Care for Walk-in

Organizing a walk-in based Preoperative Assessment Clinic

in University Medical Centre Utrecht

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Management summary

Patients that are planned for elective surgery need an individualized plan regarding their anesthesia. As part of the preoperative process, the patient is therefore assessed by an anesthetist. One of the ways to organize this assessment is by means of a Preoperative Assessment Clinic (PAC), where patients visit an anesthetist a couple of days or weeks in advance of surgery.

In University Medical Centre Utrecht (UMCU), management decided that the PAC should be organized on a walk-in basis: patients should be able to visit the PAC directly after having visited the outpatient clinic. Currently, the PAC uses an appointment system so that all patients need to return to the hospital on a later day. At the same time, current waiting times are experienced to be too high. This research focuses on the organization of a walk-in based PAC that minimizes waiting times.

We use various data sources to study the current design of the preoperative process and the design and performance of the PAC:

1. Data set regarding all mutations in the appointment system of both the outpatient clinics and the PAC.
2. Data set containing an overview of registrations on the surgery waiting lists.
3. Data from the information system used by the anesthetists that gives the number of registered assessments.
4. Paper records of the number of patients assessed at the PAC.
5. A time motion study performed at the PAC.
6. A patient survey for patients that visited the PAC.
7. Data regarding the number of inpatient and outpatient surgeries.

The time motion study is used to quantify patient throughput at the PAC. In UMCU, patients are either assessed by an anesthesiology trained nurse or a resident. We show that the expected waiting time per provider substantially differs (22 minutes for a nurse and 38 minutes for a resident). Regarding the design and performance of the PAC we additionally conclude that:

1. 35% of all patients wait longer than 30 minutes.
2. Digitalizing the questionnaires at the clerk desk requires too much time.
3. The current design of the appointment system is not transparent due to the differentiation to specialties, user-groups, and appointment types.

4. An appointment slot size of 30 minutes might not be sufficient for residents.
5. Making an ECG takes the patient 20 minutes on average; 25% of the patients need more than 25 minutes.
6. Appointments in the morning start with a delay (high provider tardiness).

The results of the patient survey suggests that an average waiting time between 15 and 20 minutes is acceptable. We find that the estimation of the future number of walk-ins is complicated by the fact that the number of patients that visit the outpatient clinics heavily fluctuates per day as well as during the day. Furthermore, we have no information about the preference of the patient to visit the PAC on walk-in.

We analyze five interventions that might improve waiting time:

Intervention A1: An alternative schedule for TCs.

Intervention A2: Excluding the ECGs.

Intervention A3: Decreasing the (effective) service time at the clerk desk by 50%.

Intervention A4: Decreasing the (effective) service time of residents by 50%.

Intervention A5: Scheduling patients directly to providers.

Based on an extensive data analysis, we derive the number of walk-ins per hour of the day. We suggest two alternative appointment systems that reserve capacity for walk-ins: one based on an appointment slot size of 30 minutes per provider, the other based on an appointment slots size of 40 minutes for residents and 30 minutes for nurses.

We design a discrete-event simulation model of the PAC and use it to study the effect of various process interventions. The model also includes functionality to evaluate appointment systems under walk-in conditions. By means of the simulation model, we conclude that:

1. Excluding ECGs and balancing TCs over the day does not (greatly) improve waiting times.
2. Decreasing the processing time at the clerk desk by 50% improves the expected waiting time by 5 to 6 minutes on average.
3. Decreasing the preparation time of residents by 50% reduces the expected waiting time for a resident by 13 to 14 minutes on average.
4. Assigning patients directly to providers when scheduling appointments reduces waiting time by 2.5 to 3 minutes for nurses and 4 to 6 minutes for residents.
5. The combined effect of (2), (3), and (4) equals the sum of the individual interventions. Waiting times can be reduced by 7 to 8 minutes for nurses and 21 to 23 minutes for residents.
6. An appointment system that incorporates a 40 minute slot size for residents slightly outperforms one than incorporates 30 minutes.
7. It is essential that most appointments are scheduled in the morning and that workload is evenly balanced over the week. If these criteria are not met, the PAC risks that staff members need to work in overtime (after 4 PM).

8. An appointment system based on the criteria of (7) in combination with the process intervention of (5) suggest that the PAC can be successfully organized on walk-in and at the same time drastically reduce waiting times.

At the time of publication of this report, implementation had not yet started. Although we believe our data analysis gives a good indication of the future number of walk-ins, possible deviations from our estimation must be addressed as soon as possible during implementation. We therefore support future implementation with a computer tool that can be used to register all walk-in patients that visit the PAC. This allows the PAC to easily evaluate the number of walk-ins per hour per day and consequently the robustness of the appointment system that has been implemented.

Our research leaves an extensive database regarding the preoperative process in general and the PAC in particular. Our simulation model provides the means for management to study various process interventions. The model is suitable for modeling other (outpatient) clinics given some slight modifications.

Preface

With this thesis, I successfully finish my Master *Industrial Engineering & Management – Production & Logistic Management* track – at the University of Twente. During my study, I developed a special interest into the applications of industrial engineering in health care. My bachelor graduation study focussed on the inventory management of disposables in an OR theatre, and in 2008 I performed an additional research into the optimization of instrument trays.

