per hour are not rare and the mean number of arriving patients lies at four patients per hour for the whole day. We conclude that the arrival of the patients highly fluctuates during the day. The results of the hour of arrival are supported by the staff. They experience the same peak hours as shown in the graph.

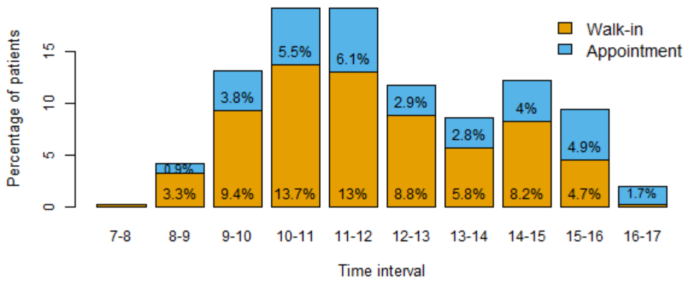


Figure 2.5: Percentage of patients per hour (Jan.2015-Nov.2015, PAC agenda).

2.1.3 Patient routing

A visit at the PAC begins for a patient with reporting at the secretary desk. Here the patients hand over a completed question form. Based on the answers, it could be that the patient needs to undergo some test(s), cardiopulmonary measurements (CPMs), which includes an ECG or a lung test. In that case, the patient is first seen by a nurse who performs the CPM. Sometimes the question form does not give enough evidence to perform the test in advance, but the anaesthetist still wants to see the result of the test. In that case, the patient has to go to the nurse after the consult. When the anaesthetist does not have a complete overview of the health of the patient, then the patient receives no PAC consent. In this case, additional information about the history of the patient is requested or the patient needs to undergo tests, for example, a blood test. The patient does not have to wait for the consent at the PAC, but can leave the hospital. The anaesthetist reads the status of the patient again when the additional information is available. The described three patient paths through the PAC are shown in Figure 2.6. Based on the patient paths of 166 patients during one week of measurements, percentages of the paths are computed. Observe that we assume that the paths needing CPM are mutually exclusive since the patient only undergoes a CPM once.

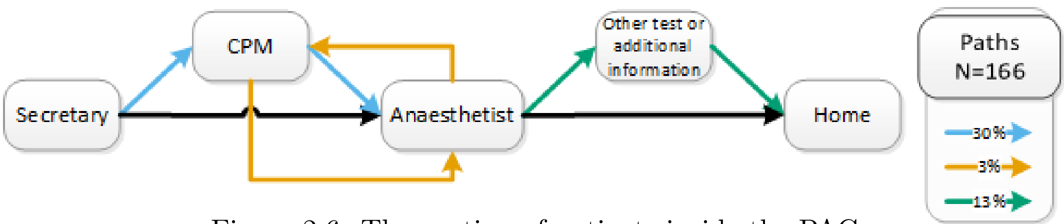


Figure 2.6: The routing of patients inside the PAC.

2.1.4 Consultation times

During the first week of September, the consultation times are measured for all of the patients. Unfortunately, there is only data available from this week. As mentioned before, the data represents not the total patient population, so are there more patients from ASA category 3. In this section, we describe per process the consultation times of the current situation. The waiting times are not included here but presented Section 2.3.

Secretary

The consultation time of the secretary is shown in Figure 2.7. The mean consultation time is 3.6 minutes. Not only PAC patients are reporting at the secretary desk, but we made the assumption that the other patients are not taken into account.

Nurse

The completed question form, which the patient hand in at the secretary desk, can give reason to perform some test(s). Figure 2.8 presents the consultation time of the nurse to perform the CPMs, which take on average 8.5 minutes.

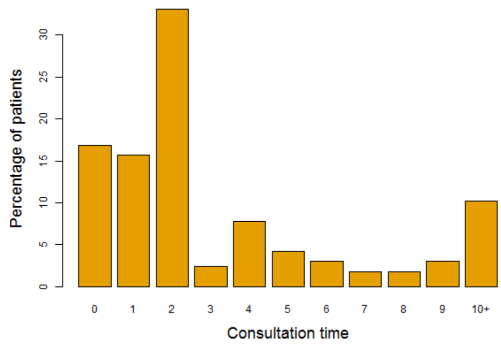


Figure 2.7: Consultation time of the secretary (N=166, week 36 2015).

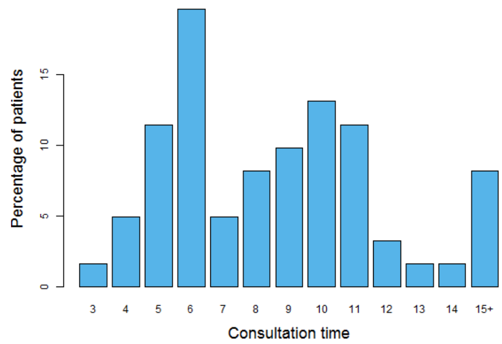


Figure 2.8: Consultation time of the nurse (N=166, week 36 2015).

Anaesthetist

The consultation time of the anaesthetist is shown in two histograms in Figure 2.9. The left histogram presents the time of the anaesthetist with the patient. When we take into account the preparation time to read the patient file and the completion time to finish the patient file, we get the right histogram. On average the components of a consult takes 6 minutes for reading the dossier, 17 minutes for the consult with the patient, and 4.5 minutes for completing the dossier. The average working time for the anaesthetist per patient is 24.4 minutes. Furthermore, we analysed several factors that influence the consultation time, as the ASA category of patients. Unfortunately, there was no significant relation shown between the consultation time and any of the factors.

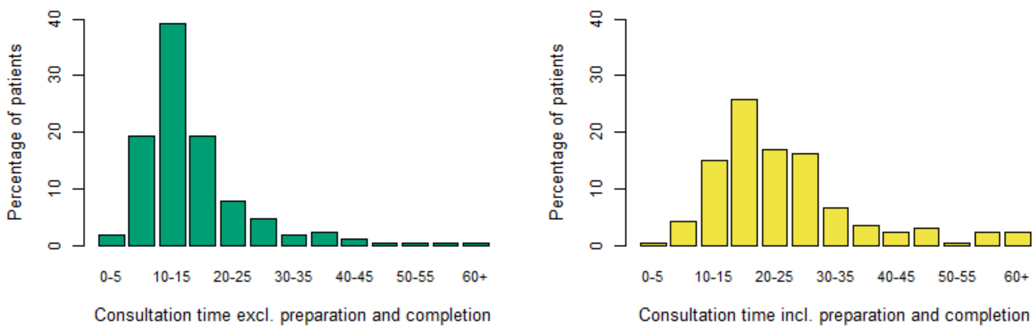


Figure 2.9: Consultation time of the anaesthetist (N=166, week 36 2015).

2.1.5 Capacity

At VUmc, three different kinds of staff members are working at the PAC, namely the secretary, the nurse, and the anaesthetists. The secretary desk is always occupied by one secretary. One nurse performs the CPMs. In the case of absence of the nurse, the task could also be done by someone from the secretary. The medical staff is composed of one anaesthetist and two residents, one junior and one advanced senior resident. A third resident can be called during peak hours and lunch time, so between 11 and 2 o'clock.

The PAC has five examination rooms available, one of them with the medical equipment to perform CPMs, which is used by the nurse.

2.2 Process control

In this section, the opening hours are set and the current appointment system is explained.

For walk-in patients and patients with an appointment are the opening hours of the PAC from 8:00 - 15:45 on Monday to Thursday. On Friday, the PAC is only open for appointment patients from 8:00 - 11:30 and there is a telephone consultation in the afternoon. During lunch breaks, the PAC is still open, but not on full occupation, since the staff pauses alternating.

Currently, one anaesthetist is responsible for the appointments during the whole day. The other two anaesthetists are seeing the walk-in patients. Appointment slots of 30 minutes are used, which result in a schedule consisting a total of 14 time slots per day. The appointment for the patients is planned by the secretary of the PAC. The time slots are not assigned to patient categories and there are no formal planning rules, so the secretary schedules an appointment in agreement with the patient.

2.3 Current performance

The current performance of the PAC can be determined according to three performance indicators, namely the waiting time, the idle time, and the access time. In this section each of the indicators will be defined and measured.

2.3.1 Waiting time

At the moment, there is the complaint that long waiting times occur at the PAC. The waiting time for the patient is defined as the time between the processes of the pre-operative screening, starting after reporting at the secretary desk and ending with the departure of the patient. The waiting time of the patient relates to the utilization rate of the staff. The non-linear relation can be seen in Figure 2.10. From the figure can be seen that patients do not have to wait when the utilisation of the staff is very low, so the staff has a lot of idle time. It is impossible to reach an utilization rate of 100% since this results in extremely long waiting times.

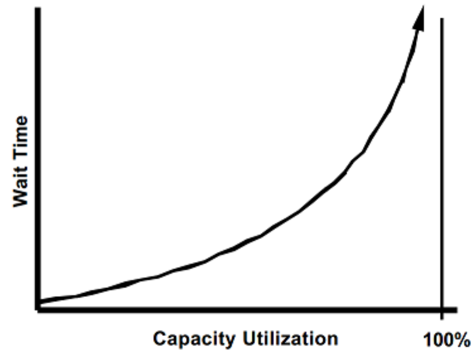


Figure 2.10: The relation between waiting time and utilization (Howell et al., 2001).

Figure 2.11 shows the waiting times for all patients during the first week of September in 2015. During this week, the average waiting time for the patients was 39 minutes. We even see that 25% of the patients has to wait more than 60 minutes. Where a walk-in patient has to wait on average 45 minutes, is the waiting time for a patient with an appointment 16 minutes.

We split up the total waiting time by process, the waiting time for the CPM and the waiting time for the anaesthetist are presented in Figure 2.12. Patients needing a CPM wait on average 17 minutes for the nurse and they wait on average 34 minutes for the anaesthetist. Patients who only need to see an anaesthetist have an average waiting time of 33 minutes. We conclude that the anaesthetist mainly causes the long waiting times.

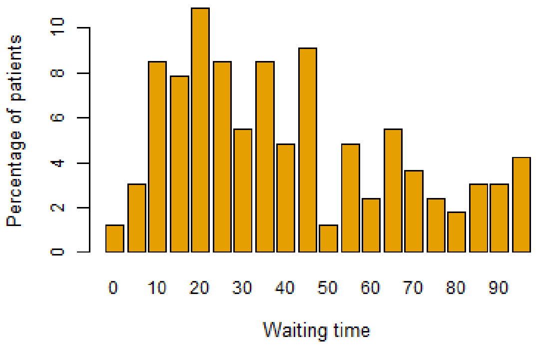


Figure 2.11: Total waiting times for all patients (N=166, week 36 2015).

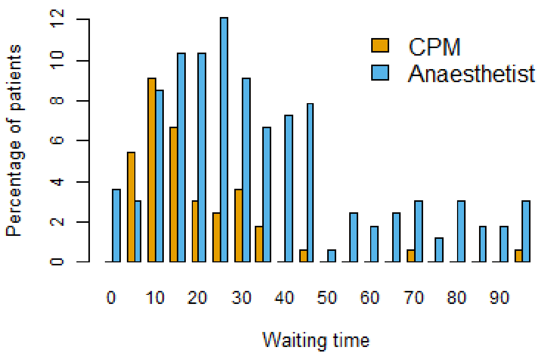


Figure 2.12: Waiting times for CPM and anaesthetist (N=166, week 36 2015).

2.3.2 Idle time

The counterpart of the waiting time for the patient is the idle time for the staff. Unfortunately, the idle time is hard to measure. For that reason, we will look at the utilization rate instead. The utilization of a process is the probability that the staff is busy (Zijm, 2003). The number of patients per hour is used from the registration system of the hospital to approximate the utilization rate. This number is multiplied by the standard consultation time of 30 minutes and divided by the number of staff. Table 2.3 presents the utilization rate per hour, which excludes lunch breaks. During the peak hours from 10 till 12 o'clock, the approximate utilization is above the 100%, which should not be possible in reality, but from practice, we know that long waiting times occur and that the staff has no idle time at those moments. So this approximate utilization rate gives us an indication of the real utilization rate.

2.3.3 Access time

As third performance indicator, we discuss the access time for the patients. We define the access time as the number of days between the moment of scheduling of the appointment and the consult at the PAC. Long access times at the PAC can be a threat to the operation room schedule since the screening has to be consistent before surgery. On the other hand, due to the PAC consent validity of 6 months, some patients are receiving intentional long access times.

The mean access time per day is shown in Figure 2.13. The registration system of the hospital only registers the average access time of all appointments of one day. The average access time is 17 days, including weekends. However, we conclude that the access time is not a cause for concern at the moment, considering the possibility of walk-ins and the fact that there is always room for emergency patients, patients which requesting an appointment the next day or an appointment in the same week.

Hour	Rate
7-8	2%
8-9	25%
9-10	77%
10-11	113%
11-12	113%
12-13	69%
13-14	51%
14-15	72%
15-16	56%
16-17	12%

Table 2.3: Utilization rate per hour (Jan.2015-Nov.2015, MSBI).

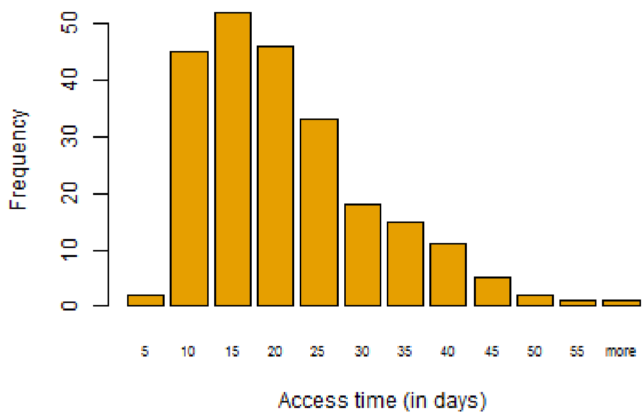


Figure 2.13: Average access time for the PAC (Jan.2015-Dec.2015, MSBI).

2.4 New design

For the new design of the PAC, the management of the hospital made already some strategic decisions, which have impact on the design and control of the processes at the PAC.

As mentioned in Chapter 1, VUmc introduces the carrousel principle, where patients are visiting several pre-operative processes within one appointment. The introduction of the carrousel should lead to better information provision to the patients and a better information transfer between the care providers.

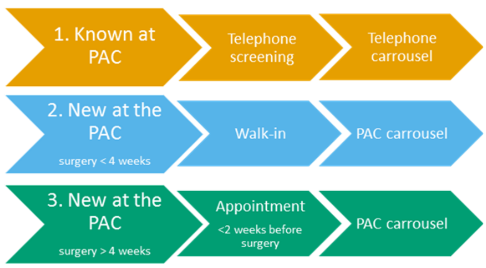


Figure 2.14: Patient flows.

Another strategic decision of VUmc is the introduction of three patient flows. The first patient flow serves patients who are already known at the PAC, which get a telephonic screening. The second patient flow provides the walk-in possibility for patients with their surgery within four weeks. Patients with their surgery planned later than four weeks are receiving an appointment and also patients who do not want to wait, getting an appointment. An overview of all patient flows is shown in Figure 2.14.

2.5 Conclusions current situation

This chapter has discussed the current situation and the performance of the pre-operative department. From the process description, we conclude that fluctuation in the arrival of patients makes it hard to match the demand and supply of the department, which the main cause of the long waiting times for the patients. We have seen that a quarter of the patients waits longer than 60 minutes during their visit at the PAC and the staff is having a high workload, so improvements are required. The current appointment system gives rise to researching approaches to control the processes, as appointment rules. In the next chapter, planning and control rules to reduce the waiting time and workload will be reviewed from the literature.

Chapter 3

Literature review

Having discussed the current situation, this chapter reviews the literature for planning and control rules to improve the current performance. To define the position of the research, we look into a framework for healthcare planning and control in Section 3.1. With the use of appointment scheduling, the pre-operative processes can be controlled the most. This topic is reviewed in Section 3.2. Several model methods can be used to test the different appointment systems. Section 3.3 discusses the advantages and disadvantages of two of the model methods. The final section of this chapter presents the conclusions which can be drawn from the literature review.

3.1 Framework for healthcare planning and control

The specific characteristics of hospital care make research in this area diverse and complex. For that reason, it is important to determine the position of the research first. According to the framework for healthcare planning and control of Hans et al. (2012), the position will be determined. For an example of the application of the framework see Figure 3.1.

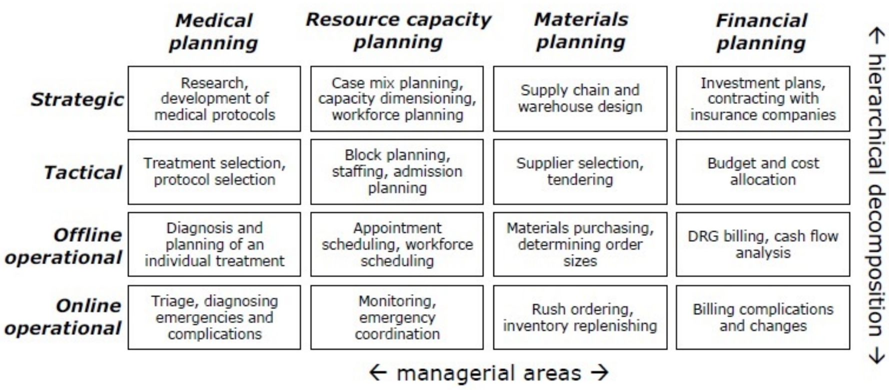


Figure 3.1: Healthcare planning and control framework (Hans et al., 2012).

The horizontal axis of the framework presents the four managerial areas. The medical planning contains the medical decision making which is done by clinicians, for example, the definition of medical protocols. Resource capacity planning is the planning and control of renewable resources such as staff, equipment, and facilities. Materials planning addresses the planning and control of consumable materials. The last managerial area is the financial planning, which focuses on the coordination of the costs and revenues of the organization.

On the vertical axis of the framework, the hierarchical levels are defined. Hans et al. uses the hierarchical decomposition of the manufacturing planning and control, which consists three levels, namely strategic, tactical and operational. At a strategic level, structural decisions are made for the long-term. The decisions consist for example the capacity dimensioning and the patient mix. The tactical decisions are made for the mid-term and involve the organization of the operations, like the allocation of capacity over the specialties. The short-term decisions are taken at the operational level. The decomposition of the online and the offline operational level is made. Offline decisions consist of the planning in advance, so the scheduling of the patients and the staff. Online decisions deal with the demand of reactive decisions making. It involves the monitoring of the processes as well the reaction to unforeseen events, like emergencies. This research will focus on resource capacity planning at all hierarchical levels.

3.2 Appointment scheduling

Long waiting times at the pre-operative department is the main problem of this research. With the use of an appointment system, the processes of the PAC can be controlled. In this section, the scheduling of outpatient clinics in general and scheduling of the carrousel appointments are discussed, followed by a review of the impact of the walk-ins and different routing rules.

3.2.1 Outpatient scheduling

Scheduling can be defined as a decision-making process that deals with the allocation of resources to tasks over given time periods. The goal of scheduling is to optimize one or more objectives (Pinedo, 2012). Here a trade-off needs to be made between a reduction of variability, due to planning, and a reduction of complexity, due to not planning (Hans et al., 2007).

Two main objectives can be defined for the healthcare sector, the waiting time for the patient and the idle time of the doctor. Both are closely connected, since reducing one of them will automatically lead to an increase of the other. Fetter and Thompson (1966) found seven variables which affect the relationship between waiting time and idle time, (1) appointment interval, (2) service time, (3) patients' arrival pattern, (4) number of no-shows, (5) number of walk-ins, (6) physicians arrival pattern, and (7) interruptions in patients' services. Dexter (1999) reports three factors that further exacerbate long patient waits at pre-anaesthesia evaluation clinics. The three factors are the lack of patient punctuality, the provider tardiness, and the patients without appointments. For this research, we will focus on the impacts of the walk-ins.

Outpatient scheduling takes the planning of appointments into account, which requires an appointment system. Vissers (1979) defines different appointment systems within an outpatient setting according to three characteristics, (1) the initial block, this is the number of patients scheduled on the first appointment time, (2) the block size, the number of patients scheduled on the same appointment slot, and (3) the appointment interval, the time between two appointment times. For the appointment system of the carrousel, the most interesting characteristic is the appointment interval.