June 2008, I contacted Arjan van Hoorn to discuss options for a graduation project at University Medical Centre Utrecht. Arjan is responsible for a hospital-wide project that aims to split non-urgent elective care from specialized care. Part of this project is the ambition to organize a walk-in PAC so that the patient service level in the preoperative process is improved. To me, this concept sounded very challenging and the prospect of designing a simulation model (and moving from Enschede to Utrecht) made me decide to accept Arjan's offer.

My research was performed in the period October 2008 to May 2009. Although I started out with the idea that walk-in based PACs were fairly innovative, I was quickly disappointed. A number of hospitals in The Netherlands had already implemented a walk-in based PAC, though with mixed results. We visited a few of these hospitals to inform ourselves of the difficulties of implementation and management of a walk-in clinic. Most notable was the story of a hospital that explained that they had given up on controlling walk-ins and waiting times and that their main focus had shifted to attaining a reasonable patient service level by providing extra personal attention to those that wait in the waiting room. In practice, this meant that patients were provided an extra cup of coffee. Naturally, this story did not encourage our PAC's management.

During the first days of my research I was (again) amazed by the complexity of daily operations in health care. Especially regarding the preoperative process, which involves numerous departments that all have their own policies, working methods, information systems, and people. As a result, creating a clear overview of all operations involved in the preoperative process was complicated.

I must conclude that a part my data analysis – that is, the part that was most time consuming – can now be considered superfluous. For determining the expected number of walk-ins, I initially thought I was restrained to a single strategy. In the end, after having operationalized this strategy, it appeared that an alternative was already available. Luckily I was able to adopt this alternative in the end, since it appears more reliable than the first strategy.

I enjoyed my research period and my workplace in UMCU. Many people contributed to the successful completion of this research and I thank all of them. I especially thank Arjan van Hoorn for providing me this research assignment, his supervision and feedback. Arjan was always available for thinking along with me and my research. Likewise he appreciated my feedback on several matters too, so it was a nice trade-off. Furthermore, it was nice to see how Arjan strives to make hospital logistics more prevalent in UMCU and manages to do so. I thank Bregt Michel en Wilton van Kleij for allowing me to do my graduation project at the PAC of UMCU and their flexibility to discuss my research findings. I hope they will be able to successfully implement my suggestions. Special thanks to Peter Hulshof and Erwin Hans for their supervision and constructive feedback. I appreciated Erwin's enthusiasm with regard to my plans to start my own company and hope for a fruitful collaboration in the (near) future.

From the first week to the last, I enjoyed working on my graduation project. This is due to my enthusiasm for doing research into hospital logistics but moreover due to the enthusiasm and positive comments of my – both formal and informal – supervisors. I thank my parents and girl friend for their support in me finishing my (slightly extended) study in Enschede.

I close this preface with some short airy findings that originate from my research period:

1. Bregt Michel, chief of the PAC, was concerned about our plans to organize a walk-in based PAC after having visited the hospital I described. In the weeks that passed, additional stories emerged about hospitals that were not able to successfully implement a walk-in based PAC. Now that I finished my research, the last time I spoke Bregt, she indicated that she now believes a walk-in based PAC can be realized, which I was glad to hear.
2. I started my research behind a desk in a redecorated storage room with a clear view on four walls. I ended up at the management alley, in a room with three nice colleagues, and a topnotch coffee machine.
3. In the early days of my research, Erwin suggested that my writing style should also be evaluated on being to-the-point, in light of my business plan. I managed to keep this report within 100 pages.
4. Creating a 1.1 GB data collection in a 7 month period exceeds my wildest expectations.
5. When using large data sets, I would like to inform the reader that Excel 2007 can handle a lot more records than preceding versions. For me: having known this earlier might have saved a lot of additional work.
6. Thinking about the possibilities regarding the options to maybe start up your own company is fun. Actually starting it is even better.

Abbreviations and termininology

AS Appointment System

Effective service time The service time adjusted for availability of the provider, defined by the service time divided by the availability of the provider.

ENT Ear, Nose, Throat (ENT) specialty. Branch of medicine that specializes in the diagnosis and treatment of ear, nose, throat, and head and neck disorders. The full name of the specialty is otolaryngology-head and neck surgery [3].

ES Expected service time.

ET Expected sojourn time, where $ET = EW + ES$.

EW Expected waiting time.

FCFS First Come, First Serve rule. Means that the patients or files are served/processed in order of arrival.

OC Outpatient clinic or outpatient department.

PAC Preoperative Assessment Clinic.

Perioperative process Consists of the pre-, per-, and postoperative process. These respectively involve the patient care before, during, and after surgery.

Provider tardiness The difference between the planned starting time of a provider and the actual starting time. Provider tardiness is negative when the provider starts earlier than planned. It can thus be considered as the lateness of the provider.

SAD The Surgery Administration Desk. At the SAD, patients that have received a surgery indication are registered and scheduled for surgery.

Surgery indication A formalization of a request for surgery provided by the surgeon, submitted on paper or electronically.

SCV Squared Coefficient of Variance, σ^2/μ^2.

UltraGenda The name of the appointment system (manufacturer and) software package used in UMCU.

Contents

List of Figures

List of Tables

CHAPTER 1

Introduction

Patients that are scheduled for elective surgery have to be examined by an anesthetist prior to their surgery. During this medical assessment, the patient's physical condition is evaluated and, if necessary, upgraded. In consultation with the patient, the anesthetist then composes an individualized plan for a patient's anesthesia during perioperative care. This medical assessment is part of the preoperative process, which involves all activities that are required to prepare the patient for surgery. Most hospitals in the Netherlands have nowadays organized their preoperative process by means of a Preoperative Assessment Clinic (PAC) [17]. The PAC is an outpatient clinic where patients are assessed by an anesthetist a number of days or weeks in advance of surgery.

The PAC in the University Medical Centre Utrecht currently uses an appointment system to schedule all patient visits. In the near future, patients should be able to visit the PAC on walk-in basis, while patient sojourn time at the PAC should be controlled. The objective of this research is to determine how the preoperative process at the PAC can be organized from an operations management point of view.

1.1 Research context: University Medical Centre Utrecht

University Medical Centre Utrecht (UMCU) is a large health care provider with medical, educational, and research facilities located in Utrecht. It consists of a university hospital (*Academisch Ziekenhuis Utrecht*, AZU), a pediatric hospital (*Wilhelmina Kinderziekenhuis*, WKZ), and a medical faculty. UMCU has a total capacity of 1000 beds. Annually, approximately 334,000 patients visit the outpatient clinics and 24,000 surgical treatments are performed [1, 28]. Aside from regular health care services, the UMCU offers top-clinical care for patients with non-regular diseases.

1.2 Problem description

All patients that request to consult a surgeon at the outpatient clinic are scheduled for an appointment. A fraction of the patients is planned for a surgical treatment. For others, additional medical testing might be needed or the surgeon decides on a non-surgical treatment resulting in, for example, a drug prescription. When the surgeon and patient agree on a surgical treatment, the request for surgery is formalized by means of a *surgery indication*, which can either be a paper form or electronic request. Patients with a surgery indication enter the preoperative process, which entails the following activities:

Registration for surgery. All patients that receive a surgery indication are registered on the surgery waiting list. The surgery administration desk (SAD) is responsible for the administration of surgical patients and, regarding some specialties, the scheduling of surgeries. There are two types of SADs in UMCU: the first is a single centralized desk where all daycare patients are processed; the second is decentralized to every specialty and only processes clinical patients.

A ward screening. Contrary to daycare patients, patients that are planned for inpatient surgery are hospitalized. Clinical patients therefore need additional screening by the ward department. A nurse evaluates the physical and mental conditions of the patient and informs the patient about his or her stay in the hospital. The organization of the ward screening is dispersed: some specialities assess their patients on the same day as the PAC screening (i.e. a number days or weeks in advance of surgery), while others assess their patient on the day of hospital admission.

The preoperative assessment. At the PAC, patients visit an anesthetist who more thoroughly assesses the patient's health and physical condition. If the anesthetist considers the patient physically able to undergo surgery, a *surgery fiat* is provided. In consultation with the patient, the anesthetist then decides on the type of anesthesia to be used during surgery, and on optional pain relief before and after. In UMCU, the screening at the PAC is performed not only by anesthetist, but also by trained nurses.

UMCU distinguishes between two types of patients: clinical and daycare patients. Clinical patients are admitted before surgery and expected to recover in the hospital. These patients often receive invasive surgery requiring relatively long recovery and health monitoring. Daycare patients are not hospitalized and thus admitted and discharged on the same day as surgery. These patients often require relatively short surgery and recovery time and do not receive a ward screening. All patients, besides those who receive surgery with local anesthesia, require screening at the PAC, resulting in 10,000 PAC visits per year.

Currently, patients that receive a surgery indication, have to make a seperate appointment for the PAC and/or ward screening. The current organization of the preoperative process entails two problems:

1. Patients have to return to the hospital on a later day only for the PAC and/or ward screening.
2. The general opinion is that patients incur high waiting times in the waiting room of the PAC.

The PAC is experienced to be the main bottleneck in the preoperative process, inducing a relatively long access and waiting time. Hospital management decided that the access time to the PAC should be minimized: all patients should be able to visit the PAC directly after a surgery indication. Hence, the PAC should be organized on a walk-in basis. At the same time, UMCU strives to keep waiting times to a minimum. The future situation is illustrated in Figure 1.1 from the perspective of queuing theory. Per day, a number of patients leaves the outpatient clinic with a surgery indication. Some of these patients prefer to visit the PAC and ward screening directly. Others prefer to return for screening on a later day. Both options should be available for the near future.

This raises the question how to organize the preoperative process from a logistics point of view. What are the consequences for the required capacity and patient waiting time when implementing a walk-in based PAC?