Edward et al. (2008) propose an appointment system where the reserved consultation time is dependent on the patient ASA physical status. Taking the ASA categories into account, Edward et al. determined how long the consultation time should be. The classification reduces the maximum waiting time of all patients, by reducing the standard deviation of the consultation time. For this research we decided to reduce the complexity of the planning by not introducing a categorisation by ASA score. The motivation for this decision is the lack of data to support the definition of different consultation times by the patient ASA physical status.

3.2.2 Carrousel appointments

The scheduling of the carrousel appointments is more complex than the scheduling of regular appointment since the transfers between the different processes within one appointment needs to take into account as well. The carrousel scheduling problem has a lot in common with the scheduling of job shops, where a job needs to perform several production steps, literature about this subject is reviewed.

According to Pinedo and Chao (1998), the job shop problem can be described as follows. A number of jobs need to be scheduled. Each of the jobs follows a predetermined route, visiting a number of machines where each machine can only process at most one job at a time and a job can be processed by one machine. Usually, the objective is to find a schedule in which the time to process all jobs is minimal. This problem is one of the hardest combinatorial optimization problems (Schutten, 1998).

Comparing the job shop problem with the planning of the carrousel appointements, we see that they have in common that the patients follow a predefined route, visiting all processes. However, within the carrousel, the predefined route is almost the same for all patients. Another difference is that the processing times of the patients are not known in advance. Both differences require another approach of the scheduling problem than the job shop problem. For that matter, the impact of the walk-ins and the routing rules is discussed next.

3.2.3 Walk-ins

The presence of walk-ins affects the relationship between the waiting time and the idle time (Fetter and Thompson, 1966). To be able to reduce the waiting times, more information about the disturbance of the walk-ins is needed. In this section, the strong point and weak spots of the walk-in principle are presented, followed by a review of different approaches to deal with the walk-ins.

In the application of the walk-in principle, Murray and Berwick (2003) analysed six elements which are important, namely (1) balancing supply and demand, (2) reducing backlog, (3) reducing the variety of appointment types, (4) developing contingency plans for unusual circumstances, (5) working to adjust demand profiles, and (6) increasing the availability of bottleneck resources. The concept of walk-in is already introduced in VUmc, so we do not have to cope with all of the elements of Murray and Berwick. The introduction of the carrousel demands for balancing supply and demand again and the bottleneck resources of this new process need to be determined. Both will be discussed during the capacity dimensioning.

Open access scheduling takes walk-in patients into account by holding open an amount of time slots for same-day appointments. The open access schedule ofHerriott (1999) shows one of the advantages of the walk-in principle. The introduction of the schedule resulted in benefits for the satisfaction of the patients and the staff while it also increases the productivity. Another practical example is the open access scheduling of Mallard et al. (2004), where the waiting times of the patients decrease, the number of no-shows decreases, the number of new patients increases, and the productivity of the provider increases.

One of the main disadvantages of the walk-in principle is caused by the variability of the demand. The variability causes varieties in the waiting times of the patient and the utilization of the staff. To tackle this disadvantage, Rising et al. (1973) presents a case study where an analysis of the daily arrival pattern was used to schedule more appointments during the periods of low walk-in rates. In this way, the overall daily arrivals were smoothed. The implementation of the new system results in an improved efficiency, the number of patients seen increased, where fewer physician hours were scheduled.

Kortbeek et al. (2014) look at the appointment system as two distinct queuing systems, the 'access process' and the 'day process'. The access process concerns patients making an appointment and waiting until the day of the appointment. The day process includes the process of a service session during a particular day. Two models for the two processes are presented, including an interactive algorithm to connect the models. This approach consists a high level of flexibility since both models can be updated separately.

In this research, the approaches of Rising et al. and Kortbeek et al. will be combined. A model will be designed to construct an appointment schedule based on the waiting times during a time slot, which means that the appointments are scheduled on the time slots with the lowest waiting times.

3.2.4 Routing rules

From the production industry, it has been shown that the order in which jobs are prioritized in the queue have an impact on the throughput time of a job. A routing rule, priority rule or job sequencing, defines the order of the jobs in the queue. Well known routing rules based on the order of the job arriving in the queue are First Come First Served (FCFS) and Last In First Out (LIFO). Jobs can also be prioritized by their attributes, like Earliest Due Date (EDD) or Shortest Processing Time (SPT) (Haupt, 1989). The four rules are some examples of the long lists of routing rule in the production industry.

Unfortunately, not all priority rules can be implemented in the healthcare sector. For example, the processing time of a patient is not known. According to Cayirli and Veral (2003), there are many studies which serve patients on a First Come, First Served basis. Given punctual patients, this queue discipline is identical to serving patients in the order of their appointment time. Cayirli and Veral state that when the department is dealing with walk-ins, there is a need to set a priority rule to determine the order in which those patients will be seen. In general, the first priority is given to the scheduled patients and the lowest priority to the walk-ins which are seen on an FCFS basis. For justice perception, it is essential to use the FCFS policy (Mandelbaum et al., 2012). In practice, it is more fair to use a policy of calling patients in the order of appointments, while trying to fit in walk-ins and late patients as early as possible.

At the moment, there are long waiting times between the processes of the PAC. Within the carrousel, there are even more transfers between the processes. Therefore, the impact of the routing rules on the waiting time will be researched in this thesis.

3.3 Model approaches

This section discusses two mathematical models to study the system of the PAC, beginning with a discrete-event simulation. According to Law (2007) the discrete-event simulation concerns the modelling of a system as it evolves over time by a representation in which the state variables change instantaneously at separate points in time.

A simulation study is a common approach within the healthcare sector since simulation is often used for systems which are highly complex. With simulation, it can be seen how the inputs in question affect the performance of the output Law (2007). Jun et al. (1999) surveys the application of discrete-event simulation modelling of healthcare departments and systems of clinics. The conclusion is drawn that simulation is a good method to tackle problems related to multiple performance measures of health care systems, as the idle time and the waiting time. Therefore, a simulation model is a great tool to test new scenarios and to assist the planning and management of the department (Harper and Gamlin, 2003).

One main disadvantage of simulation is that it requires a lot of detailed information, which is not always available. With an analytical queuing model, this is not the case. According to Green (2006) queuing theory is a powerful and practical tool since it requires relatively little data and is simple and fast to use. That for the pre-operative department a queuing model can be used is proved by Zonderland et al. (2009). Zonderland et al. state that a queuing model is more appropriate than simulation since you can get lost in the details and lose sight of the real problem within a simulation study. The queuing model is used for comparison purposes and not to make a prediction of the actual length of stay of a patient. In our research, a queuing model will be used to define the capacity needed for the carrousel and more detailed scenarios are tested with the use of a simulation model.

3.4 Conclusions literature review

In this chapter, the position of the research is defined, namely the resource capacity planning on all hierarchical levels. The PAC of VUmc is facing long waiting times at the moment, which demands planning and control rules. The literature has emphasized the impact of the walk-ins on the waiting times of the patients. Walk-ins causes variability of the demand and can be controlled with the use of an appointment schedule. The waiting times between the processes can be decreased with the use of routing rules, which controls the prioritizing of patients between the processes.

For this research, two modelling methods will be used. With the use of a queuing model, the capacity of the clinic will be defined given a set of service levels. A more detailed model is needed to predict the actual length of stay of patients, here a simulation study is used. With the simulation model, different settings for the appointment system and routing between processes will be analysed.

Chapter 4

Solution approach

This part of the thesis presents two models, a queuing model and a simulation model. Figure 4.1 shows the steps of a simulation study according to Law (2007). This chapter discusses the first six steps of the procedure, and most steps are also applicable for the queuing model. The chapter begins with the formulation of three design factors in Section 4.1. Section 4.2 discusses the collected data as input for both models, followed by the presentation of the queuing model (Section 4.3) and the simulation model (Section 4.4), which explains the conceptual model and the computer program. The chapter concludes with the verification and validation of both models in Section 4.5.

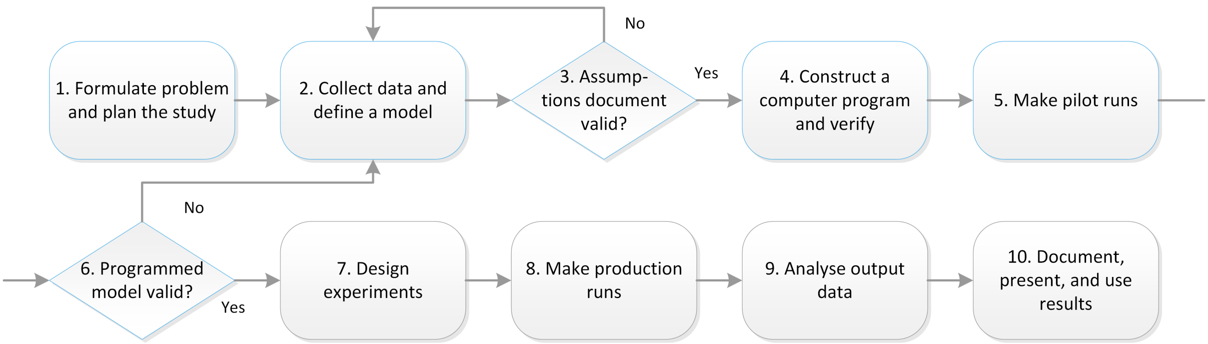


Figure 4.1: Steps in a simulation study (Law, 2007).

4.1 PAC design factors

From the analysis of the current situation, we conclude that the PAC of VUmc is facing long waiting times and that there is a need for appointment rules. With the use of the literature study, we have found three design steps useful for this study, as explained in Section 4.1.1 to 4.1.3.

4.1.1 Capacity dimensioning

The first design step is on strategic level, where the introduction of the carrousel requires a capacity dimensioning. In the carrousel, four stations of care providers are visited by the patients. For each of the four stations, we have to define the capacity. The capacity dimensioning requires information about the number of patients visiting the PAC and the consultation times of each station. By means of a queuing model, an estimation of the required capacity is made based on a constant arrival rate and a predefined set of service levels, like the utilization rate of the staff and the maximum waiting time for the patients. A simulation model is used to define the capacity dimensioning by weekday on a more detailed level.

4.1.2 Appointment scheduling

As explained earlier, VUmc provides the option of walk-in to serve urgent patients and the option of an appointment for the patient with an elective surgery after four weeks. For the second design step, we are looking for a way to control both patient arrivals as good as possible. For this, an appointment schedule will be introduced. From a given blueprint containing all time slots of the week, the appointment schedule defines the time slots dedicated for appointments. We design a heuristic within the simulation model to construct the appointment schedule.

4.1.3 Routing rules

The third design step focuses on the routing rules, which defines the order of the patients in the waiting rooms between the processes of the carrousel. Cayirli and Veral (2003) stated that the combination of walk-ins and appointment patients is requesting a priority rule. At the PAC, attributes to prioritize are the waiting time, the appointment time and the estimated processing time based on the patient path. We formulate five routing rules and test them with a simulation model. The routing rules are defined as:

1. **First Come, First Served (FCFS):** Patients are served according to the order that they arrive at a station. No distinction is made between the walk-ins and the patients with an appointment.
2. **Longest Waiting Time First (LWTF):** With this policy, patients with the longest total waiting time are served first.
3. **Earliest Appointment Time (EAT):** Serves patients based on their appointment time given by the secretary. The walk-ins get an appointment as well, namely the first available time slot.
4. **Arrival on Earliest Appointment Time (AEAT):** Only at the first station the patients are prioritized by their appointment time. For the other stations, it holds that the patients will be served according to FCFS.
5. **Shortest Estimated Processing Time (SEPT):** Serves patients based on the shortest estimated service time determined by the patient path. This rule holds only for the nurse, where three patient paths with different consultation times need to be served. The other stations are prioritized according to FCFS.

4.2 Model input

This section presents the input data for the queuing model and the simulation model. Both of the models require information about the patient arrival and the consultation times. The assumption is made that the distribution of the patient paths and the probability distributions of the consultation times are the same for both models. For the simulation model, the arrival of patients is described in more detail, while the queuing model deals with a constant arrival rate. This section discusses the patient paths, the patient arrival and the consultation times per process.

During this research, a pilot study of the carrousel is started for three patient specializations, namely general surgery, urology, and orthopaedics. The pilot started in December 2015 and has a minimum duration of 6 months. From the beginning of the pilot, a time registration project collects information about the processes of the carrousel with the use of time registration forms (Appendix F). On the form, the staff registers the start time and the end time of the consults per patient. For this research, we have collected and analysed a total of 327 forms. Data of the months January and February 2016 is used to motivate the model input containing 145 patients with 112 completed forms. As well data from the registration system of the year 2015.

4.2.1 Patient paths

Figure 4.2 presents the three patient paths through the pre-operative department. The paths depend on whether a patient needs a test (CPM) or not, where the nurse anamnesis and the CPM can be performed by the same nurse. To represent the PAC in a model, the ratios per patient path needs to be known. In the current situation, the nurse has to perform a CPM by 33% of the patients, while this number is 67% during the pilot. An explanation for this big difference is that the patient population of the pilot gives no good representation of the total patient population. Together with the implementation of new guidelines for performing CPMs, the expectation is that the total number of CPMs decreases when implementing the carrousel and that the guideline leads to an increase in the number of requested additional CPMs (P3). Table 4.1 shows the ratios per patient path.

Table 4.1: Patient paths through the PAC.

Path	**Ratio**	**Description**
P1	0.70	Patients not needing a CPM.
P2	0.25	Patients requiring a CPM following on the nurse anamnesis.
P3	0.05	Patients which require an additional CPM on advise of the anaesthetist.

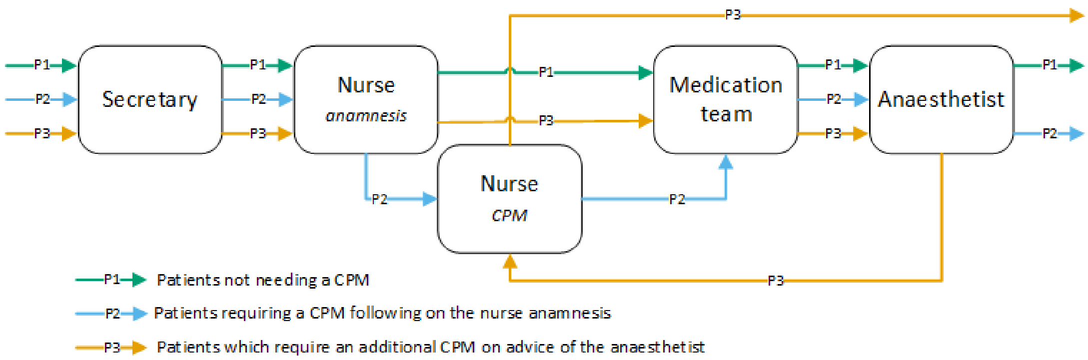


Figure 4.2: The three patient paths through the pre-operative processes.

4.2.2 Patient arrival

The queuing model uses a constant arrival rate, with the assumption that for the arrival of patients no distinction is made between walk-ins and patients with an appointment and that the arrival of the patients is Poisson distributed. The total arrival rate per hour is based on the average number of patients per week and the working hours per week. In the year 2015, on average 150 patients visited the PAC, which corresponds to 4.725 patient per hour. In reality, the patients are not equally divided over the hours during the day. For example, fewer patients arrive between 8 and 9 o'clock than between 11 and 12 o'clock. To take this into account, a ratio of 80% is used, which results in a constant arrival rate of 5.91 patients per hour.

The patient arrival of the patient paths is independent, so the characteristics of the Poisson distribution allows us to divide the arrival rate by the patient path ratios, which is also Poisson distributed. The patient arrivals per hour can be found in Table 4.2.

Table 4.2: Patient arrival per patient path.

Patient path	**Arrival rate**
P1	4.13
P2	1.48
P3	0.30
Total	5.91

For the simulation model, the patient arrival needs to be described in more detail, so we can build a more realistic model. First, the number of patients visiting the PAC per week needs to be defined. The number of patients visiting the PAC per week is normally distributed with mean 149.45 and a sigma of 26.24. Appendix A presents the fitting of the distribution. The scope of this research focuses on the walk-in patient flow and the appointment patient flow, which have a division of respectively 40% and 60%. The numbers are based on matching the pre-operative screening dates and the surgery dates of patients from the registration system. However at this way, access time are neglected. In consideration with a delegation of the PAC staff, the division of the patient flows is set.

The arrival of appointment patients dependents on the time of the appointment and the lateness factor of the patient. Data from the appointment patients of the current situation and the carrousel is used as a guideline for the lateness factor, but there was not enough data available to define the probability distribution of the lateness correctly. For this research, we assume that the lateness of appointment patients is normally distributed with parameters μ=−780 seconds and σ=900.

The arrival of the walk-in patients depends on the hour of the weekday. In the current situation, every patient has the choice to use the walk-in possibility. However, within the carrousel patients having their surgery within four weeks are defined as walk-in patients. We made the assumption that they arrive according to the same arrival pattern. Seen walk-in patients are only allowed from Monday to Thursday, presents Figure 4.3 the walk-in patterns per hour for those four days.

4.2.3 Consultation times

During the pilot period of the carrousel, the time registration project has provided more insight in the consultation duration of all processes. Per process the consultation time is analysed and a probability distribution is fit. However, the patients from the pilot are not a good representation of the total patient population, so some adjustments are made.

Inspecting the data of the secretary, it results that some of the consultation times of the secretary desk were zero, which is not desirable since the secretary needs to perform some tasks for each patient. We have taken a minimum of 30 seconds for the consultation time of the secretary.

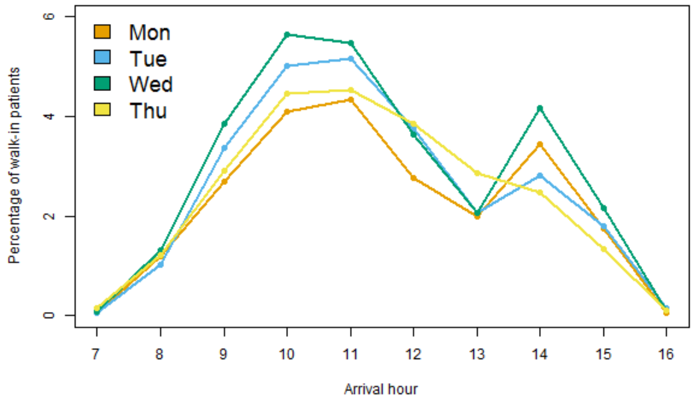


Figure 4.3: Distribution of arrival of the walk-in patients (Jan.2015 - Nov.2015, MSBI).

The consultation time of the anaesthetist requested an adjustment. During the pilot period, the consultation times are longer than the consultation times of the current situation, because of the patient group is not a good representation of the total patient population. The decision is made, to use the combined data from the pilot and the data of the current situation to fit the probability distribution of the anaesthetist.

Table 4.3 presents the probability distributions for all processes. To test the significance of the distribution fits, a goodness-of-fit test is used. Therefore, the Kolmogorov-Smirnov test was chosen, with the significance of a 95% confidence interval. When the number of the goodness-of-fit test is below the critical value, the distribution fitting is not rejected. Details of the distribution fitting can be found in Appendix A. Unfortunately, the distribution for the secretary, the nurse for patient path 3, and the anaesthetist is rejected. To get a good distribution fitting for the secretary, an accurate time registration is needed. The measurement of the consultation time in minutes is not accurate enough here. For nurse path 3, also more accurate time registration is required, now it is often rounded to 5 minutes. For the anaesthetist, it holds that more information of the total patient population is necessary. In this research, we assume that the probability distribution represents the reality since no better probability fit can be found with the current data set.

Table 4.3: Probability distribution of the consultation times.

Process	**N**	**Distribution**	**Par.1**	**Par.2**	**Mean**	**SCV**	**Rejected**?
Secretary	143	Gamma	1.03	2.65	2.73	0.97	Yes
Nurse P1	144	Gamma	5.22	4.26	22.25	0.19	No
Nurse P2	91	Gamma	6.47	4.34	28.07	0.15	No
Nurse P3	91	Gamma	7.74	0.74	5.71	0.13	Yes
Medication team	136	Lognormal	2.13	0.74	11.01	0.08	No
Anaesthetist	268	Lognormal	2.77	0.55	18.56	0.03	Yes

4.3 Queuing model

With a queuing model, we evaluate the performance of the PAC as a system with a constant arrival rate. In this thesis, the model determines the capacity, given a set of service levels. In queuing theory, the system of the PAC can be defined as a multi-class Open Queuing Network (OQN). With this model, more insight can be obtained in the patient waiting, the patient length of stay, the number of patients at the PAC, and the utilization rate of the staff. For the performance measurements, only accurate approximations are known.