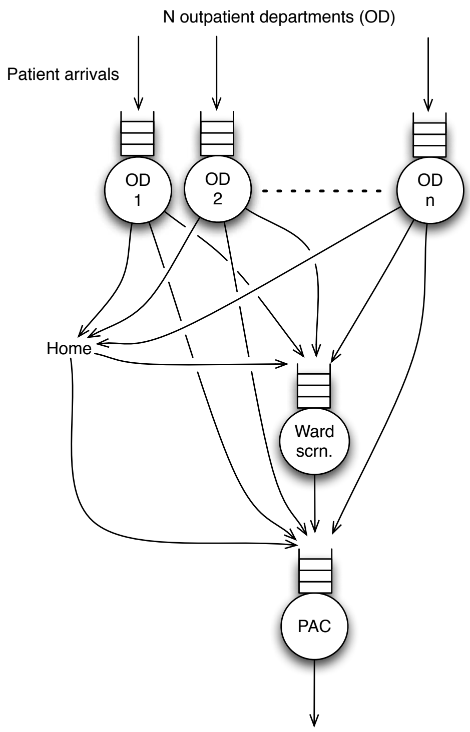


Figure 1.1: The preoperative process on a walk-in basis.

1.3 Research objective

Both daycare and clinical patients should be able to visit the PAC on walk-in basis. The appointment system should remain available for patients that prefer an appointment for a later day. Therefore, our main research question is:

How should the walk-in based PAC be organized while keeping waiting times to a minimum?

We focus on the appointment system and capacity planning. The appointment system should facilitate the PAC in scheduling appointments for patients that request to visit the PAC with an appointment and reserve capacity for walk-in patients. Additionally, the appointment system should support the PAC in keeping patient waiting times to a minimum.

1.4 Research questions

The main research question is supported by the following investigative questions, which illustrate our research design and the outine of this report:

Chapter 2: The current situation.

1. Which data sources can be used to evaluate the process at the PAC and the preoperative process in general?
2. Which performance measures should be used to evaluate the PAC's performance?

Section 2.1: The preoperative process: How is the preoperative process organized?

1. What are the various patient pathways in the preoperative process?
2. What stages and activities can be distinguished?
3. Which outpatient clinics are involved?
4. How many patients visit the outpatient clinics per day of the week?
5. What is the fluctuation of patient arrivals at the outpatient clinics during the day?
6. How many patients visit the PAC per day of the week?
7. What is the service time at the PAC?

Section 2.2: The organization of the PAC: How is the PAC currently organized?

1. What is the PAC's current capacity regarding physicians and nurses?
2. How is the PAC's appointment system designed?
3. What are the current arrival rates at the PAC?

Section 2.3: The performance of the PAC.: What is the PAC's current performance?

1. What is the mean waiting time at the PAC?
2. How do patients experience these waiting times?
3. What is the provider tardiness, patient punctuality, and number of no-shows?
4. What is the effect of an ECG requirement on patient sojourn time?

In Chapter 2, we describe the preoperative process and the current organization and performance of the PAC. We introduce the data sources that are available in our research and specifically the results of a time motion study carried out at the PAC. The time motion study is used to determine the performance indicators of the PAC. As described in Section 1.2, the preoperative process involves numerous administrative and medical tasks performed at multiple departments. Furthermore, the preoperative process entails multiple patient pathways and outpatient clinics. Section 2.1 deals with these topics. Section 2.2 describes the current organization of the PAC regarding its appointment system and capacity. The characteristics of the preoperative process combined with the organization of the PAC directly affect its performance. Here, our main interest goes out to the waiting time that patients incur. The performance of the PAC is discussed in Section 2.3.

Chapter 3: Literature.

1. What does the literature state on organizing walk-in based clinics?
2. What strategies can be adopted to decrease waiting times?
3. What are the critical building blocks of an appointment system?
4. Which appointment system designs are suggested?
5. Which modeling technique is successfully used to model hospital clinics?

In chapter 3, we provide an overview of the literature that is available on clinic scheduling. Primarily, our interest goes out to the literature that is available on organizing a walk-in based outpatient clinic and the options for designing the appointment system. Furthermore, we summarize options for minimizing patient waiting times.

Chapter 4: The process interventions at the PAC.

1. Which process interventions might decrease waiting time at the PAC?
2. How many walk-in patients will visit the PAC in the future?
3. How can the appointment system be redesigned to reserve capacity for walk-in patients?

Chapter 4 proposes process interventions and alternative designs for the PAC's appointment system. In this chapter, we discuss interventions that might decrease patient waiting times and estimate the future number of walk-in patients. The latter is used to design a number of alternative appointment systems that will be evaluated in our simulation model.

Chapter 5: The computational approach used for assessing the interventions.

1. How to design a simulation model of the PAC?
2. What is the conceptual flow model of the PAC?
3. How to determine unknown input parameters for the simulation model?
4. Which distributions can be used to model the arrival rates and service times at the PAC?
5. What are the parameters of these distributions?

Chapter 5 describes the design of a discrete event simulation model of the PAC. We illustrate how a conceptual flow model can be used to model the various activities at the PAC as a series of workstations. Per workstation, we define the parameters and distributions of the arrival rates and service times. Since the processing times for some activities (or stations) at the PAC are unknown, we resort to a queuing model for deriving these processing times based on the average waiting time. The results of the queuing model analysis are then used for designing the simulation model. This computational approach is explained in more detail in Chapter 5.

Chapter 6: Computational results and implementation.