In this research, we want to analyse the PAC with different patient classes, but the OQN is only able to compute one single patient class. To tackle this problem, the complete reduction method from the lecture notes of Zijm (2003) will be used. The method consists of three steps:

1. Aggregation of the R classes to reduce the given R class OQN to a single class OQN.
2. Analysis of the single class OQN.
3. Disaggregation of the single class OQN to obtain the performance measures per class for the given R classes.

We define the patient classes (r) according to the three patient paths from Figure 4.2 and the stations (i) by the four processes.

r=1	Class P1	i=1	Secretary
r=2	Class P2	i=2	Nurse
r=3	Class P3	i=3	Medication team
		i=4	Anaesthetist

For station i, the number of servers (available staff) is represented by c_i. To perform the complete reduction method, the characteristics of the arrival distribution and consultation time distributions have to be known. Those are presented with the following parameter:

λ_{ir}	Arrival rate of patient class r at station i
C^2_{a1r}	Squared Coefficient of Variation of the arrival of patient class r at station 1
ES_{ir}	Mean average service time of patient class r at station i
C^2_{sir}	Squared Coefficient of Variation of the service time of patient class r at station i

Step 1: From multi-class to single class OQN
To reduce the multi-class network to the single class network, we have to compute the aggregated utilization rate per server and the aggregated arrival rate per station. The aggregated utilization rate of a station can be defined by the sum of the utilization rates per patients class (4.1). The utilization rate per patient class depends on the number of arrivals and the expected service time (4.2). For the utilization rate, it holds that ρ_i and ρ_{ir} should be < 1. The staff cannot be utilized more than 100%.

$$\rho_i = \sum_{r=1}^{3} \rho_{ir} \quad \text{for i=[1..4]} \tag{4.1}$$

where

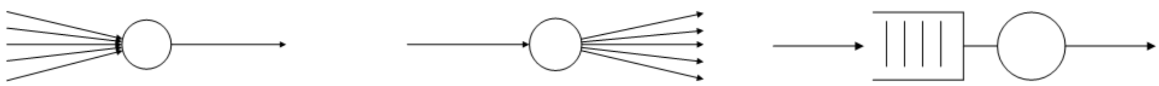
$$\rho_{ir} = \frac{\lambda_{ir} ES_{ir}}{c_i} \quad \text{for i=[1..4] and r=[1..3]} \tag{4.2}$$

To find the aggregated arrival rates per station, the arrival rates of the patient class are added.

$$\lambda_i = \sum_{r=1}^{3} \lambda_{ir} \quad \text{for i=[1..4]} \tag{4.3}$$

With equation (4.1), (4.2), and (4.3) we have reduced the multi-class network to a single class OQN, which now can be analysed.

Step 2: Analysis of the single class OQN
To obtain the performance measurements of the system, like the waiting times, we have to analyse the queuing network. Per station the arrival distribution and the distribution of the service times needs to be known. In a queuing model we assume that the stations are in equilibrium, this means that the number of patients arriving a station is the same amount patients who leave the station. The arrival of patients at a server is described by the arrival rate and the squared coefficient of variation (SCV) of the arrival process per station. The distribution of the service times is described by the mean of the consultation times and the SCV of the consultation times. To analyse the arrival of the processes, three basic network operations can be applied (Whitt, 1983), see Figure 4.4. With the use of so-called traffic variability equations, we obtain the arrival SCV for each station based on external and internal arrivals. How to do this, we will explain station by station.



(a) (b) (c)

Figure 4.4: Basic network operations: (a) Merging, (b) Splitting, (c) Departure.

For the arrival process of station 1, the secretary, we have to combine the arrival of the three patient classes. This is done with the following set of merging equations, where C^2_{a1} is the SCV of the arrival at station 1 and Q_{1r} is the arrival flow into station 1 of patient class r.

$$C^2_{a1} = w_1 \sum_{r=1}^{3} Q_{1r} C^2_{1r} + 1 - w_1 \tag{4.4}$$

where

$$w_1 = [1 + 4(1-\rho_1)^2(v_1 - 1)]^{-1} \tag{4.5}$$

$$v_1 = [\sum_{r=1}^{3} Q^2_{1r}]^{-1} \tag{4.6}$$

$$Q_{1r} = \frac{\lambda_{1r}}{\lambda_1} \quad \text{for r=[1..3]} \tag{4.7}$$

Next we compute the mean consultation time of station 1 and the corresponding SCV with

$$ES_1 = \frac{1}{\lambda_1} \sum_{r=1}^{3} \lambda_{1r} ES_{1r} \tag{4.8}$$

$$C^2_{s1} = \frac{1}{\lambda_1 ES^2_1} \sum_{r=1}^{3} \lambda_{1r}(ES_{1r})^2(C^2_{s1r} + 1) - 1 \tag{4.9}$$

The SCV of the departure at station 1 can now be computed by

$$C^2_{d1} = 1 + (1-\rho^2_1)(C^2_{a1} - 1) + \frac{\rho^2_1}{\sqrt{c_1}}[max(0.2, C^2_{s1}) - 1] \tag{4.10}$$

Next we compute the arrival SCV of the patients at station 2, the nurse. Two patients flows are merged, namely the flow from station 1 to station 2 (λ_{2_1}) and from station 4 to station 2 (λ_{2_4}), therefore we use the merging equations again. For λ_{2_1} it holds that the SCV of the arrival is equal to the SCV of the departure at station 1, so $C^2_{a2_1} = C^2_{d1}$. A splitting equation is used for λ_{2_4}, where P_{42} is the fraction of patients at station 4 flowing to station 2.

$$C^2_{a2_4} = P_{42}C^2_{d4} + 1 - P_{42} \tag{4.11}$$

Since at the moment the departure SCV of station 4 is not known, we assume $C^2_{d4} = 1$. When the model is defined completely, the value of C^2_{d4} is found iteratively. The merging equations for station 2 are

$$C^2_{a2} = w_2(Q_{2_1}C^2_{2_1} + Q_{2_4}C^2_{2_4}) + 1 - w_2 \tag{4.12}$$

where

$$w_2 = [1 + 4(1-\rho_2)^2(v_2 - 1)]^{-1} \tag{4.13}$$

$$v_2 = [Q^2_{2_1}Q^2_{2_4}]^{-1} \tag{4.14}$$

$$Q_{2_1} = \frac{\lambda_{2_1}}{\lambda_2} \tag{4.15}$$

$$Q_{2_4} = \frac{\lambda_{2_4}}{\lambda_2} \tag{4.16}$$

The mean consultation time, the corresponding SCV, and the departure SCV of station 2 can be computed with equations (4.8), (4.9), and (4.10).

For station 3, the medication team, a splitting equation is needed to compute the arrival SCV, so

$$C^2_{a3} = C^2_{23} = P_{23}C^2_{d2} + 1 - P_{32} \tag{4.17}$$

For the consultation time, the SCV of the consultation time and the departure SCV we use the same set equations as for station 1 and 2.

At the last station, the anaesthetist, there holds that $C^2_{a4} = C^2_{d3}$. Given this, we can directly use the same set of equations as for the previous stations. Now we have collected all the information needed to compute the performance measurements.

Step 3: Disaggregation to obtain performance measurement per patient class
In step 3, we disaggregate to obtain the performance measurements per patient class. With the mean consultation time and the corresponding SCV, the waiting time in the queue for every station is computed. Station 1 can be seen as a G/G/1 queue and therefore the waiting time is

$$EW_{Q1} = \frac{C^2_{a1} + C^2_{s1}}{2} EW_{Q1}(M/M/1) \tag{4.18}$$

with

$$EW_{Q1}(M/M/1) = \frac{\rho_1}{1-\rho_1} ES_1 \tag{4.19}$$

For the other stations, it holds that they can be seen as a G/G/c queue. To compute the average waiting time in the queue, the following set of equations is used

$$EW_{Qi} = \frac{C_{ai}^2 + C_{si}^2}{2} EW_{Qi}(M/M/c) \quad \text{for i=[2..4]} \tag{4.20}$$

with

$$EW_{Qi}(M/M/c) = \frac{(c_i\rho_i)^2}{c_i! G_i} \frac{1}{(1-\rho_i)^2} \frac{ES_i}{c_i} \quad \text{for i=[2..4]} \tag{4.21}$$

where

$$G_i = \sum_{n=0}^{c_i-1} \frac{(c_i\rho_i)^n}{n!} + \frac{(c_i\rho_i)_i^c}{(1-\rho_i)c_i!} \quad \text{for i=[2..4]} \tag{4.22}$$

Now we can compute the expected time in the system for the patients of class r, taking into account that P3 visits the nurse station twice.

$$EW_r = \sum_{i=1}^{4} EW_{Qi} + ES_{ir} \quad \text{for r=1,2} \tag{4.23}$$

$$EW_3 = \sum_{i=1}^{4} EW_{Qi} + ES_{i3} + EW_{Q2} + ES_{23'} \tag{4.24}$$

With the use of the formula of Little, the number of patients in the queue for all stations can be computed, followed by the computation of the number of patients within each station.

$$EL_{Qi} = \lambda_i EW_{Qi} \tag{4.25}$$

$$EL_i = EL_{Qi} + \lambda_i ES_i \tag{4.26}$$

For the number of patients in the whole system, the number of patients per station can be summed

$$EL = \sum_{i=1}^{4} EL_i \tag{4.27}$$

With equations (4.18) - (4.27), the performance of the PAC is described. The queuing model can be used to estimate the capacity by keeping the performance measurements below the given set of service levels.

4.4 Simulation model

The literature study shows that a simulation study is a useful tool to discover how the inputs are affecting the performance of the output. The queuing model makes it possible to evaluation the performance with a constant arrival rate. However, the arrival rate of the PAC fluctuates, with the simulation model the arrival can be described in more detail. A discrete-event simulation model will be used to research combined arrival of walk-in and appointment patients. With the simulation model, the impact of the routing rules between the processes on the performance can be analysed.

This section introduces the simulation model. First, the model description and the model assumptions define the conceptual model. Next, the simulation model which represents the PAC is described, followed by the explanation of the heuristic which will be used to construct the appointment schedule.

4.4.1 Model description

Given the model input from Section 4.2, we define the level of detail for the simulation model. Figure 4.5 presents the flowchart which describes the simulation processes. In the flowchart the time is standing still and are the begin events are triggered by the arrival or departure of a patient. The left flowchart presents the arrival process, which are activated by a new patient arriving at the PAC or an arrival of a patient at the queue of a station. The right flowchart presents the departure process, which is triggered by the departure of a patient from a process. The step 'choose patient from queue', uses the current routing rule to find the first patient in the queue, see Appendix B for the corresponding flowchart.

4.4.2 Model assumptions

To model the complex reality, we have to make several assumptions. The model assumptions are divided into three categories, general assumptions, arrival assumptions, and process assumptions.

General assumptions

- A week consists five days, weekends are not modelled.
- Public holidays are not included.
- Lunch breaks of the staff are excluded.
- Opening hours of the PAC are taken into account. After closing time, walk-in patients are sent away with an appointment.

Arrival assumptions

- The telephone appointments are not taken into account. Those take place on Friday afternoon and are beyond the scope of the research. From the three patient flows, only the walk-in patients and the patients with an appointment are modelled.
- At the beginning of a week, all the appointments for the week are scheduled.
- The ratio walk-ins and appointments over a week is the same for all weeks. Since the total number of patients differs week by week, the number of walk-ins and appointments differs too.
- The ratio walk-in patients per weekday is the same for all weeks.
- No-shows of appointment patients are not taken into account.
- All appointment patients are treated, no matter their arrival time. Walk-in patients can be sent away, but only at the end of the day and with an appointment.

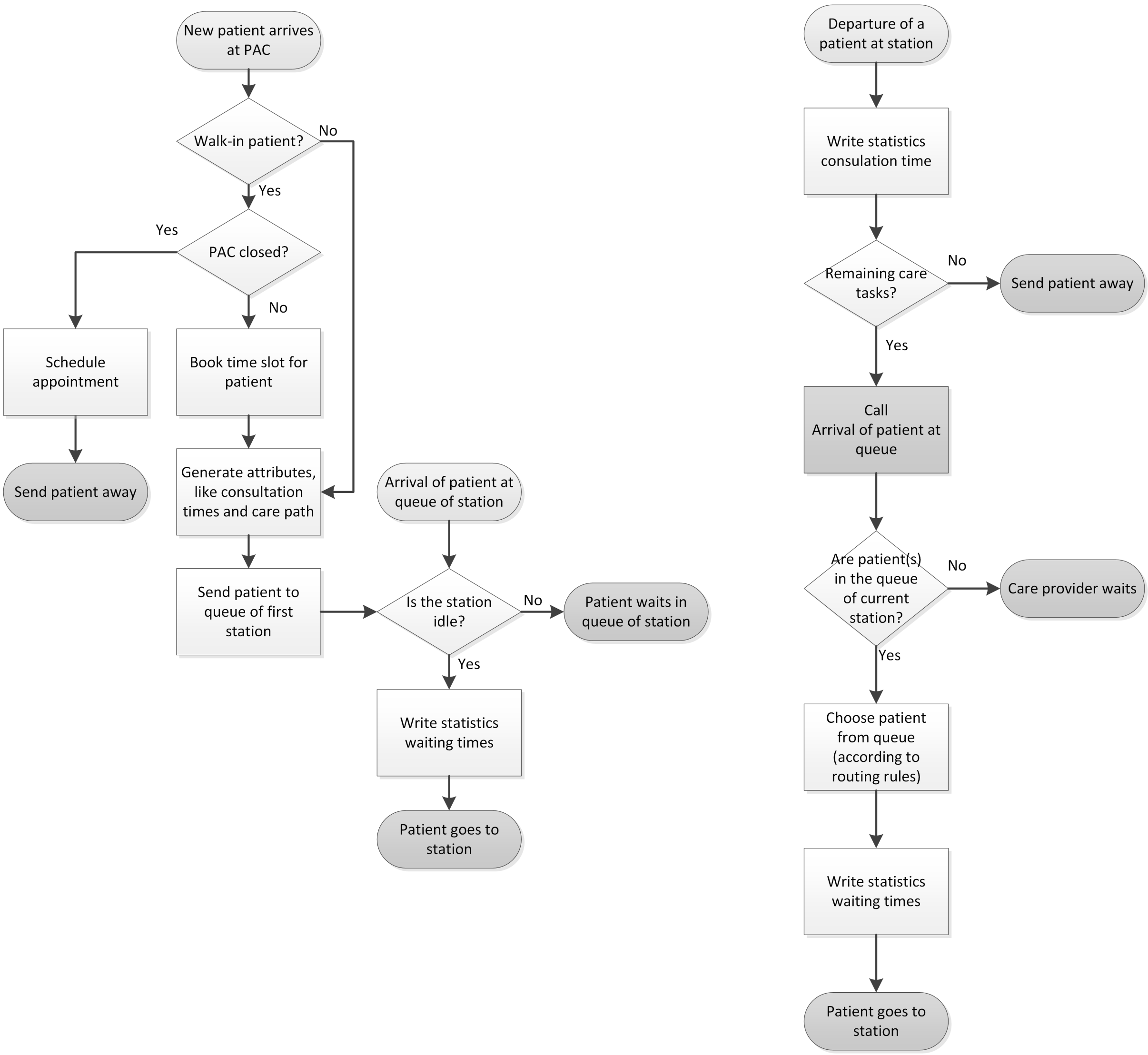


Figure 4.5: Flowchart for simulating the processes of the patient of the PAC.

Process assumptions

- All waiting rooms have infinite capacity. The waiting room of the PAC is big enough to handle the current number of patients waiting. We assume that this will also be the case implementing the carrousel.
- Travel distance and travel times between the waiting room and the processes are neglected.
- The secretary desk is dedicated to the PAC patients.
- Walk-in patients have the same probability distribution at the secretary desk as appointment patients.
- A patient is handled by one care provider at the time and a care provider handles one patient at the time.
- Reviewing patient records is not taken into account. At the moment, reading the patient record takes times, especially for the anaesthetist, which have to gather information from several information systems. The introduction of the electronic patient records will lead to faster reviewing of the records.
- All employees of the same process have the same consultation distribution. Faster working employees are not taken into account and employees do not speed up their work in case of longer queues.

4.4.3 Introduction of the model

The simulation model consists of five main components (see Figure 4.6). We will briefly explain all of the components.

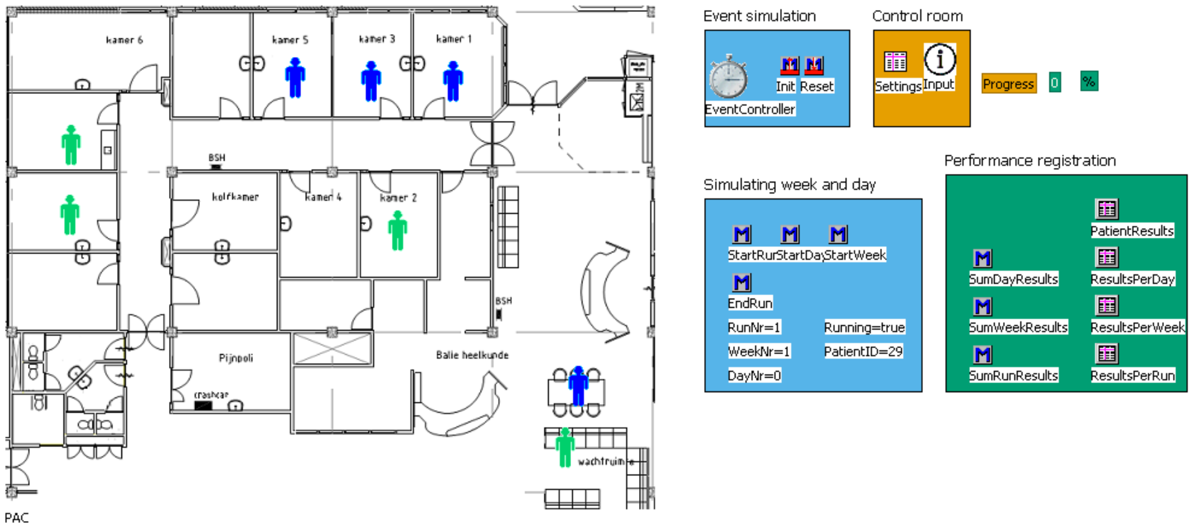


Figure 4.6: Screenshot of the simulation model.

1. PAC model

The PAC model represents the pre-operative department of VUmc. All care providers of the carrousel with the corresponding number of staff are present and patients are moving through the carrousel. Before every station, there is a buffer, which corresponds to the waiting room. The visual distinction is made between the green walk-in patients and the blue appointment patients.

2. Event simulation

The component event simulation presents the elements which are required to run the simulation, including the simulation clock and the initialization routine in the methods Init and Reset. The simulation clock tracks the current simulation time, the time 'hops' because the clock skips to the next event start time as the simulation proceeds.

3. Control room

Inside the control room, the settings and the input can be defined. Settings contain information that can be changed per run, for example, the capacity and the opening hours of the PAC. The input contains the model input, which is the same for all runs.

4. Simulating week and day

In this component, the model is initialized per run. We want to be able to make adjustments per day and week, for instance, the allocation of the staff per day or the number of patients per week, which can be done in the methods StartDay and StartWeek. It shows variables which are tracking totals like the number of patients and the day number.

5. Performance registration

From each patient visiting the PAC, we register information. Statistics are registered such as the arrival time, waiting times and consultation times. This information is summarized per day, per week, and per run in the corresponding tables.

4.4.4 Heuristic

To deal with the combination of walk-ins and appointments we develop an appointment schedule. The schedule defines the time slots of the blueprint for appointments based on the waiting times. It is hard to compute the waiting time per time slot exact. Therefore, we include a heuristic in the earlier described simulation model. To generate an appointment schedule we use a heuristic which prioritizes the waiting time per time slot to reduce the average waiting times for all patients. The heuristic will contain a construction phase and an improvement phase, which we discuss next.

For the construction heuristic, we use a Greedy approach see Algorithm 1 (Schutten, 2013). In every step the time slot with the lowest waiting time is added to the appointment schedule. In this phase, appointments are first scheduled on the appointment schedule and remaining appointments are scheduled randomly. The heuristic stops when the appointment schedule contains the correct amount of time slots.

while *counter* < *required number appointment slots* **do**
    Run model to determine waiting time per time slot;
    Find time slot with lowest waiting time;
    Add time slot to appointment schedule;
    Update counter;
end

Algorithm 1: Construction heuristic.

The improvement heuristic of Algorithm 2 looks for improvements in the constructed schedule. We use the 2-opt local search method of Lin (1965), wherein every swap two exchanges take place. To test a swap, the performance of the swap is compared with the best performance so far. When the current performance is better than the best performance so far, the swap is accepted. Otherwise, the swap changed back. For this, we have run the model with the swapped appointment schedule. The number of swaps performed depends on the runtime available. In the next chapter, the required number of replications to test an exchange will be computed, which defines the computation time of one swap.

while *counter* < *total number of swaps* **do**
    Find two random time slots to swap;
    Swap;
    Run model to determine temporary performance;
    if *temporary performance* < *best performance* **then**
        Keep swap;
        Store new best performance;
    else
        Swap back;
    end
    Update counter;
end

Algorithm 2: Improvement heuristic.

4.5 Verification and validation

The last step before designing the experiments is the verification and validation of the models. Verification is needed to check the model implementation. Validation is needed to check whether the computer models are an accurate representation of the reality.

4.5.1 Verification

To check the correctness of the model implementation, we debugged the model while programming it. For this, we used the debugging options of the simulation model, the observation of animations, the review of the program by others, and the running of pilot runs. With the use of the pilot runs, we checked the correctness of the simulation model input and compared it with the historical data and the input of the queuing model, which Table 4.4 shows.

From Table 4.4, the conclusion can be drawn that the number of patients per week of the simulation model is in line with the historical numbers. The consultation times from the historical data and the model data differs. The mean consultation time of the secretary desk is in the historical data lower than in both models, caused by the modification made during the distribution fitting, as described earlier. The same explanation holds for the difference in the consultation time of the anaesthetist. The difference between the consultation times of the nurse is due to the percentage of performed CPMs was high during the pilot. For the medication team, it holds that the fitting of the distribution causes the small difference. With the use of all verification approaches, we conclude that the models are correct implemented.

Table 4.4: Verification of the carrousel data.

		Historical	**Queuing**	**Simulation**
Number of patients per week	Mean	149.45	-	149.58
	St. dev.	26.52	-	26.03
Consultation times in min.	Secretary	2:39	2:43	2:44
	Nurse	24:55	23:59	23:59
	Medication team	10:52	11:01	11:01
	Anaesthetist	20:15	18:33	18:33

4.5.2 Validation

After verifying the models, we validate the models with the reality. Unfortunately, we were not able to collect representative historical data. For this two main reasons can be assigned, namely the disturbance of the current patients flow during the pilot period and the introduction of a new electronic patient records system. The introduction will require more time in the beginning, but saves a lot of time in the future, since it combines all system into one system. We used other methods to validate the models, like reviewing the model by professionals and the comparison of the outputs of the queuing model with the simulation model.

The performances of the queuing model and the simulation model are presented in Table 4.5. For the validation purpose, a simulation model with a constant arrival rate is used. Some differences between the waiting times of the queuing model and the simulation model can be observed. We see that the differences between the waiting times are increasing per process. A part of the differences can be caused by rounding errors of the simulation model. This model allows only two decimals per parameter while the queuing model takes more specified input.

Together with the other validation approaches, we conclude that both models are correctly programmed and are an accurate representation of reality.

Table 4.5: Validation of the models with the carrousel.

		Queuing	**Simulation**
Waiting time in min.	Secretary	0:59	0:58
	Nurse	13:42	13:19
	Medication team	1:51	2:08
	Anaesthetist	1:58	2:18
Utilization rate	Secretary	27%	27%
	Nurse	79%	78%
	Medication team	54%	54%
	Anaesthetist	61%	60%

4.6 Conclusion solution approach

In this chapter, the two quantitative modelling approaches are introduced. Section 4.2 presented the input for both models by the patient paths, the patient arrival, and the consultation times. The queueing model was introduced to estimate the capacity in the next chapter, followed by the presentation of the simulation model, which will be used as a more specified representation of the PAC from VUmc. In the last section, we proved the correctness of both models by the verification and validation of the models. The models can now be used to test the PAC design factors.

Chapter 5

Analysis of the results

This chapter analyses the performance of the three PAC design factors and explains the design of the experiments. Besides, the implementation of the three design factors will be discussed. Section 5.1 defines the design of the experiments. Next, the capacity dimensioning is defined in Section 5.2, followed by the results of the experiments on the routing rules and appointment scheduling in Section 5.3 and Section 5.4. The impact of the input parameters is examined in the sensitivity analysis in Section 5.5. The chapter concludes with a conclusion on the results in Section 5.6.

5.1 Design of experiments

The design of the experiments is defined by the experimental design, which defines the order of the experiments. For the experiments, performance measurements are formulated and the number of replications for the simulation study needs to be determined.

5.1.1 Experimental design

Figure 5.1 presents the experimental design of this research. On strategic level, a capacity dimensioning is required. With the use of the queuing model, the capacity needed for one week is estimated. The simulation model gives insight into the capacity dimensioning on day level. The result of the capacity dimensioning is a weekly capacity planning on day level.

The capacity planning is used as input for the next experiments on operational level. The common objective of reducing the total waiting times creates a dependency between the arrival experiments and the routing experiments. Because of this, the following experiment set-up is designed. First, ten different appointment schedules are formulated to test the routing rules. The performances of the five rules will be analysed and the best rule is used as input for the appointment scheduling experiment. With the use of the heuristic in combination with the simulation model, an appointment schedule will be constructed which reduces the waiting time for all patients at the PAC. The appointment schedule is analysed and translated into scheduling rules which can be implemented as work agreements. The last experiment identifies the performances of those scheduling rules.

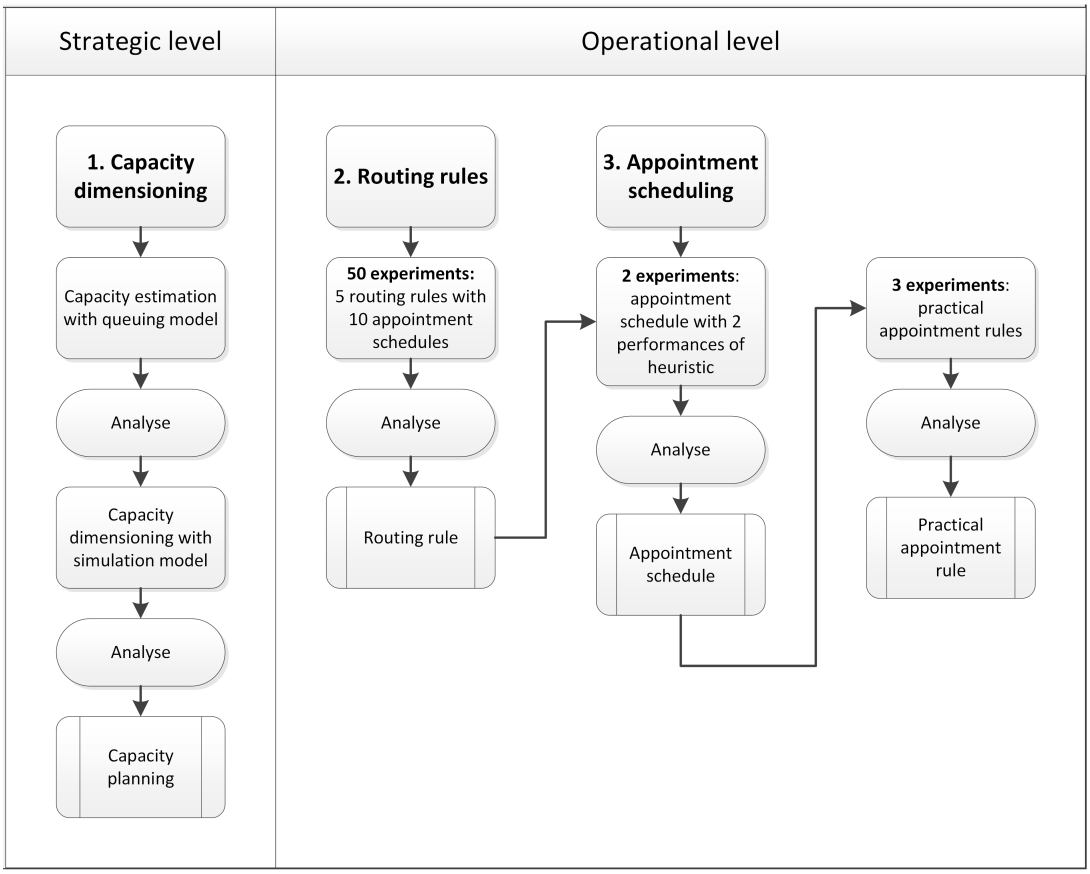


Figure 5.1: Experimental design.

5.1.2 Performance definition

We define the performance of the experiments by two indicators, the waiting time of the patient and the idle time of the staff. Earlier in this thesis, the access time is described as a performance indicator. Considering this factor is not a cause for concern, the access time will not define the performance of the experiments.

The waiting time is defined as the time the patient spends in the waiting room. To compute the total waiting time, the waiting times of all processes is added, from the secretary desk till the anaesthetist. Where the queuing model defines only the average of the waiting times, the simulation model also computes the 90th and 95the percentile of the waiting times, which corresponds to the maximum waiting time of all patients. The distinction made between the waiting time of the total patient population, the walk-in patients and the patients with an appointment. This is done since walk-in patients are more willing to wait than patients with an appointment (Scholtens, 2009).

The percentiles are computed with the use of the Nearest Rank method. The P-th percentile of a list of N ordered values is the smallest value in the list such that P percent of the data is less than or equal to that value. We obtain this number by computing the ordinal rank with equation (5.1) and taking the value from the ordered list that corresponds to that rank.

$$n = \lceil \frac{P}{100} \cdot N \rceil \tag{5.1}$$

The idle time for the staff is defined as the time between the consults of the patients. For the queuing model, this is computed with the use of the utilization rate. For the simulation model, the assumption is made that the staff of the same process starts and ends their workday at the same time. The working day starts at the time of the first time slot and ends when the last patient is seen by one of the care providers of the process. This means that potential overtime of the staff is included in the working hours. The idle time is computed as follows:

$$\text{Idle time per station} = \frac{\text{Working hours} \cdot \text{Capacity} - \sum \text{Consultation times}}{\text{Working hours} \cdot \text{Capacity}}$$

5.1.3 Number of replications

For the simulation study, the length of a run needs to be defined and the number of replications set. The opening hours of the department define the begin and the end of a simulation run. This means that the model is a terminating simulation. The length of a replication is set to one week. We have to compute the number of replications needed to achieve the desired level of confidence of the model output. The sequential procedure as proposed by Law (2007) is used. We compute $\overline{X}_n$, the average of the n replications, and S_n, the variance in the n replications. The smallest n for which the following formula holds needs to be computed.

$$\frac{t_{n-1,1-\alpha/2}\sqrt{S_n^2/n}}{\overline{X}_n} \leq \gamma'$$

In this formula, n is the number of replications, $t_{n-1,1-\alpha/2}$ is the student t-value for $(n-1)$ degrees of freedom and a confidence interval of $(1-\alpha)$ and γ' is the corrected relative error.

With a confidence interval of 95% and a relative error of 0.05 (γ' of 0.048), we calculate the required number of replications for six output performances. The 95th percentile represents the maximum waiting time. The maximum number of replications needed is 1031 for the average waiting time of the walk-in patients. For all other performance measurements, it holds that 725 replications are sufficient. In this research a number of replications of 1000 is used, which corresponds with 5000 days and a runtime of approximate 45 seconds.

Table 5.1: Number of replications per performance measurement.

Performance	Flows	Number of replications
Average waiting time	Total	669
	Walk-in	1031
	Appointment	355
Maximum waiting time	Total	725
	Walk-in	617
	Appointment	203

5.2 Capacity dimensioning

On strategic level, the introduction of the carrousel requires a redefinition of the capacity of the PAC. This section defines the service levels for the capacity dimensioning, we analyse the capacity on week level with the use of the queuing model and the simulation model is used to set the capacity on day level.

5.2.1 Service level

In consultation with a delegation of the staff of the PAC, the following service levels are set:

1. Maximum waiting time for the first process: 30 minutes;
2. Maximum waiting time between the processes: 10 minutes;
3. Maximum utilization rate per station: 80%.

The established maximum utilization rate seems to be low, considering the expensive staff members. However, this is done because of the fluctuations in the arrival of the walk-in patients and the additional administration tasks. The utilization rate will be even lower, since the breaks are excluded.

The performance output of the queueing model defines only the mean value of the waiting times, therefore a reformulation of the service levels are needed. For the queuing model, the average waiting time for the first process is set on 15 minutes and the average waiting time between the processes on 5 minutes. The simulation model makes a distinction between the waiting times for all patients, the walk-in patients, and the patients with an appointment. We use the 90th percentile of the waiting times to define the maximum waiting times, since it is to be expected that improvements in the extreme values are made with the other PAC design factors.

5.2.2 Capacity dimensioning on week level

This section presents the weekly capacity estimation by the use of the queuing model with a constant arrival rate and based on the service levels. To describe the capacity per process, we use the following notation (s,n,m,a), whereby s denotes the number of secretary staff members, n the number of nurses, m the number of medication team members, and a the number of anaesthetists.

Table 5.2 presents the waiting time and the utilization per station for three different capacity settings as computed with the queueing model. The minimum occupation is defined as the capacity setting where the utilization rate is below the 100% for each station. For the PAC, the minimum occupation is (1,3,2,2). However for this setting, service levels 2 and 3 are not met, seen the anaesthetist has an average waiting time of 31:38 minutes and an utilization rate of 91%. The capacity setting of (1,3,2,3) is needed to reach all three service levels.

Table 5.2: Performance of different capacity settings.

	(1,3,2,2)		(1,3,2,3)		(1,4,2,3)	
	EW_{Qi}	ρ_i	EW_{Qi}	ρ_i	EW_{Qi}	ρ_i
Secretary	0:59	27%	0:59	27%	0:59	27%
Nurse	13:42	79%	13:42	79%	2:21	59%
Medication team	1:51	54%	1:51	54%	2:10	54%
Anaesthetist	31:38	91%	1:58	61%	2:14	61%

By means of the queueing model, more information can be gathered about the capacity setting, so we analyse the capacity setting (1,3,2,3) in more detail. Table 5.3a presents the mean number of patients in the queue per station (EL_{Qi}) and mean number of patients at a station (EL_i). On average 7.43 patients are in the system, whereof 1.89 patients in the waiting room. Another performance measurement we computed is the expected time in the system per patient path (EW_r), which is shown Table 5.3b.

Table 5.3: Detailed results of the queueing model for setting (1,3,2,3).

	EL_{Qi}	EL_i
Secretary	0.10	0.36
Nurse	1.42	3.78
Medication team	0.18	1.27
Anaesthetist	0.19	2.02
System	1.89	7.43

(a)

Path	EW_r
P1	73.05
5 P2	78.86
P3	92.46
Average	75.47

(b)

The relation between the arrival rate and the average waiting time per station for capacity setting (1,3,2,3) is presented in Figure 5.2. It can be seen from the figure that the patient arrival rate can be increased to 6 patients per hour, without exceeding the service levels of the waiting times. An arrival rate of 6 patients per hour corresponds with an expected average waiting time of 15 minutes for the first station and an utilization rate of 80% for the nurses, see Figure 5.3. Appendix C presents the relation between the arrival rate and the total waiting time for the three capacity settings.

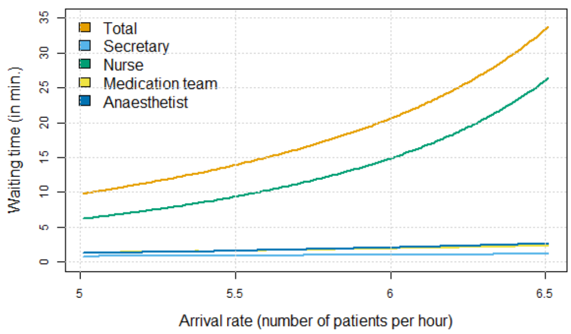


Figure 5.2: Relation arrival rate and waiting time for setting (1,3,2,3).

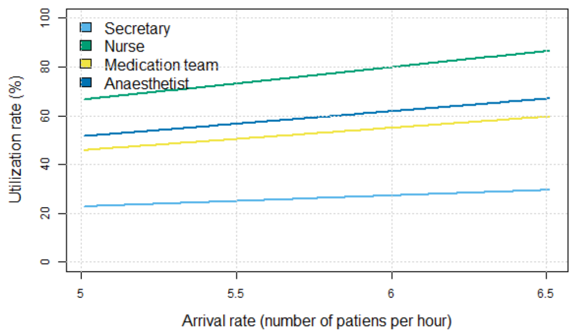


Figure 5.3: Relation arrival rate and utilization rate for setting (1,3,2,3).

5.2.3 Capacity dimensioning on day level

The previous section defines a weekly capacity of (1,3,2,3), using the queuing model with a constant arrival rate. However, the PAC copes with fluctuation in the arrival of walk-ins and patients with an appointment. By means of the simulation model, we compute the capacity on day level, based on the weekly capacity estimation, whereby we keep in mind the translation from the capacity definition to financial costs. We are not looking for the setting with the lowest waiting time, but we consider also the financial costs of the capacity settings and the utilization rate of the staff.

Currently, at the PAC applies the routing rule Arrival on Earliest Appointment Time, which prioritize the patients by their appointment time at the nurse station and serves the patients at the other stations according to the First Come, First Served principle. In practise this means that the first priority is given to the appointment patients and the walk-in patients are fit in as good as possible. To determine the capacity, this rule is used. The appointments are scheduled randomly, which means that every time slots has the same chance to be used as appointment slot.

We set the capacity for the pre-operative department station by station, to keep the possible combinations within reasonable bounds. The capacity of the secretary desk, which is set on one employee for all weekdays. Subsequently, we determine the capacity of the nurse. Figure 5.4 compares on the x-axis all 32 possible capacity settings from two nurses per day to 3 nurses per day, the corresponding waiting times for all patients in minutes is shown at the y-axis. The colour distinction shows the differences in the number of required staff between the settings. For each setting the 90th percentile of the waiting time for all patients is presented by the asterisk and the dot presents the average waiting time for each setting. As can be seen from the figure below, (3,3,3,3,2) nurses per weekday are needed to reach the service level of the maximum waiting time of 30 minutes. The second half of the capacity settings is split up into the waiting times of the walk-in patients in Figure 5.5 and waiting times of the patients with an appointment in Figure 5.6. For now, the capacity setting of (2,3,3,3,2) nurses per weekday is chosen as the best combination of maximum waiting time and financial staff costs. The setting corresponds to a 90th percentile of the waiting time of the nurse of 33.4 minutes for all patients, 14.9 minutes for the patients with an appointment and even 60.9 minutes for the walk-in patients. The utilization rate of the nurses is 57% (see Appendix C).

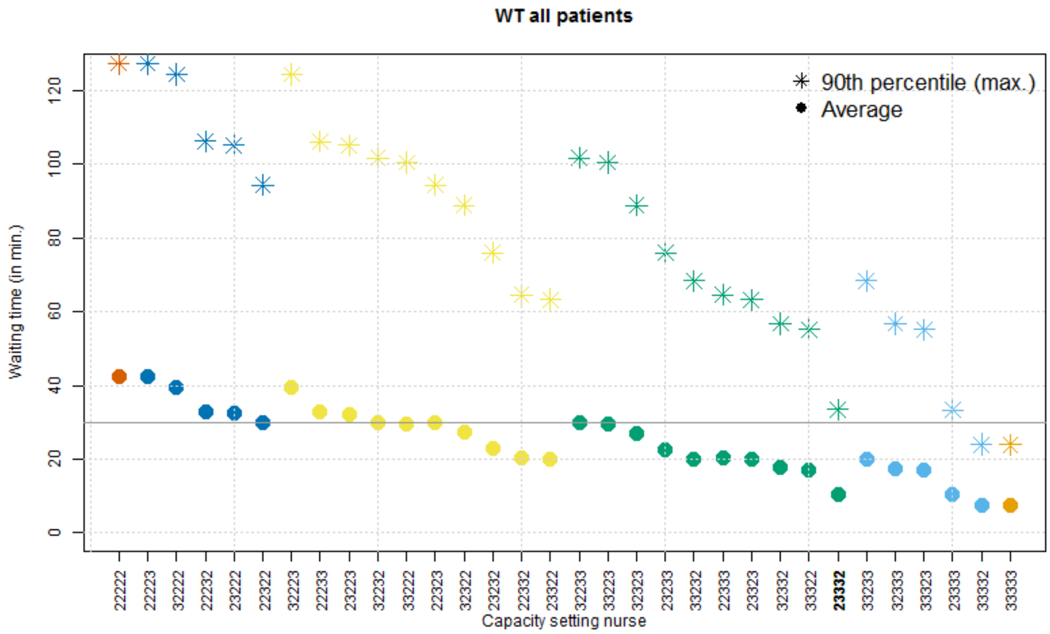


Figure 5.4: Capacity settings for the nurse based on the wt of all patients.