1. What are the results of simulating the process interventions?
2. What are the results of simulating the alternative appointment systems under walk-in conditions?
3. What is the best option available for improving patient waiting time?
4. How should the appointment slots be assigned over the day?
5. How should the new appointment system be implemented?

Chapter 6 presents the simulation results concerning the interventions presented in Chapter 4. We present the process intervention that results in the largest improvement of waiting times and the appointment system that best facilitates the PAC in reserving capacity for walk-in patients. We furthermore reflect on the options available to support the implementation of the new appointment system.

In Chapter 7, we discuss the results of our research and put forward the main recommendations regarding the organization of the PAC. We suggest options for further research, especially with regard to the simulation model which allows hospital management to study a large variety of interventions.

CHAPTER 2

The current situation

This chapter describes the current design and performance of the PAC. Section 2.1 describes the preoperative process in more detail: the various patient routings and departments involved, the main administrative and/or medical tasks performed per department, the number of appointments at the OCs and PAC, and the time needed for the PAC assessment (*service time*). Section 2.2 presents the current design of the PAC's appointment system (AS) and the related capacity planning. The AS's design directly influences the waiting time at the PAC. This performance measure – along with the provider tardiness, patient punctuality, and number of no-shows – will be discussed in Section 2.3.

Throughout this research, we present the results of data analyses carried out with one or more of the following 8 data sets:

Data set $\mathbb{A}$: Overview of mutations in the ASs (*UltraGenda*) of the outpatient clinics. Gives an overview of patient visits to the outpatient clinics in the period October 2007 – December 2008 ($n = 118,918$), excluding all end-of-treatment visits .

Data set $\mathbb{B}$: Overview of mutations in the PAC's AS (*UltaGenda*). Provides all registered PAC appointments registered in the period July 2008 – December 2008 ($n = 5,778$).

Data set $\mathbb{C}$: Overview of registrations on the (various) surgery waiting lists (*Chipsoft, Wachtlijst II, COPS*). Provides an overview of all patients that were placed on the surgery waiting list (clinical and daycare) in the period October 2007–December 2008 ($n = 26,292$).

Data set $\mathbb{D}$: Data from the information system used by the anesthetists in the operating room (*Vier-Kleurenpen*. Gives an overview of all surgeries performed in the period January 2007 – March 2009 ($n = 25,050$) for which an assessment was registered based on the patient's medical file.

Data set $\mathbb{E}$: Paper records of the number of patient visits registered per day in the period January 2009 – April 2009 ($n = 53$). Every morning, the appointment schedule is printed on paper and supplied to the medical staff members. The clerk manually adds urgent patient visits to this schedule, making it a complete overview of daily patient throughput at the PAC

Data set $\mathbb{F}$: A time motion study performed at the PAC during the period September 2008 – December 2008 ($n = 1,167$). Allows us to determine service, waiting, and throughput times as will be illustrated later-on.

Data set $\mathbb{G}$: A patient survey for patients that visited the PAC during the period September 2008 – January 2009 ($n = 153$). Provides us with information about patient satisfaction concerning PAC visits.

Data set $\mathbb{H}$: The number of daycare and clinical surgeries performed in the period December 2007 – December 2008 ($n = 24,018$).

The time range of the data sets differ, though all data lie between November 2007 and April 2009. For data set $\mathbb{A}$, some outpatient clinics have appointment data available that cover a couple of months, while others cover a complete year. Appendix A illustrates how the time ranges per data set and per outpatient clinic overlap and gives an overview of all variables that are available in each data set.

The time motion study forms an essential part of this research. Figure 2.1 illustrates the design of our time motion study. We registered the patient arrival time, appointment time, the time the clerk finishes the administrative tasks (*medical file ready*), and the time the patient enters and leaves the consultation room. Furthermore, we registered the time of departure and return at the PAC for patient that are requested to make an ECG. The time motion study enables us to define time ranges:

1. The punctuality of patient arrivals defined as $Arrival\ time - Appointment\ time$. A punctuality of 5 minutes means the patient arrives 5 minutes in advance of his or her appointment time. If punctuality < 0, than the patient arrives to late.
2. The provider tardiness defined as $Time\ start\ consultation - Appointment\ time$. A tardiness of 5 minutes means the provider starts 5 minutes later than the planned starting time. If tardiness < 0, than the providers starts earlier than planned.
3. The expected time needed for making an ECG.
4. The expected time needed for the administrative activities at the clerk desk.
5. Expected waiting time, EW.
6. Expected service time, ES.

In our patient survey, patients rated various aspects of their PAC visit, like the waiting time, pleasantry of treatment, accessibility for scheduling appointments, and expertise of the nurse/physician. In the context of this research, we are primarily interested in the ratings of the waiting time. We relate these subjective measures to the registered times so that we can quantify “acceptable” waiting times. This topic is covered in section 2.3.

2.1 The preoperative process

One of the anesthetist’s tasks encompasses the controlling and relief of pain for patients in the pre-, per-, and postoperative process [10]. Therefore, all patients scheduled for elective surgery have to

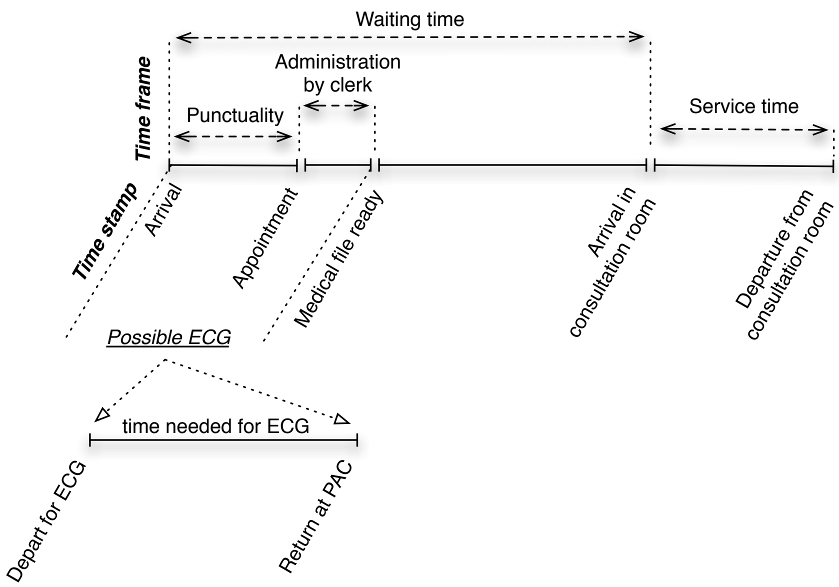


Figure 2.1: The design of the time motion study.

be assessed by an anesthetist. This assessment is part of the preoperative process and can either be performed a few hours, days, or weeks in advance of surgery. Traditionally, elective patients were assessed on the same day as surgery, i.e. a few hours before surgery. Most hospitals in the Netherlands nowadays organize the assessment by means of a centralized PAC [17] where patients visit the anesthetist a number of days or weeks in advance of surgery. The PAC supports the anesthetists in a timely evaluation and optimization of a patient's health status, facilitates the planning of anesthesia and peri-operative care, and is used to obtain informed consent with the patient [13]. When a patient is considered physically able to undergo surgery, an (medical) approval for surgery is provided by the anesthetist.

Most patients are assessed at the PAC, however, assessments are also done at the ward. These assessments involve patients admitted in the hospital that are, due to their condition, unable to visit the PAC. In most cases, these patients have an above average urgency and their surgery is scheduled for one or two days later. Figure 2.2 shows an overview of four assessments types that are distinguished in this research. These assessments all involve screening for regular surgery; emergency surgery is thus outside our scope.

Regarding Figure 2.2, type (1) PAC requests refer to all patients that have previously visited one of the surgical outpatient clinics, are planned for surgery, and subsequently need a pre-surgery assessment. These patients are scheduled for a *regular* appointment. Type (2) and (3) requests consist of high priority patients admitted in the hospital for which surgery is scheduled one or two days later. These patients need to be assessed on short notice. These assessment requests arrive randomly throughout the day and are scheduled in addition to regular appointments. Here, type (2) PAC request refer to patients that are able to visit the PAC themselves and are scheduled as

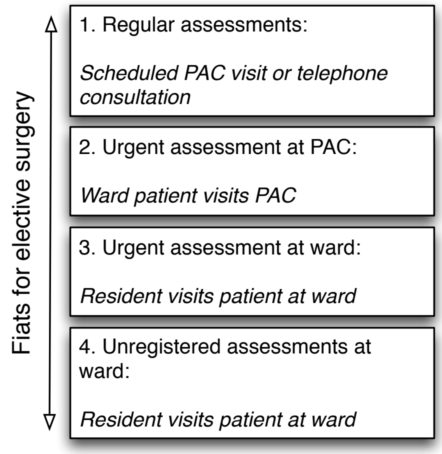


Figure 2.2: In the preoperative process, assessments can either performed at the PAC (request type 1 and 2) or by an anesthetist visiting the patient at the ward department (request type 3, 4).

urgent appointments, while type (3) PAC requests refers to patients that have to be seen at the ward. Finally, request type (4) consist of patients for which residents are directly contacted at the PAC and requested to see a patient at the ward. Type (4) assessments are not registered as a consultation at the PAC, since the clerk desk is not consulted. The majority of assessments (95%) are type (1) assessments. The walk-in based PAC is primarily designed for this population of patients.

For the latter type of patients, we distinguish between four pathways in the preoperative process, based on four patient types. All patients can be characterized along two dimensions: the type of surgery they are planned for and the type of anesthesia that will be administered. There are two types of surgery: inpatient and outpatient surgery. Patients scheduled for inpatient surgery are referred to as clinical patients; patients scheduled for outpatient surgery are referred to as daycare patients. Regarding the types of anesthesia, we distinguish between (1) local anesthesia and (2) general and regional anesthesia. The first is administered by the surgeon without the intervention of an anesthetist. These patients do not visit the PAC. The latter type(s) of anesthesia can only be administered by an anesthetist or, in some cases, an anesthesiology trained nurse. From hereon, we refer to this type of anesthesia as simply *general* anesthesia. Patients that require general anesthesia, and consequently close monitoring during surgery, all visit the PAC. The 4 patient types are:

1. Daycare patients receiving local anesthesia; Daycare-Local (DL) pathway
2. Daycare patients receiving general anesthesia; Daycare-General (DG) pathway
3. Clinical patients receiving local anesthesia; Clinical-Local (CL) pathway
4. Clinical patients receiving general anesthesia; Clinical-General (CG) pathway

Figure 2.3 illustrates the 4 preoperative pathways. All pathways start at the outpatient clinic where the patient is diagnosed, which might require the patient to return a number of times due to testing or trying out (non-surgical) treatments. Depending on the success of alternative treatments, a fraction of the patients receives a surgery indication. The surgeon then requests the patient to be planned for surgery, either electronically or by a paper form. From hereon, the patient continues via one of the 4 pathways. As can be seen from Figure 2.3, all pathways currently require the patient to go home after leaving the outpatient clinic with a surgery indication and to return on a later time. These shaded steps can be skipped in the future if the patient prefers to continue to the PAC directly. Currently, a small group of patients is already served on a walk-in basis (indicated by dotted line *a*). For some specialties, the ward screening is performed one day before or on the day of surgery (indicated by the dotted lines *b*). In general, surgery for daycare patients is performed at another location than clinical patients.

We summarize the pathways as follows:

DL: Daycare patients that require local anesthesia do not need further medical screening and are placed on the waiting list at the (central) outpatient SAD. The patient goes home and is contacted when his or her surgery is scheduled. This group of patients accounts for 23% of the total number of regular surgeries.

DG: Daycare patients requiring general anesthesia are registered at the outpatient SAD, schedule an appointment at the PAC, and return on a later day. The DG-group accounts for 28% of the total number of regular surgeries.

CL: Clinical patients that require local anesthetics. These patient report at the SAD of the corresponding specialty and request for an appointment at the PAC. Consequently, patients return on a later day for their assessment. These patients account for 5% of the total.

CG: Clinical patients requiring general anesthesia also report at the SAD of their corresponding specialty. At most SADs, the clerk schedules a dual appointment for the ward screening and PAC visit. The CG-group accounts for 44% of the total.

This is a rather general representation of the preoperative process, since the organization of the preoperative process and its patient pathways slightly differ per specialty. For example, some specialties perform the ward screening one day before or on the day of surgery instead of combining it with the PAC visit. And likewise, the E.N.T. specialty arranged walk-in appointments at the PAC on wednesdays to allow one specific type of patients to be assessed on the same day as their visit to the outpatient clinic. However, for the majority of patients the preoperative process consists of the chronologic steps as depicted in Figure 2.3.

Regarding the stages of patient visits in the preoperative process, we distinguish the SAD, the ward screening, and the PAC. The preoperative process is initiated by the physician that plans the patient for surgery. Most surgery request originate from the outpatient clinics, where the surgeon decides on the surgical treatment and type of anesthesia that is required. We now discuss these stages one by one.

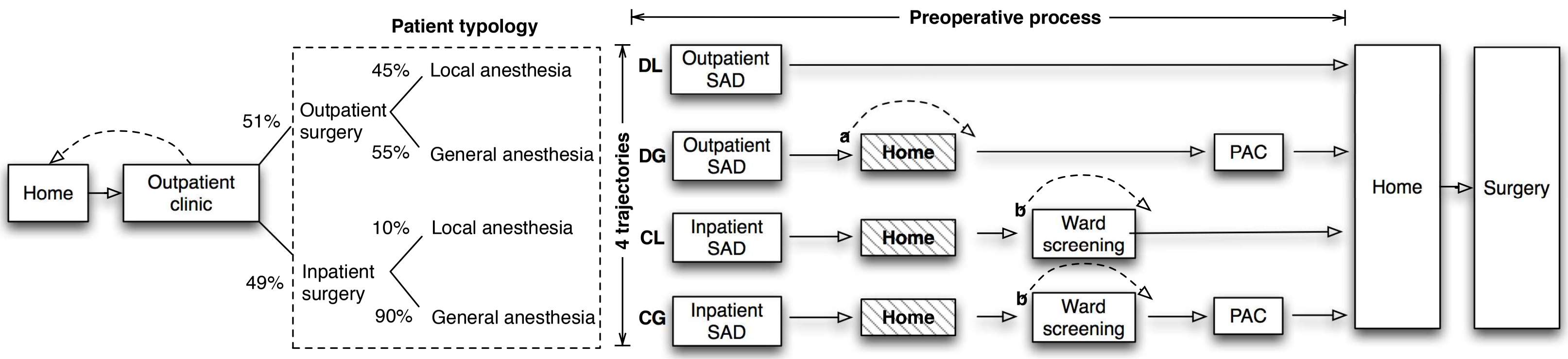


Figure 2.3: The 4 patient pathways in the preoperative process:. **a** refers to a specific group of patients of the ENT specialty that is already served as walk-ins at the PAC; **b** means that not all specialties schedule a ward screening (a number days or weeks) in advance of hospitalization.

Table 2.1: The average number of appointments scheduled for all relevant OCs per working day (data set $\mathbb{A}$). T_{weeks} indicates the number of weeks covered in the data set; $N_{patients}$ indicates the sample size.