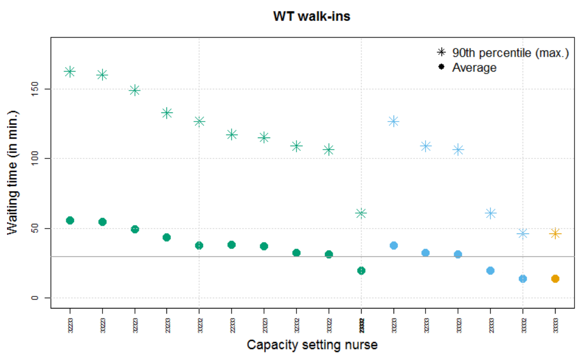


Figure 5.5: Second half capacity settings for the nurse based on wt of walk-in patients.

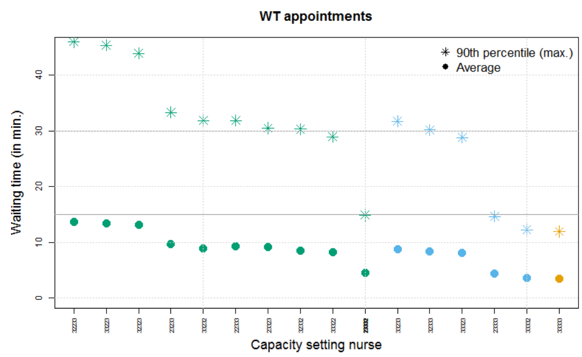


Figure 5.6: Second half capacity settings for the nurse based on wt of appointment patients.

The capacity of the medication team is set on (2,2,2,2,1), where the 90th percentile of the waiting time for all patients is 5.3 minutes and the utilization rate is 39%. For the anaesthetist, the capacity setting is defined as (2,3,3,3,2), corresponding with a 90th percentile of the waiting time for all patients of 7.1 minutes and an utilization rate of 46%. The corresponding figures are shown in Appendix C and Table 5.4 summarizes the capacity of all stations per weekday.

Table 5.4: Capacity per process per weekday.

	Mon	Tue	Wed	Thu	Fri
Secretary desk	1	1	1	1	1
Nurse	2	3	3	3	2
Medication team	2	2	2	2	1
Anaesthetist	2	3	3	3	2

5.3 Routing rules

In this section, we analyse the performance of the five routing rules, First Come, First Served (FCFS), Longest Waiting Time First (LWTF), Earliest Arrival Time (EAT), Appointment Earliest Arrival Time (AEAT), and Shortest Estimated Processing Time (SEPT). To analyse the routing rules, we formulate ten appointment rules, see Table 5.5. The capacity setting per weekday is used as input for the in total 50 experiments.

Table 5.5: Definition of the 10 appointment rules.

	Appointment rule
1	Random scheduling of the appointments
2	Appointments on the first 23 time slots of each day
3	Two out of three time slots for appointments
4	One out of two time slots for appointments
5	Two out of three until 11 o'clock, thereafter one out of two time slots
6	No appointments between 11 and 1 o'clock, otherwise two out of three
7	First 11 time slots and last 11 time slots for appointments
8	Three appointments per hour, divided over the hour
9	First three time slots of the hour for appointments
10	Appointments at moments of low walk-in ratios

The performance of the routing rules per appointment schedule are similar, the EAT and AEAT generates the highest waiting time for all patients, see Figure 5.7 which presents the 95th percentile of the waiting time for all the patients. The 95th percentile is used to define the maximum waiting time for the patients. Since the rules differentiate between the walk-in patients and the patients with an appointment, the performance measurements should be differentiate as well.

For the walk-in patients, the maximum waiting time is shown in Figure 5.8 and Figure 5.9 presents the maximum waiting time for patients with an appointment. What is interesting in those figures is that the rules performs well for the walk-in patients or for the patients with an appointment. Appendix D presents the average waiting times per patient flow. The other performance measurement, the utilization rate, is hardly influenced by the routing rules. To be able to make a fair comparison between the routing rules, we rate the rule by the waiting time per patient flow in Table 5.6.

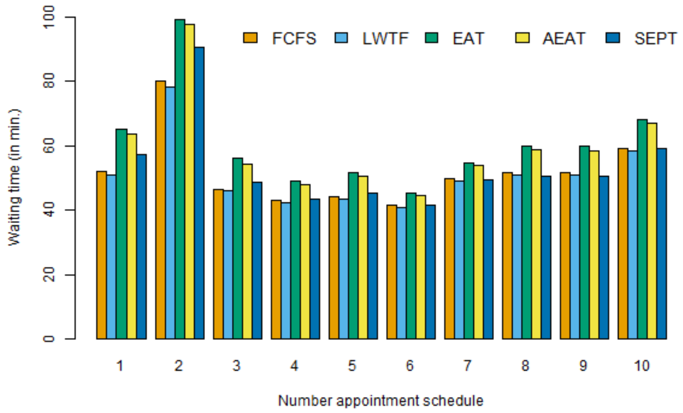


Figure 5.7: 95th percentile wt for all patients per routing rule by appointment schedule.

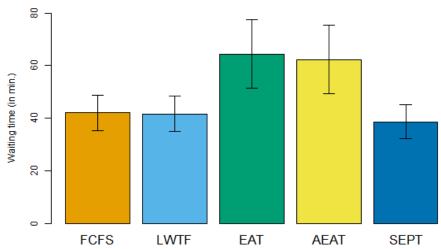


Figure 5.8: 95th percentile wt for walk-in patients per routing rule.

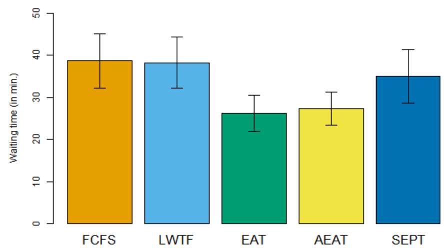


Figure 5.9: 95th percentile wt for patients with an appointment per routing rule.

Besides the quantitative performance measurement, we rank the routing rules also by degree of practical implementation. We base the ranking on the following motivations. From the literature, we discover that in practice, it is more fair to use a polity of calling patients in the order of appointments, while trying to fit in walk-ins and late patients as early as possible (Cayirli and Veral, 2003). Mandelbaum et al. states that the FCFS principle is fair to the patients. The FCFS rule is easy to implement and is fair to the patients in the waiting room, however the rule does not distinguish between walk-in patients and patients with an appointment, which disadvantages the appointment patients. The major drawback of the LWTF rule is that it requires a lot of administration time. In our case, it does also not distinguish between the patient flows and patients with long waiting times for the first station are favoured in the waiting room of the other stations. The EAT and AEAT rules can be implemented easily. The AEAT rule fit the best the description of Cayirli and Veral (2003). The SEPT rules requires additional administration by the secretary desk, since the processing time per patient needs to be estimated. The rule harms patients with long estimated processing times and this leads to high variation in the waiting times of the patients. With the outlined explanations, we complete the practical implementation column of the decision matrix.

With the use of the decision matrix of Table 5.6, we are able to decide which routing rule performs the best overall, whereby the practical implementation has the same weight as the maximum waiting times. We present two rules to the management from which the performances are equal, namely the FCFS rule and the AEAT rule. The FCFS rule treats patients with an appointment the same as walk-in patients, while the AEAT rule prioritize on the patients with an appointment. For this research, we continue with the AEAT rule, since this rule is already applied at the PAC and we consider the waiting time of the appointment patients more important than for the walk-in patients.

Table 5.6: Decision matrix for the routing rules.

Routing rule	Max wt			Practical implementation
	Total	Walk-in	Appointment	
FCFS	+	+	−	+
LWTF	+	+	−	−
EAT	−	−	+	+
AEAT	−	−	+	+
SEPT	+/−	+	+/−	−

5.4 Appointment scheduling

The appointment scheduling contains two steps, constructing the appointment schedule and testing the appointment rule. A heuristic combined with a simulation model is used to construct an appointment schedule. For the heuristic, we define initial settings, like the number of appointment slots and the number of swaps. Next, we construct the appointment schedule, followed by the performance analysis of three practical scheduling rules.

5.4.1 Heuristic settings

For the construction of the appointment schedule, we use a two-phase heuristic with a construction phase and an improvement phase, as described in Section 4.4.4. Figure 5.10 presents the performance during each of the phases. The first run of the heuristic is the initialization run, which schedules the appointment at random. Next, the construction phase starts, where in every iteration, the time slot with the lowest waiting time is included in the set of appointment slots. For both phases, it holds that one iteration equals one simulation run of 1000 weeks. The construction heuristic stops when the total number of appointment slots is reached. The number of appointment slots is computed by the mean and standard deviation of the number of visits per week and the appointment ratio, $(\mu+\sigma)\cdot$appointment%. The number of appointment slots is set on $(145.45 + 26.24) \cdot 0.60 = 105$ time slots.

The second phase is the improvement phase, where we aim to improve the solution of the construction phase. Testing a swap in the improvement phase takes one run and has a duration of approximately 25 seconds, this means that the total number of swaps is restricted by the amount of run time. The improvement phase is conducted with 500 runs, as shown in Figure 5.10. Within the first 100 swaps, the biggest improvements are reached. Seen the small decreases later on, we conclude that an amount of 500 runs is enough to find a good solution. However this solution will not be the optimal solution, since a better solution remains possible. The two-phase heuristic contains now a total of 606 runs, which corresponds to a run rime of approximately four and a half hours.

To be able to generate the appointment schedule, we have to define the performance criteria of the improvement phase, where a swap is accepted if the temporary performance is better than the best performance so far. Two appointment schedule are designed with two different criteria, the average waiting time for all patients and the maximum waiting time for all patients. The differences between the criteria are very small, the maximum waiting time results in a better performing appointment schedule, therefore we will use this criteria to construct the appointment schedule in the next section.

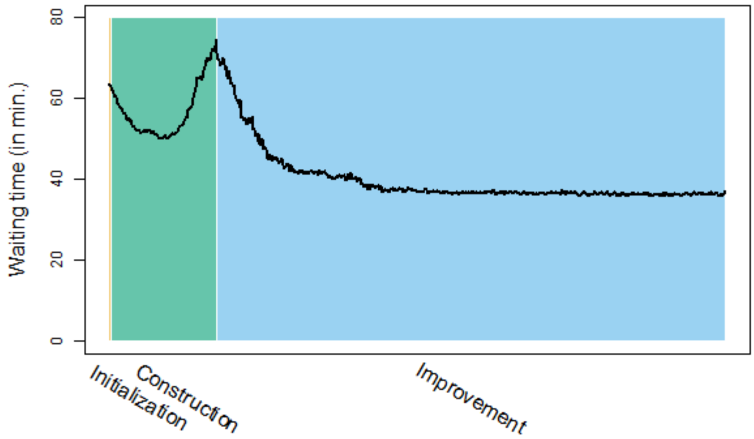


Figure 5.10: Performance per heuristic phase.

5.4.2 Appointment schedule

In this section, we analyse the performance of the appointment scheduling. Given a blueprint with time slots for one week, the appointment schedule is created with the use of the two-phase heuristic. For this research, we use as input the blueprint of Appendix E. The blueprint is designed with the data of the analysis of the service times during the pilot of the carrousel. Figure 5.11 shows maximum and average waiting time per patient flow for the phases of the heuristic. The implementation of an appointment schedule, decreases the maximum waiting time for all patients with 42% and the average waiting time with 44%. Mainly, the waiting times of the walk-ins are reduces with the schedule. The idle time of the staff is not influenced by the introduction of the appointment schedule.

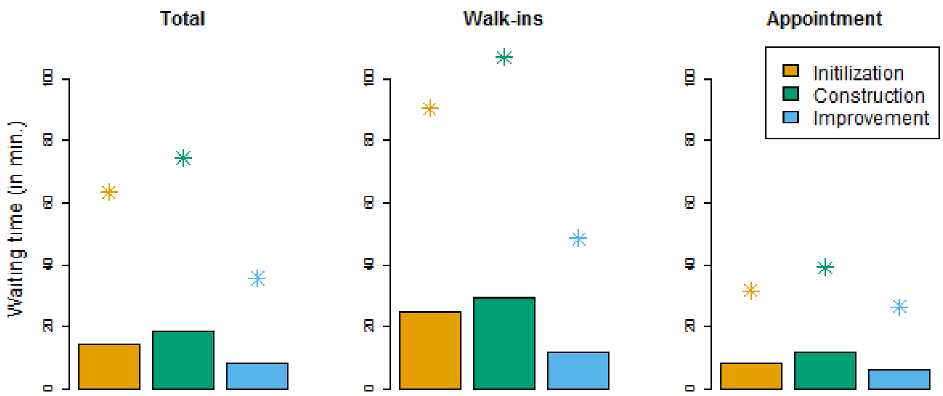


Figure 5.11: Performance of the heuristic per phase.

Not using an appointment schedule corresponds with randomly scheduling of the appointments on the available time slots of the week. Figure 5.12 shows that random scheduling creates an enormous peak in the waiting time during the day, which does not decrease in the afternoon. The implementation of the appointment schedule decreases the average waiting times significant. Figure 5.13 presents the average waiting time per time slot on Monday. From the figure it can be seen that appointment schedule keeps the waiting times per time slots on an acceptable steady level during the day, which holds also for the other weekdays. The waiting times per time slot of the other weekdays is presented in Appendix E.

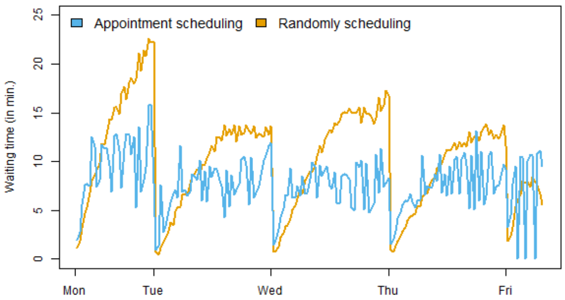


Figure 5.12: Average waiting time per time slot for one week.

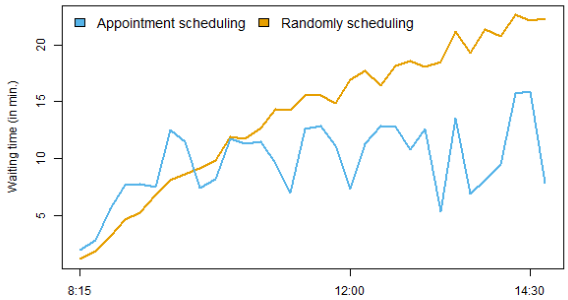


Figure 5.13: Average waiting time per time slot for Monday.

From the analysis so far, we conclude that the use of an appointment schedule has a positive impact on the performance of the waiting times at the PAC. Now, we investigate the relation between the positioning of the appointment slots and the waiting times per time slot. Figure 5.14 presents the waiting time per time slot together with the scheduled appointments. It can be seen that most of the appointment are scheduled at the beginning and the end of the day, but it is also interesting to investigate the positioning of the appointment slots during the day in more detail. Furthermore, we see that not all time slots of the Friday are used for appointments, while only appointment patients are visiting the PAC. Both striking point needing a more detail analysis, which will be discussed next.

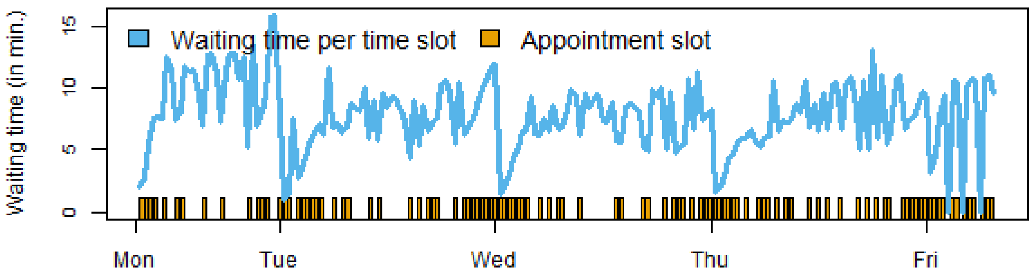


Figure 5.14: Average waiting time per time slot and the positioning of the appointment slots.

The first notable point is the positioning of the appointments during the day. We compare the appointment slots with the walk-in ratio during the days, see Figure 5.15. We see some overlap between the moments of low walk-in ratios and the appointment slots. Therefore, we present in Figure 5.16 the performance of an appointment schedule with the same number of appointment slots based on the walk-in ratio as suggested by Rising et al. (1973). The appointment schedule of the heuristic performs a lot better than the schedule based on the walk-in ratios. A possible explanation for these results may be the lack of adequate data of the walk-in ratios. Currently, the ratios are known per hour of the weekdays, more accurate should be walk-in ratios per half hour or even per time slot. So the walk-in ratios does not explain the positioning of the appointments during the day. Having a closer look at the appointment slots, it is apparent that appointment intervals influences the positioning. It appears that time slots in rapid succession are more likely to be used for appointments, what happens, since the intervals are not the same for every slot.

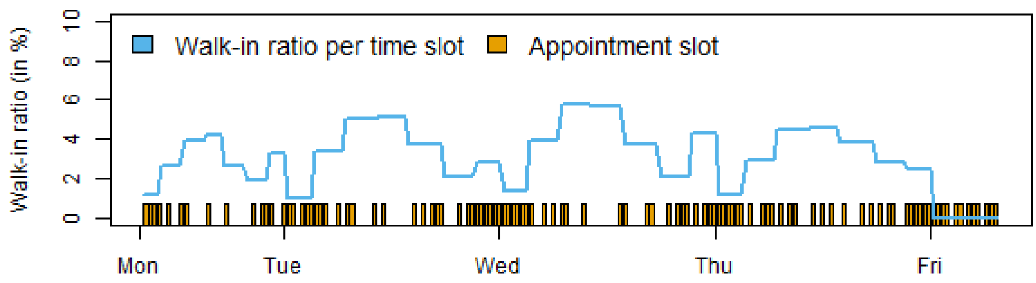


Figure 5.15: Walk-in ratio and appointment slots.

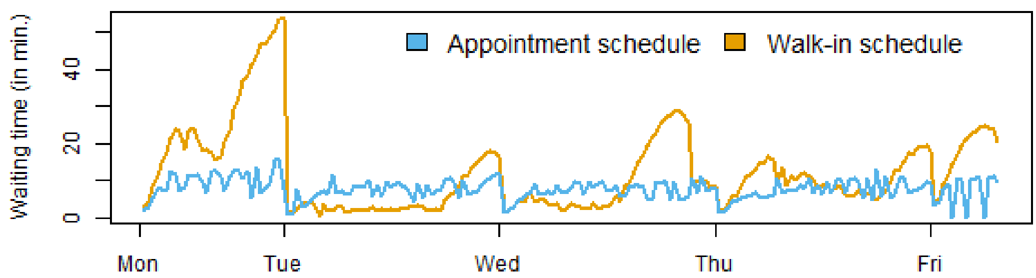


Figure 5.16: Waiting time of an appointment schedule based on the walk-in ratio.

The other striking point are the unused time slots on the Friday. We see that 3 of the 15 time slots on Friday are not used for appointments. The Friday differs from the other weekdays since it treats only patients with an appointment in the morning. Figure 5.17 presents the waiting time per slot for the appointment scheduling and for the case that all time slots are used for appointments. We see huge differences in the average waiting times of the slots, where a time slot of the appointment schedule has an average waiting time of 7.2 minutes on Fridays, this number increases to 17.5 minutes when all slots are used. The cause for this difference is the capacity dimensioning. We see that on Fridays the bottleneck is the medication team with a capacity of one. Increasing the capacity of the medication team, solves the problem, see Figure 5.18. However the utilization rate of the medication team reduces with 50%. to the extreme low utilization level of 17%.

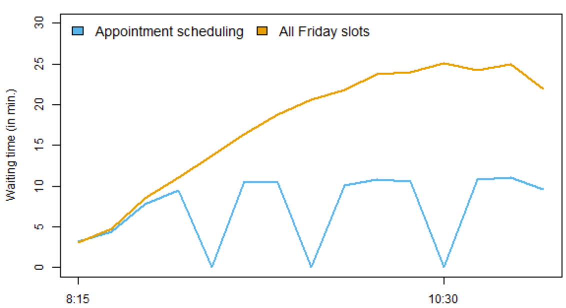


Figure 5.17: Performance of the time slots on Friday.

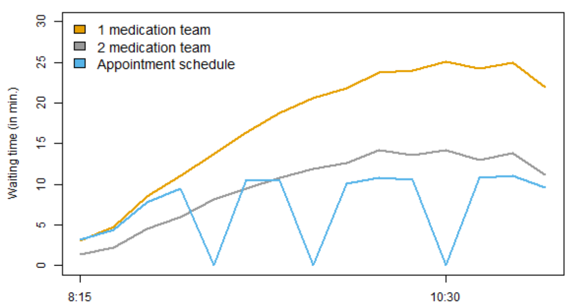


Figure 5.18: Capacity change for Friday.

In this section, we analysed the effects of introduction of the appointment schedule. The heuristic scheduled the appointments at the beginning and end of the weekdays where the walk-in ratios are low. Furthermore, the appointments are scheduled on slots with a low appointment interval, the slots with the least time until the next slot. The appointment schedule did not use all slots on Friday, since the capacity of the medication team is a bottleneck here. We advise the hospital to implement the appointment schedule without increasing the medication team on Friday, since this decreases the utilization rate extremely. Table 5.7 summarize the performances of the appointment schedule compared to randomly scheduling.

Table 5.7: Summary of the performance of an appointment schedule.

Performance	**Flows**	**Random scheduling**	**Appointment scheduling**
Average waiting time	Total	14.6	8.5
	Walk-in	24.7	12.1
	Appointment	8.4	6.2
Maximum waiting time	Total	63.6	35.7
	Walk-in	90.4	48.6
	Appointment	31.8	26.6

5.4.3 Appointment rule

The constructed appointment schedule can be implemented in the agenda system of the PAC as dedicated time slots for the appointment patients. A disadvantage of the implementation is that the freedom of the scheduling will be restricted. The advantage is that no (intentional or unintentional) mistakes can be made, which garantees the good performances. Therefore, we will look into the performance of three appointment rules, which are easier to implement, since it is a workagreement between the schedulers. Based on the analysis of the appointment schedules in the previous section, three appointment rules are defined as:

1. Schedule one out of two time slots for appointments, all time slots with odd numbers.
2. Schedule two out of three time slots for appointments and schedule no appointments between 11 and 1 o'clock.
3. Schedule two out of three time slots for appointments until 11 o'clock, after that schedule one out of two time slots for appointments.

The average waiting time per time slot of the appointment schedule and the appointment rules are shown in Figure 5.19 to Figure 5.21. From the figures can be seen that rule 2 performs the best from the three appointment rules. Table 5.8 presents more detailed performances. Appointment rule 2 scores good for the waiting times of the walk-in patients and comes close to the performances of the appointment schedule. If the management of the hospital prefers an appointment rule, we recommend the implementation of appointment rule 2, where two out of three time slots are used for appointments and no appointment are scheduled between 11 and 1 o'clock.

Table 5.8: Performances of the appointment rules.

Performance	Flows	Appointment schedule	Rule 1	Rule 2	Rule 3
Average waiting time	Total	8.5	10.4	9.2	11.0
	Walk-in	12.1	16.2	13.1	18.0
	Appointment	6.2	6.6	6.6	6.6
Maximum waiting time	Total	35.7	45.8	39.4	48.8
	Walk-in	48.6	65.5	55.7	71.4
	Appointment	26.6	27.5	27.6	27.8

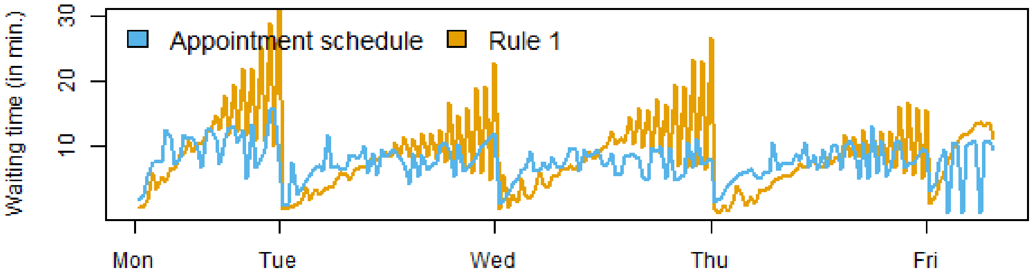


Figure 5.19: Performance appointment rule 1.

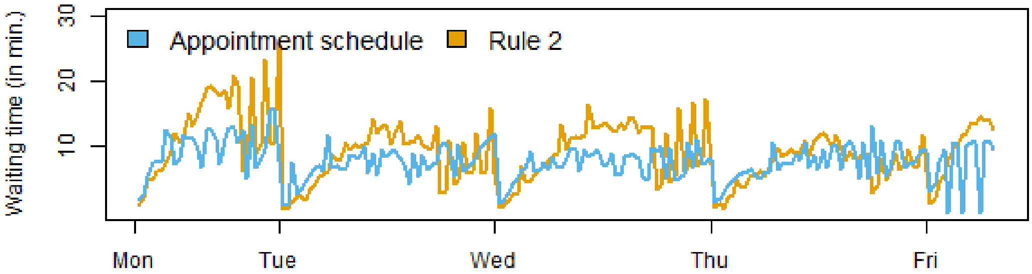


Figure 5.20: Performance appointment rule 2.

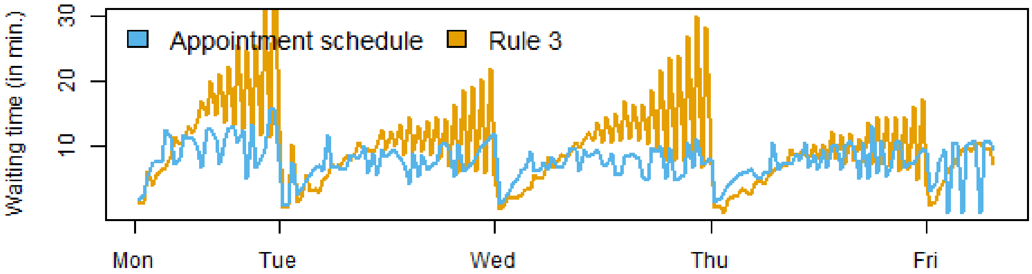


Figure 5.21: Performance appointment rule 3.

5.5 Sensitivity analysis of input parameters

Several assumptions are made for the input of the simulation model. Tn this section, we present the impact of the assumptions on the performance by means of a sensitivity analysis of three assumptions, namely the patient punctuality, the patient path ratios and the patient flow ratios.

5.5.1 Patient punctuality

In this section we analyse the impact of variations within the punctuality of the patients. For the patients with an appointment, we modelled their punctuality, which defines the actual arrival time corresponding to the given appointment time. Distinction can be made between voluntary (indirect) and forced (direct) waiting time (Amersfort, 2013). Voluntary waiting time is the time the patient has to wait until their appointment time, due to the early arrival of the patient. Forced waiting time is the time the patient has to wait after their appointment time has passed, which is experienced as a problem for the patients and the staff. For this research, no distinction is made, but the difference is interesting, since the patient punctuality causes indirect waiting time.

Figure 5.22 presents the average waiting time per time slot for the current patient punctuality and the case that all appointment patients arriving exactly on time. On Friday, we observe that the voluntary waiting times are a big part of the waiting time, namely on average 1.35 minutes are indirect waiting times, see Figure 5.22. However, in practice it is impossible to influence the punctuality of the patients, research into the indirect and direct waiting time can be worthwhile. For this research, we conclude that some variation within the assumption of the patient punctuality has no significant influence on the results of our model.

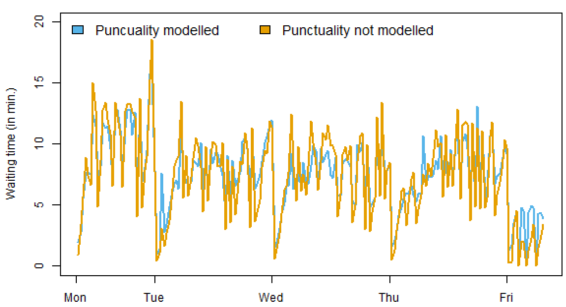


Figure 5.22: Impact patient punctuality on waiting time per time slot.

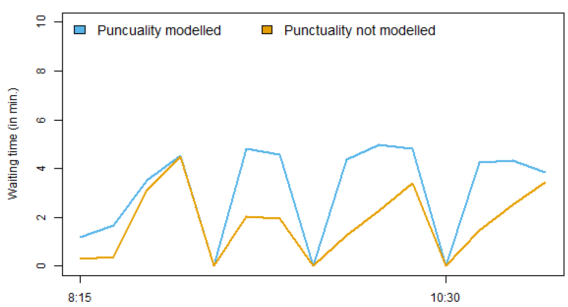


Figure 5.23: Impact patient punctuality on waiting times Friday.

5.5.2 Ratio patient paths

Another assumption we made for the model input is the ratios of the patient paths, which are set on 70%, 25% and 5% for respectively path 1 to 3. Currently the exact ratios are not known, therefore we analyse the impact of the sensitivity of this input parameter for the performance of the outcome. Figure 5.24 compares the maximum waiting time by different ratios of patient path 1, without affecting hte percentage of patient path 3. More patient with path 1, not requesting a CPM, results less maximum waiting time for the patients. This is due to the reduction of the average consultation time of the nurses.

Next, the ratio of patients with path 3 is adapted, with a constant percentage of patient path 1 of 70%, see Figure 5.25. Since the only difference between patient path 2 and 3 is the moment of the CPM, we observe no big differences. For the model it is the most useful to gather more information about the ratio of patient path 1, since this affects the maximum waiting time of the patients. A more accurate ratio, the more reliable the performance of the simulation model.

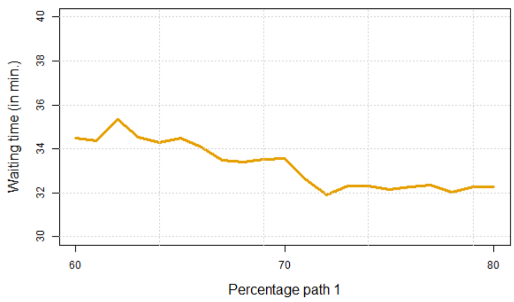


Figure 5.24: Maximum waiting time for patient paths 1.

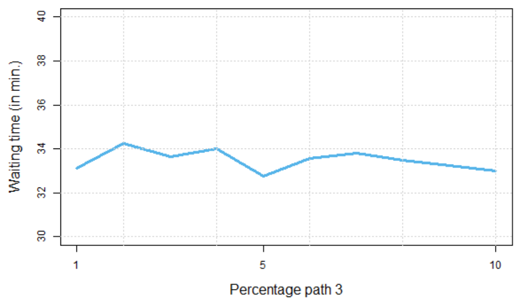


Figure 5.25: Maximum waiting time for patient paths 3.

5.5.3 Ratio patient flows

At the moment, the exact percentage of appointment patients and walk-ins is not known. For the model, the assumption is made that 60% of the patients having an appointment and the other 40% using the walk-in option. To analyse the impact of ratio of the patient flow, two approaches are used, changing the patient flows for the appointment schedule of Section 5.4.2 and constructing new appointment schedules per patient flow ratio.

Figure 5.26 compares the maximum waiting time of different patient flow ratios using the current appointment schedule. It can be seen from the figure that more appointment patients results in a lower maximum waiting time, as we would expect.

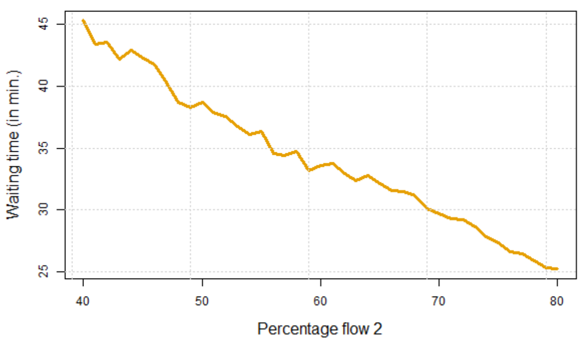


Figure 5.26: Maximum waiting time per patient flow ratio.

New appointment schedules are constructed for five patient flow ratios, see Table 5.9. Here the same trend can be observed, dedicating more time slots for the appointments and a higher appointment percentage results in lower maximum waiting times. The results show that it is important to know the percentage of appointment patients in more detail than the current approximation since it is affecting the performance. With accurate appointment percentage, the best performance can be reached with the implementation of the corresponding appointment schedule.

Table 5.9: Performances of appointment schedule per patient flow.

	% appointments	40	50	60	70	80
	Number appointment slots	70	88	105	123	141
Average waiting time	Total	9.1	8.8	8.5	8.1	7.9
	Walk-in	11.2	11.5	12.1	12.0	13.1
	Appointment	6.0	6.2	6.2	6.5	6.6
Maximum waiting time	Total	38.7	37.1	35.7	33.6	31.4
	Walk-in	45.0	46.2	48.6	49.6	55.9
	Appointment	28.2	27.2	26.6	27.2	26.9

5.6 Conclusion on results

This chapter analysed results of three subjects, the capacity dimensioning, the routing rules, and the appointment scheduling. By means of the queuing model and the simulation model, the capacity for the PAC was determined. To be able to set the capacity, service levels of the maximum waiting time and the utilization rate were defined. It results that the capacity differs per day for the best performances. So are Monday and Friday less busy days, and so less staff is needed. The capacity per weekday is shown in Table 5.4.

Next, the routing rules were analysed with the use of the simulation model. We recommend two routing rules to the management, the First Come, First Served rule, which does not differentiate between the walk-in patients and patients with an appointment and the Arrival on Earlies Appointment Time, which prioritize on the appointment time of the patients. Big advantages of both rules are that they are the easy implementation of the rules and the fairness to the patients.

Most surprising results were originating from the appointment schedule, which was constructed with the use of the heuristic integrated into the simulation model. Assigning the appointments to the time slots with less waiting time results in a schedule which reduces the maximum waiting time for all patients with 42%. Also, the use of scheduling rules was tested in this chapter. Advantage of the appointment rules is that it provides the scheduler the freedom of choosing the appointment slots according to the work agreement, which has the disadvantage that intentional or unintentional mistakes can be made. The performances of the rules stayed a little behind with the promising results of the appointment schedule. After the redesign, the scheduling of the appointment patients will happens at the PAC, but also by the planning office. Therefore, we recommend implementing the constructed appointment schedule as dedication in the agenda of the PAC.

For the model input some assumptions were made, which are analysed in the sensitivity analysis. In this section, we have seen that the punctuality of the patients is only interesting when differentiating between the voluntary and forced waiting times. The patient path ratios does not significantly influence the maximum waiting time of the patients, while the patient flow ratios does. We recommend to provide an accurate appointment percentage to be able to construct the best performing appointment schedule.

Chapter 6

Conclusion and recommendations

In this chapter, we present the conclusions of our research followed by the recommendations for the pre-operative department of VUmc and the suggestions for further research.

6.1 Conclusions

Our research is performed in order to answer the main question raised by the redesign of the PAC of VUmc. The goal of this research is to design and to test the redesign of the pre-operative process in a way that the patient satisfaction will increase. This goal is translated into the main research questions, *what causes the current waiting times at the pre-operative department? And how can the waiting times be decreased with the use of planning and control?* To answer the questions, five sub-questions are answered in the Chapters 2 to 5. A summary of the answers will be presented.

Chapter 2 has identified the current situation and the current performances. In this chapter we answer the first research question, *What is the current situation for the pre-operative screening, and what is the current performance*? Interestingly, two peaks occur, one in the morning between 10:00 and 12:00 hour and one in the afternoon between 14:00 and 15:00 hour. The same peaks are observed for walk-ins and appointment patients. Long waiting times for the patients and a high staff utilization occur, especially at those peak moments. Data shows that 25% of the patients waits longer than 60 minutes and the average waiting time for walk-in patients is 45 minutes. The waiting times occur at two places, at the first process, the nurse, and between the pre-operative processes.

With the use of the literature, the second research question can be answered, *What design and control rules can be developed for planning the carrousel*? One of the factors affecting the relation of the waiting times of the patient and the idle time of the staff is the precedence of walk-ins. Although, the arrival of walk-in patients are hard to control, we can control the planning of appointment patients using an appointment schedule. Literature from the production industry states that routing rules affect the length of stay of products. For that reason, we are interested in the impact of routing rules to reduce the waiting times between the pre-operative processes. The routing rule defines the order of the patients in the waiting room.

The planning and control rules which can be implemented to decrease the waiting times are translated into three PAC design factors, namely the capacity dimensioning, the routing rules, and the appointment scheduling. Chapter 4 answers the third research question, *What quantitative modelling approaches are suitable for the analysis of the PAC?* The chapter introduced two quantitative modelling approaches to represents the PAC of VUmc, a queuing model and a discrete-event simulation model. The simulation model is extended with a heuristic to construct an appointment schedule. With the use of the models, the performances of the PAC designs factors were analysed in Chapter 5 to answer the fourth and fifth question, *what is the performance of the designs for the per-operative department and how can the developed situation be implemented?*

For the first design factor, the capacity of the carrousel is defined, given restrictions for the maximum waiting time and the maximum utilization rate. For every process of the PAC, the consideration is made between the waiting time for the patient and the idle time of the staff. The restriction of the waiting times determined the capacity. From the fluctuation in the arrivals of the patients, it was concluded that a capacity setting per weekday performed the best.

The second design factor, the routing rule, is researched to reduce the waiting times between the pre-operative processes. The distinction is made between the maximum waiting time of the walk-in patients and the patients with an appointment. The level of implementation is also taken into account in the analysis of the five routing rules. We advise the First Come, First Served rule when the PAC of VUmc does not want to distinguish between the walk-ins and appointment. However, we recommend distinguishing, since this is more fair for the patients and therefore we advise to implement the Arrival on Earliest Appointment Time rule. This rule prioritizes patients at the first station by their appointment time given by the secretary desk. For the other stations, the FCFS rule holds.

The third design factor is the introduction of an appointment schedule. This dedicates time slots for appointments, thereby reducing the maximum waiting time of the patients (at arrival). Using an appointment system decreases the maximum waiting time for all patients by 42% and it reduces the maximum waiting time for the walk-in patients by 46%. A characteristic of the appointment schedule are the scheduled appointments at the beginning and the end of a day. Moreover, time slots are used with a small appointment interval, which defines the time between two time slots. Another apprach is with the use of appointment rules. Three rules are tested and the best performing rule schedules appointments at two out of three time slots. No appointments are allowed between 11 and 1 o'clock. An advantage of the appointment rule is that the scheduler does not lose scheduling freedom, but the drawback is that mistakes can be made. Our recommendation is to implement an appointment schedule which dedicates time slots for appointments. This can help to achieve good performances.

Several assumptions were made for the input variables. We performed a sensitivity analysis to determine the effects of changing those input variables. The amount of patients requesting an appointment have the biggest impact on the performance of the model. It is up to the PAC staff to provide an accurate ratio of those patients, after expanding the pilot study. The other two assumptions, the patient path ratios and the patient punctuality, influence the performances of the model less.

We conclude that we have reached our research goal to design and test the redesign of the pre-operative process in a way that the patient satisfaction will increase. With the defined capacity, the formulation of the routing rule and the introduction of an appointment schedule, the patient waiting times will decrease leading to more satisfied patients.

6.2 Recommendations

In this section, recommendations to the management of VUmc are provided. We advise on the implementation of the PAC design factors, the value of an additional time registration project and the limitations of this research.

Implementation of the PAC design factors
Currently, the PAC at VUmc performs a pilot study where patients from three specializations follow the carrousel principle. For a complete expansion of the pilot more staff is required. We advise implementing the capacity dimensioning per weekday as described in Section 5.2. The introduction of the carrousel also requires new working agreements, such as the routing rules defining the patient order in the waiting room. For this, we advise introducing the Arrival on Earliest Appointment Time rule. This rule is easy to implement and fair to the patients since it prioritizes patients on their appointment time.

For the implementation of an appointment schedule at the PAC, we recommend dedicating time slots for appointments in the agenda system of the PAC. This will only show the available time slots for appointments. During the day, free appointment slots and undedicated time slots are available for walk-in patients. Which time slots to dedicate is defined by an appointment schedule. To find such a schedule, the heuristic of this thesis can be used, but also the appointment rule can be applied to dedicate the time slots. This decision will have to be made by the management of the PAC, based on the available data to perform the heuristic.

Additional time registration project
If the carrousel is introduced for all patients, we suggest starting a new time registration study. As mentioned during the research, the current data of the carrousel did not cover the total patient population. With the new data, the models can be updated, increasing the reliability of the waiting times. A more accurate appointment schedule can be constructed when the exact ratio of patients requesting an appointment is known.

During this research, there was a demand for a blueprint which categorizes the patient by patients classes. Possible classes for the patients are their age or their ASA category. No relations were found in the current data set, so there was not enough evidence to categorize the patients. An advantage of patient categorization is the reduction in the variation of the consultation times causing waiting times. However, a drawback is that it limits the scheduling options. For a categorisation on the ASA score of a patient, a system needs to be implemented to indicate the ASA score at the secretary desk. Those considerations need to be made by analysing the data for patient categorization.

Limitations
One of the limitations of this research is that the lunch breaks are not taken into account. So the waiting times in the afternoon are in reality higher compared to the models. When big differences are observed, additional research is needed to prevent the afternoon waiting times. Some slight adjustments in the appointment schedule can already solve the potential problem.

6.3 Further research

Further research is needed to improve the model, to upgrade the formulation of the performances and to generalize the conclusions.

Improve the model
The main limitation of the models in this research was the run time. With further research the run time can be reduced to an acceptable level. This can be done by improving the simulation model, such that the computation time per run decreases. For example the collecting of the data from the simulation model can be programmed more efficient and unnecessary data collection can be avoided. The allocation of a time slot to the walk-in patients also takes a lot of time, for this a less time-consuming construction may be possible.

Improvements can also be made within the heuristic. At the moment, the improvement heuristic swaps two time slots randomly. By introducing smart swapping instead of the random exchanges, the heuristic may be able to find a better solution in a shorter time window. For this research no relation between characteristics of the time slots and the accepted swaps is found.

Improve formulation of the performances
In this research, a distinction is made between the waiting time of the walk-in patients and the waiting time for patients with an appointment. However, we can divide the waiting time of the appointment patients into voluntary and forced waiting time. Especially since more patients visiting the PAC with an appointment than patients visiting according to the walk-in principle, this distinction avoids a misleading performance of the waiting times.

Generalize conclusions
Our research was focussed on the pre-operative department of VUmc. Therefore, the conclusions are only applicable to this department. More general conclusions can be drawn, using different data or other settings for the models. Generalized conclusions also help to formulate components of the routing rules or characteristics of the appointment schedule.

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Appendix A

Model input

In this Appendix, we discuss the fitting of the probability distributions of the patient arrival and the consultation times with the use of the statistical program R.

Patient arrival

Estimated distribution parameters		
Normal distribution	Mu	149.45
	Sigma	26.24
K-S statistic	0.1151	
Critical value	0.2000	

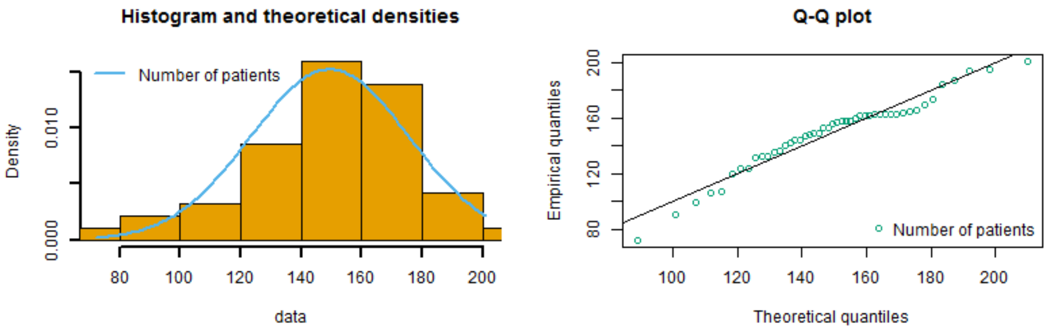

Figure A.1: Distribution fit of the number of patients per week.

Consultation times

Per process, we present the fitting of the probability distributions.

Secretary

Estimated distribution parameters		
Gamma distribution	Shape	1.028
	Scale	0.377
K-S statistic	0.322	
Critical value	0.114	

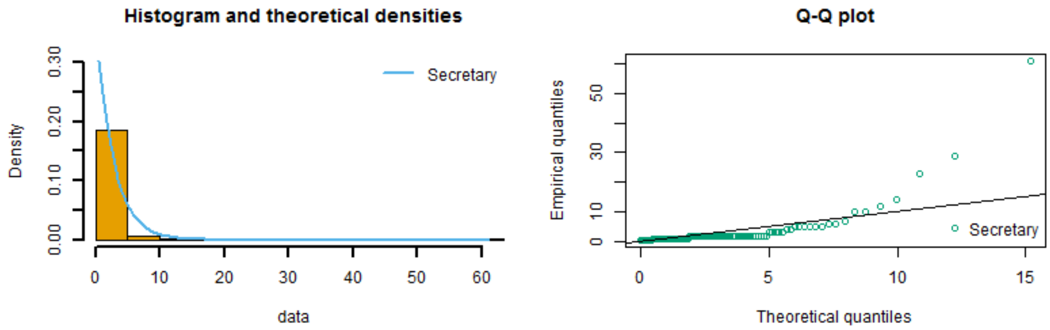

Figure A.2: Distribution fit of the consultation time of the secretary.

Nurse - Patient path 1

Estimated distribution parameters		
Gamma distribution	Shape	5.221
	Scale	0.235
K-S statistic	0.098	
Critical value	0.113	

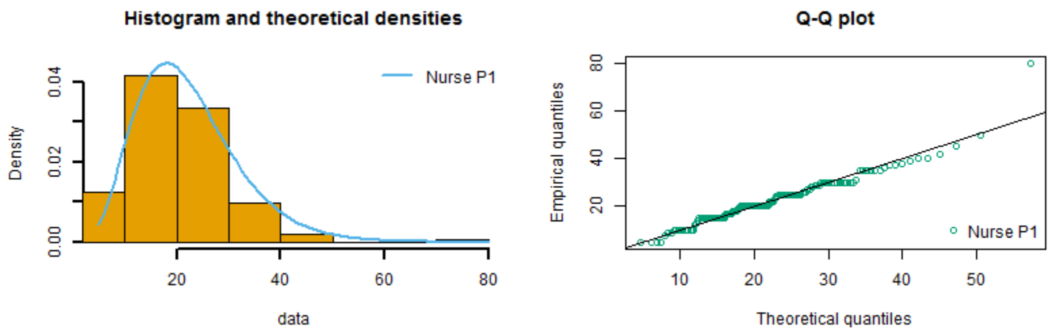

Figure A.3: Distribution fit of the consultation time of the nurse for patient path 1.

Nurse - Patient path 2

Estimated distribution parameters		
Gamma distribution	Shape	6.465
	Scale	0.230
K-S statistic	0.086	
Critical value	0.143	

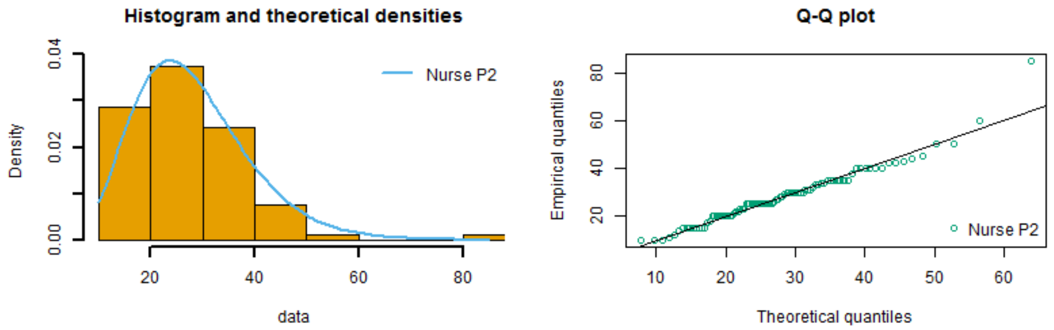

Figure A.4: Distribution fit of the consultation time of the nurse for patient path 2.

Nurse - Patient path 3

Estimated distribution parameters		
Gamma distribution	Shape	7.743
	Scale	1.355
K-S statistic	0.310	
Critical value	0.143	

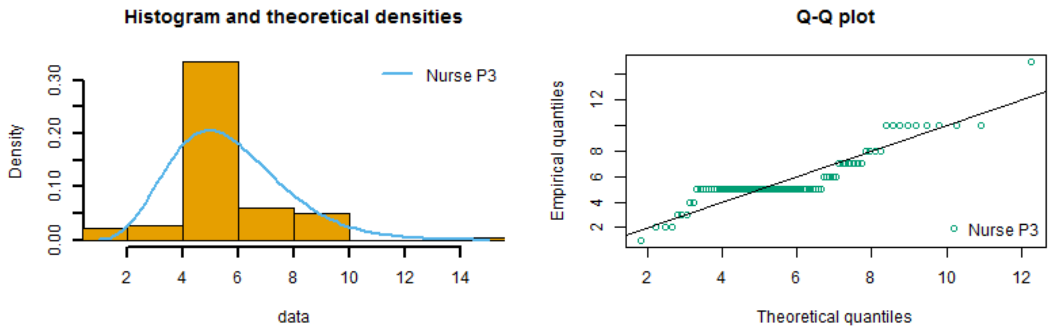

Figure A.5: Distribution fit of the consultation time of the nurse for patient path 3.

Medication team

Estimated distribution parameters		
Lognormal distribution	Meanlog	2.128
	Sdlog	0.736
K-S statistic	0.071	
Critical value	0.117	

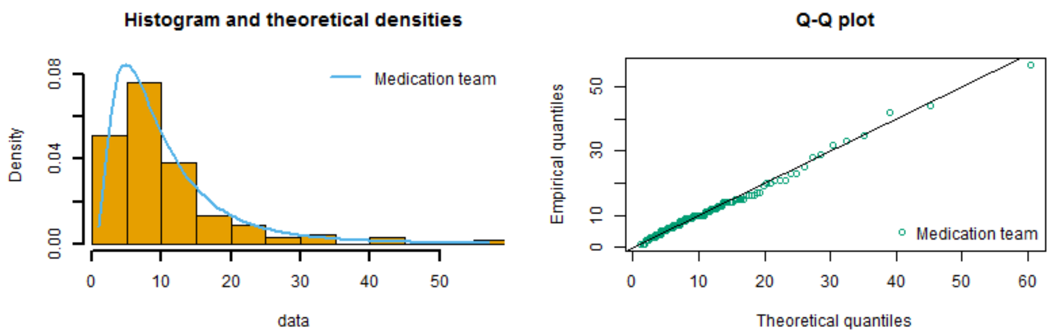

Figure A.6: Distribution fit of the consultation time of the medication team.

Anaesthetist

Estimated distribution parameters		
Lognormal distribution	Meanlog	2.769
	Sdlog	0.552
K-S statistic	0.102	
Critical value	0.083	

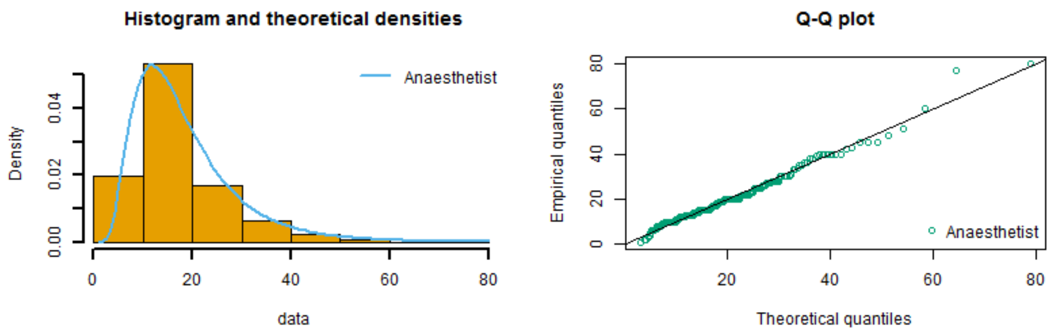

Figure A.7: Distribution fit of the consultation time of anaesthetist.

Appendix B

Flowchart routing rule

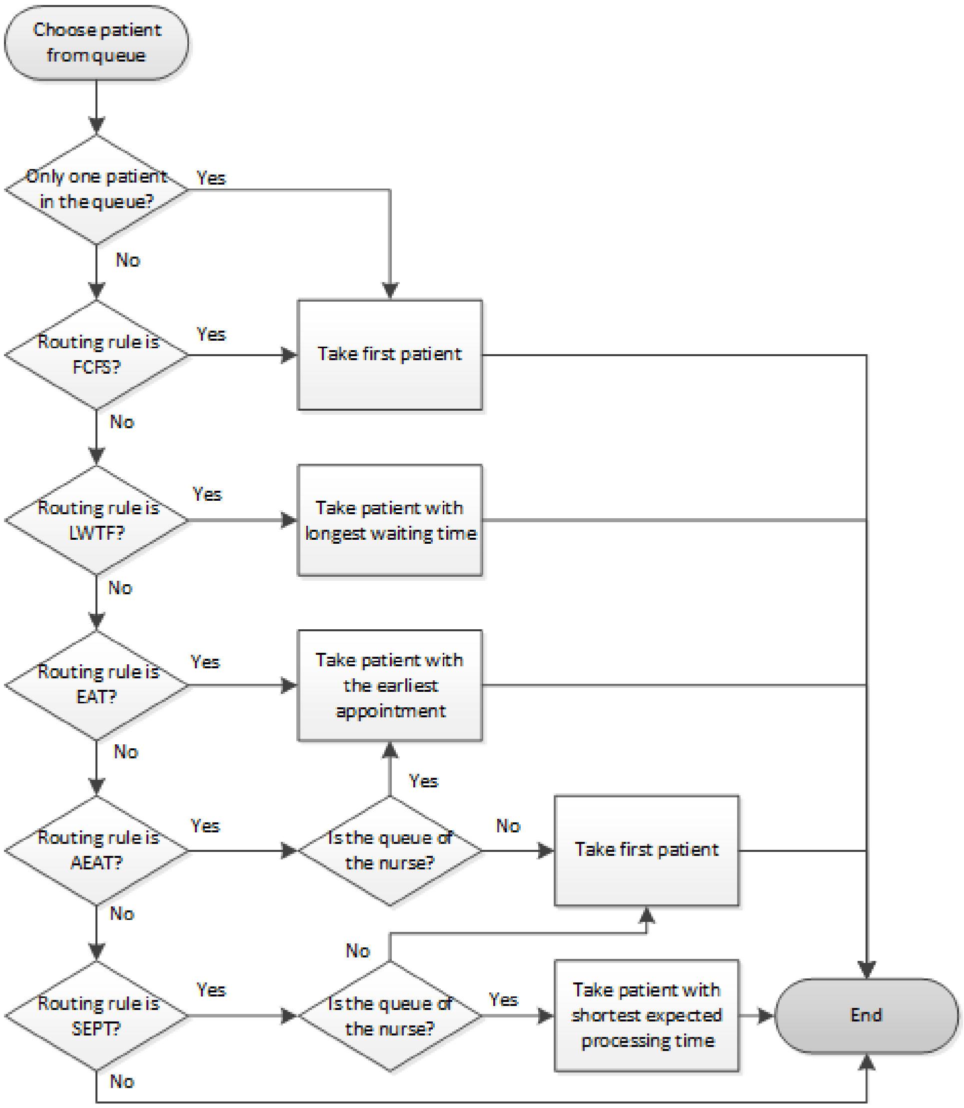

Figure B.1: Flowchart of the routing rule.

Appendix C

Capacity dimensioning results

This appendix presents additional figures for the capacity dimensioning of Section 5.2. Figure C.1 shows the relation between the arrival rate and the waiting time per setting as computed with the queuing model in Section 5.2.2.

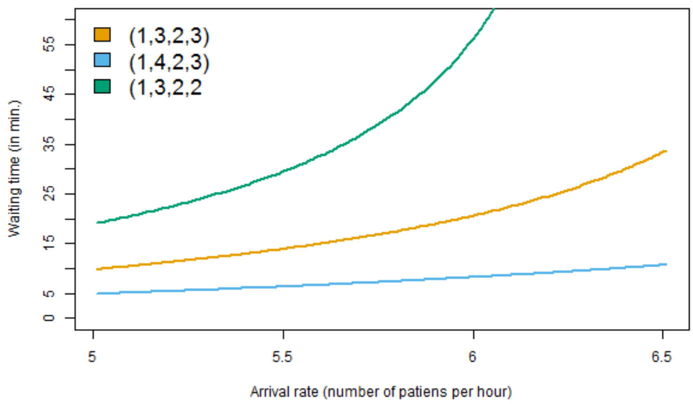

Figure C.1: Relation arrival rate and waiting time per setting.

Nurse

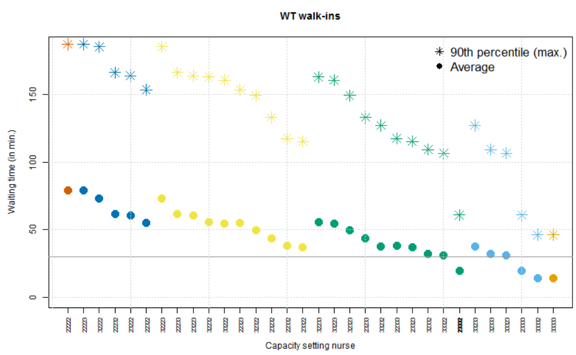

Figure C.2: Capacity settings for the nurses based on wt of walk-in patients.

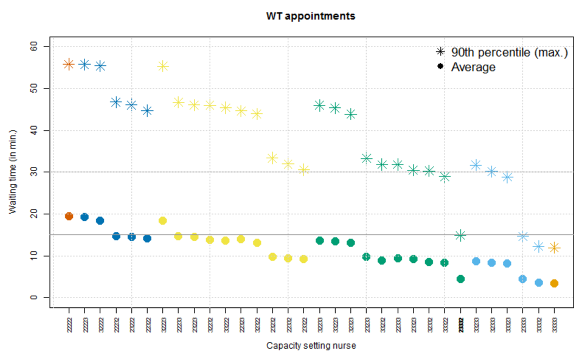

Figure C.3: Capacity settings for the nurses based on wt of appointment patients.

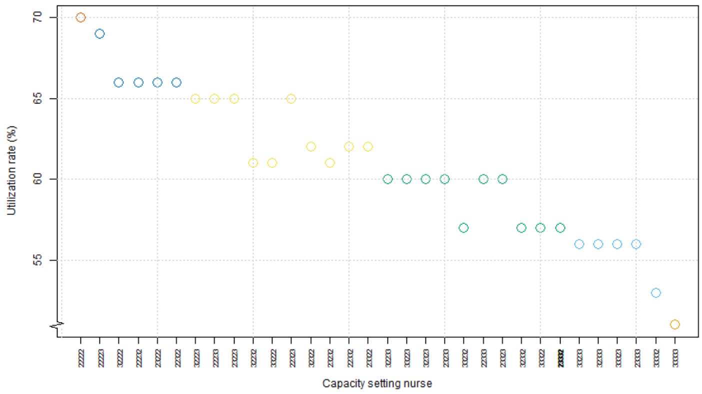

Figure C.4: Capacity settings for the nurses based on utilization of the staff.

Medication team

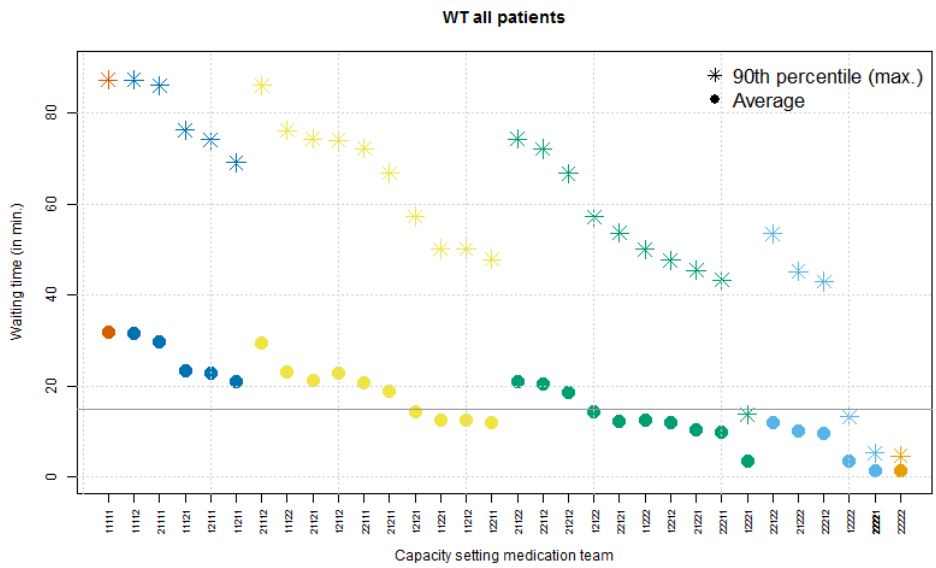

Figure C.5: Capacity settings for the medication team based on wt of all patients.

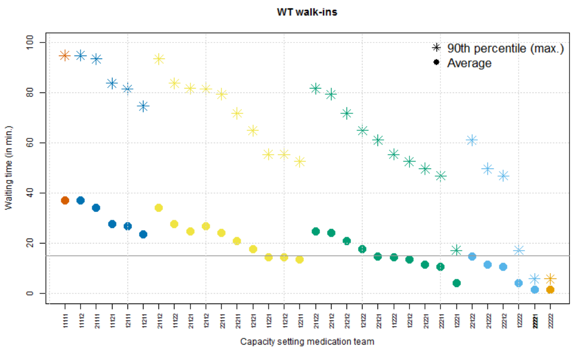

Figure C.6: Capacity settings for the medication team based on wt of walk-in patients.

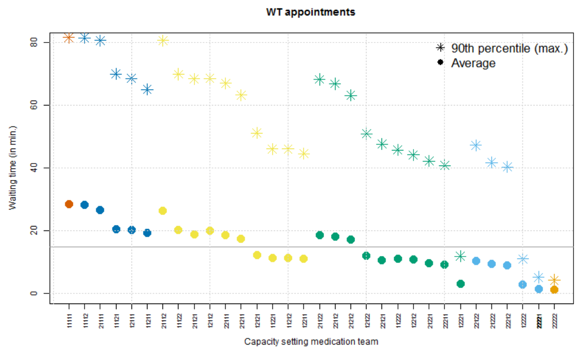

Figure C.7: Capacity settings for the medication team based on wt of appointment patients.

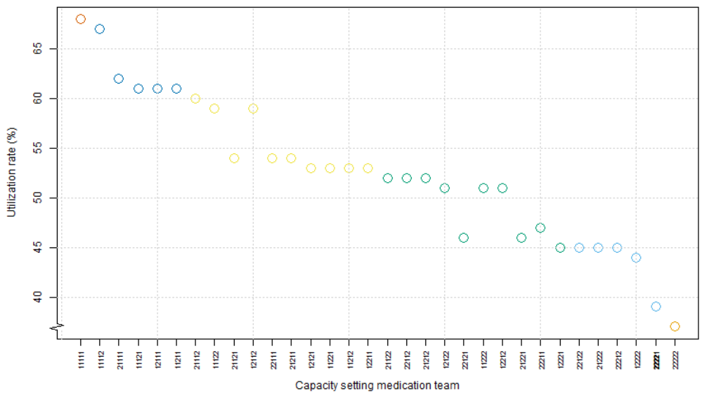

Figure C.8: Capacity settings for the medication team based on utilization of the staff.

Anaesthetist

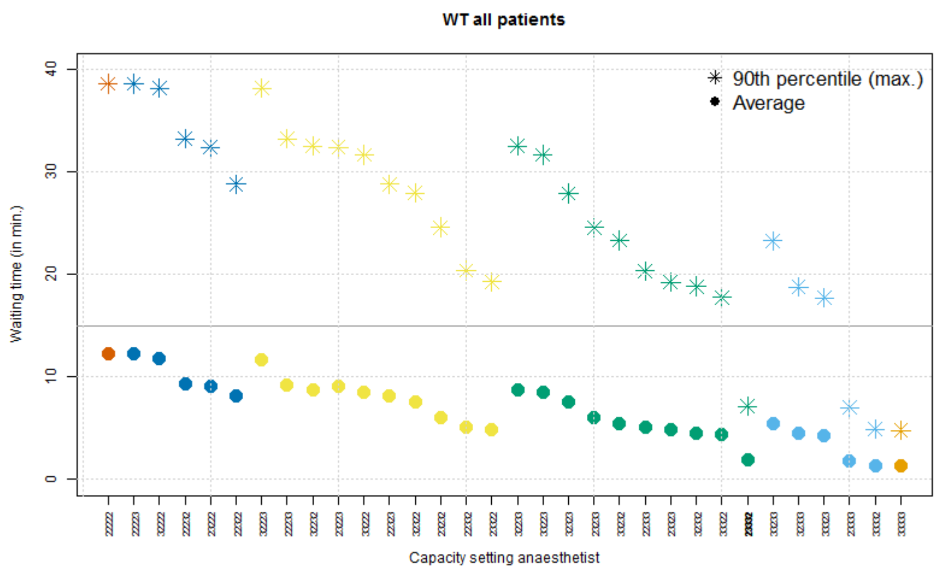

Figure C.9: Capacity settings for the anaesthetist based on wt of all patients.

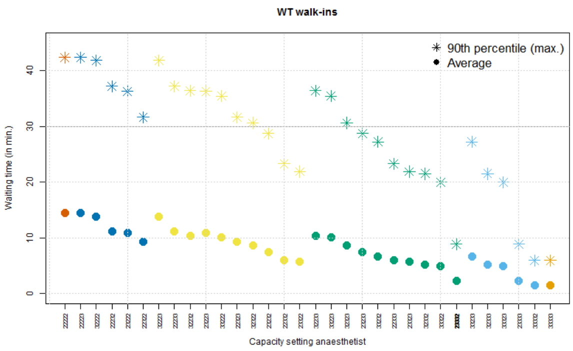

Figure C.10: Capacity settings for the anaesthetist based on wt of walk-in patients.

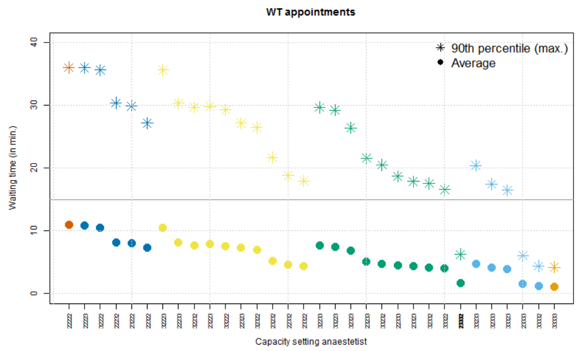

Figure C.11: Capacity settings for the anaesthetist based on wt of appointment patients.

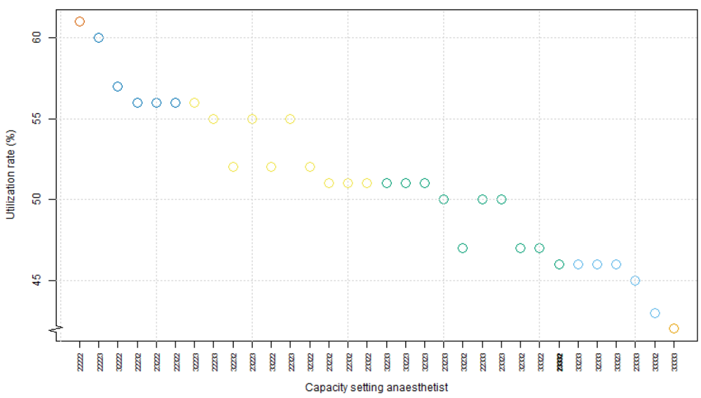

Figure C.12: Capacity settings for the anaesthetist based on utilization of the staff.

Appendix D

Routing rules results

We present additional figures of the average waiting time of the routing rules of Section 5.3 in this appendix.

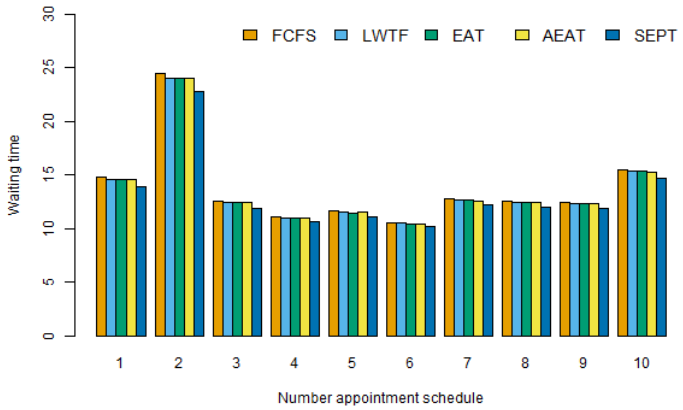

Figure D.1: Average waiting time for all patients per routing rule by appointment schedule.

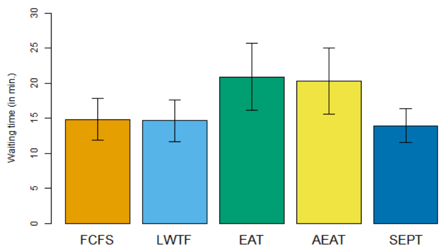

Figure D.2: Average waiting time for walk-in patients per routing rule.

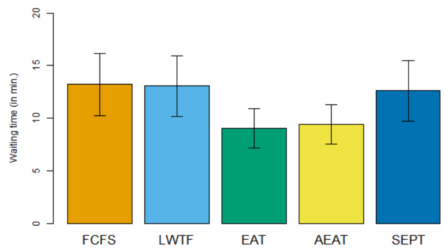

Figure D.3: Average waiting time for patients with an appointment per routing rule.

Appendix E

Appointment scheduling results

This appendix presents the performances of the appointment scheduling (Section 5.4) in more detail. The blueprint, which is used as input for the heuristic is shown in Table E.1, here appointment durations of 25 minutes for the nurse, 10 minutes for the medication team, and 20 minutes for the anaesthetist are used.

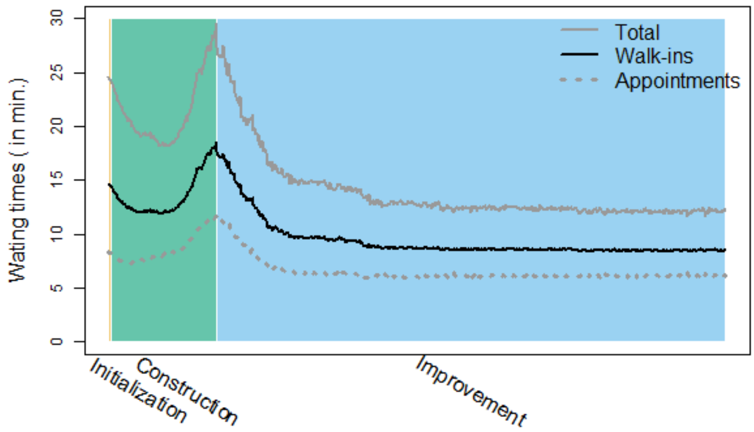

Figure E.1: Performance per heuristic phase.

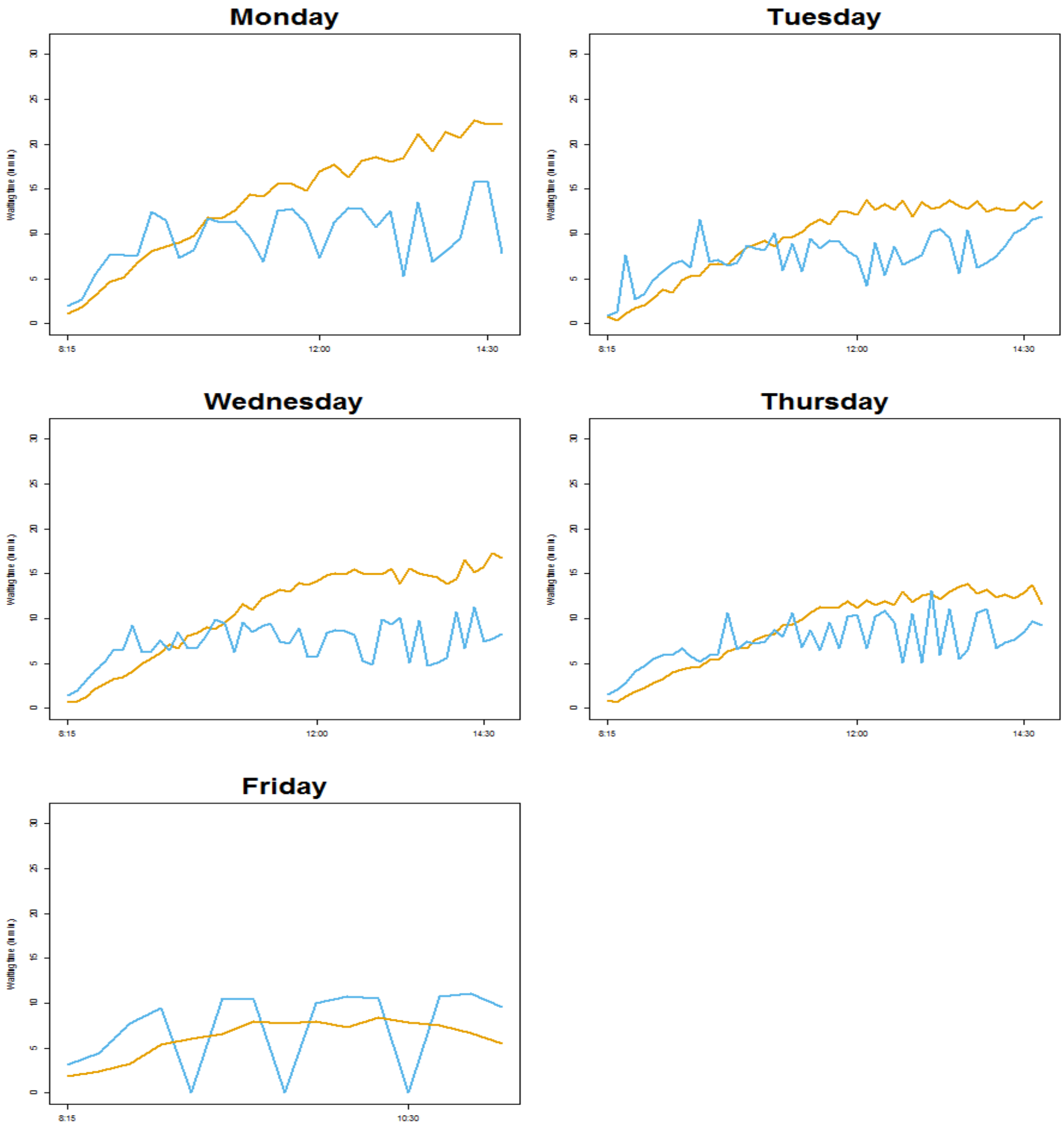

Figure E.2: Random scheduling (orange) versus appointment scheduling (blue) per weekday.

Table E.1: Blueprint with appointment schedule of the heuristic.

Monday			Thursday			Wednesday			Tuesday			Friday		
Nr.	Time	App?	Nr.	Time	App?	Nr.	Time	App?	Nr.	Time	App?	Nr.	Time	App?
1	08:15	1	33	08:15	1	81	08:15	1	129	08:15	1	177	08:15	1
2	08:25	1	34	08:20	1	82	08:20	1	130	08:20	1	178	08:25	1
3	08:40	1	35	08:30		83	08:30	1	131	08:30	1	179	08:40	1
4	08:50	1	36	08:40	1	84	08:40	1	132	08:40	1	180	08:50	1
5	09:05		37	08:45	1	85	08:45	1	133	08:45	1	181	09:05	
6	09:15	1	38	08:55	1	86	08:55	1	134	08:55	1	182	09:15	1
7	09:30		39	09:05	1	87	09:05	1	135	09:05		183	09:30	1
8	09:40		40	09:10	1	88	09:10		136	09:10	1	184	09:40	
9	09:55	1	41	09:20	1	89	09:20		137	09:20		185	09:55	1
10	10:05	1	42	09:30		90	09:30	1	138	09:30		186	10:05	1
11	10:20		43	09:35		91	09:35		139	09:35	1	187	10:20	1
12	10:30		44	09:45	1	92	09:45	1	140	09:45	1	188	10:30	
13	10:45		45	09:55		93	09:55		141	09:55	1	189	10:45	1
14	10:55		46	10:00	1	94	10:00	1	142	10:00		190	10:55	1
15	11:10	1	47	10:10	1	95	10:10	1	143	10:10	1	191	11:10	1
16	11:20		48	10:20		96	10:20		144	10:20				
17	11:35		49	10:25		97	10:25		145	10:25	1			
18	11:45		50	10:35		98	10:35		146	10:35	1			
19	12:00	1	51	10:45		99	10:45	1	147	10:45				
20	12:10		52	10:50	1	100	10:50		148	10:50				
21	12:25		53	11:00		101	11:00		149	11:00				
22	12:35		54	11:10	1	102	11:10		150	11:10	1			
23	12:50		55	11:15		103	11:15		151	11:15				
24	13:00		56	11:25		104	11:25		152	11:25	1			
25	13:15	1	57	11:35		105	11:35		153	11:35				
26	13:25		58	11:40		106	11:40		154	11:40	1			
27	13:40	1	59	11:50		107	11:50	1	155	11:50				
28	13:50	1	60	12:00		108	12:00	1	156	12:00				
29	14:05	1	61	12:05	1	109	12:05		157	12:05	1			
30	14:15		62	12:15		110	12:15		158	12:15				
31	14:30		63	12:25	1	111	12:25		159	12:25				
32	14:40	1	64	12:30		112	12:30		160	12:30				
			65	12:40	1	113	12:40	1	161	12:40	1			
			66	12:50	1	114	12:50	1	162	12:50				
			67	12:55	1	115	12:55		163	12:55	1			
			68	13:05		116	13:05		164	13:05				
			69	13:15		117	13:15		165	13:15	1			
			70	13:20		118	13:20	1	166	13:20				
			71	13:30	1	119	13:30		167	13:30	1			
			72	13:40		120	13:40	1	168	13:40	1			
			73	13:45	1	121	13:45	1	169	13:45				
			74	13:55	1	122	13:55	1	170	13:55				
			75	14:05	1	123	14:05		171	14:05	1			
			76	14:10	1	124	14:10	1	172	14:10	1			
			77	14:20	1	125	14:20		173	14:20	1			
			78	14:30	1	126	14:30	1	174	14:30	1			
			79	14:35	1	127	14:35	1	175	14:35	1			
			80	14:45	1	128	14:45	1	176	14:45	1			

Appendix F

Time registration form

Travelsheet POS carrousel – vastmaken aan dossier

Patiëntnummer: *of sticker* **Datum**:

POS balie		**START** check in	**STOP** check in	
	Tijdstip →			
		Ingevulde POS vragenlijst aanwezig?	OK aanvraag in Chipsoft?	
	Aan-vinken	JA NEE	JA NEE	
		OK binnen 4 weken?	Toestemmingformulier LSP ingevuld?	
	Aan-vinken	JA NEE	JA NEE	
Verpleegkundige		**START** gesprek	**STOP** gesprek	
	Tijdstip →			
ECG en/of longfunctie		**START** tests	**STOP** tests	
	Tijdstip →			
Medicatieteam medewerker		**START** gesprek	**STOP** gesprek	Voorbereidings **TIJD**
	Tijdstip →			
Anesthesioloog		**START** tijd lezen dossier	**START** gesprek	**STOP** gesprek
	Tijdstip →			
		START bijwerken verslag	**STOP** bijwerken verslag	
	Tijdstip →			
ECG en/of longfunctie		**START** tests	**STOP** tests	
	Tijdstip →			
OPMERKINGEN: Z.O.Z.				