Outpatient clinic	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	T_{weeks}	$N_{patients}$
General surgery	28.6	37.2	33.2	31.2	12.6	48	6,536
Gastroenterology/Oncology	27.0	2.6	17.6	4.0	43.5	48	4,052
Trauma surgery	19.8			22.3		37	1,125
ENT surgery	86.0	68.6	101.8	68.7	56.9	58	21,999
Gynecology	60.0	63.2	60.6	67.4	38.0	20	5,666
Neuro surgery	11.4	12.1	10.4		9.2	12	397
Ophthalmology.	185.5	172.6	144.6	178.7	158.2	60	50,696
Oral and Maxillofacial surgery	50.7	20.7	19.6	26.7	21.3	21	2,833
Orthopaedy	36.6	42.6	14.8	36.7	23.4	34	5,141
Plastic surgery	26.1	27.0	19.8	34.3	21.6	35	3,580
Special Care Dentistry	9.2	26.9	6.2	7.4	8.0	21	1,136
Urology	43.3	39.0	35.3	43.9	9.2	49	8,165
Vascular surgery	19.6	10.1	21.1	19.5		33	2,524
Total	650.5	594.0	555.5	602.7	445.9		

2.1.1 The outpatient clinics

The data presented in this section are based on the historic data of the outpatient clinic's ASs. Excluded from the data are the end-of-treatment visits. This type of visits refer to patients that have been treated successfully where their treatment is closed by a final visit to the physician. Since we are interested in all patient visits that might result in a surgery indication, the exclusion of this type of visits does not restrict our analysis. Not all outpatient clinics cover the same number of months: the largest data set covers one year while the smallest covers three months (see Appendix A).

Approximately 2,300 patients visits are registered at the (surgical) outpatient clinics (*OCs*), based on the period November 2008−December 2008. Table 2.1 shows an overview of all 13 OCs that are relevant for this research and the average number of patient visits per day. From this table we conclude that the number of visits per day differs considerably between the specialties. Ophthalmology accounts for most patient visits. For the total number of visits per day, Fridays are most quiet. Some clinics are closed on specific days during the working week as indicated by the blank fields. For all clinics, the SCV lies between 0.1 and 0.3.

Regarding Table 2.1, we remark that the patient visits can be further differentiated to appointment types. Frequently occurring types of patient visits are formalized in the AS in so-called *appointment types* like an *urgent return visit*, a *telephone consultation*, or a *post-surgery visit*. Some specialties have unique appointment types for specific diseases, for example, oncologic consultations (accounts for multiple specialties), or an *uveitis* or *retina* consultation (Ophthalmologic surgery only). Furthermore, appointments can be differentiated to first and follow-up visits. The range of appointment types per specialty varies between 15 and 30. It is beyond the scope of this research to discuss these appointment types in detail. The appointment types simply illustrate the diversity in types of patient-physician consultations.

Since the OCs forward patients to the PAC, the number of patients that visit the OCs during the day will directly affect the number of walk-in patients at the PAC. Figure 2.4 gives a graphical representation of the arrival rate of all patients that visit the OCs per working day aggregated to one-hour intervals. The arrival rate is represented by the number of scheduled appointments per hour. During lunch hours, the OCs schedule less appointments. Morning hours are most busy.

From Figure 2.4, only a fraction of the patients that arrive per hour directly continues to the PAC in the future. This fraction depends on:

1. The probability that the patient leaves the OC with a surgery indication.
2. The probability that the patient prefers to visit the PAC directly after leaving the OC.

If a patient receives a surgery indication and prefers to visit the PAC directly, then it is important to approximate the moment of walk-in at the PAC.

2.1.2 The surgery administration desks

The SAD functions as the first station in the preoperative process: patients that leave the outpatient clinic with a surgery indication continue to the SAD. As explained in Chapter 1, the UMCU differentiates between 2 types of SADs. All daycare patients visit the centralized SAD, from hereon referred to as the *outpatient SAD*. Clinical patients continue to the SAD of their corresponding specialty, referred to as the *inpatient SAD*. Figure 2.3 shows that all patients visit one of these SADs. The organization of the inpatient SAD is very dispersed. Some specialties have clustered their SADs at one location, others are organized individually. Figure 2.5 illustrates how the organization of the SADs differs between specialties. For daycare patients, the SAD is centralized at one location; clinical patients are referred to the SAD of their corresponding specialty. The tasks performed at these various desks roughly correspond. They involve the following activities:

1. Register patients for surgery.
2. Manage surgery waiting list.
3. Schedule dual appointments for PAC and ward screening (inpatient surgery) or single PAC appointments (outpatient surgery).
4. Schedule clinical patients for surgery (does not account for all SADs).
5. Schedule patients for additional medical tests needed prior to surgery.
6. Collect a patient's medical records for preparation of surgery.

It is beyond the scope of this research to discuss the tasks in detail. The reader is referred to Appendix B.1 for a flow chart of the activities performed at one of the largest SADs in the UMCU. This SAD covers the specialties of general, GE, trauma, orthopedic, plastic and vascular surgery and urology (as illustrated in Figure 2.5).

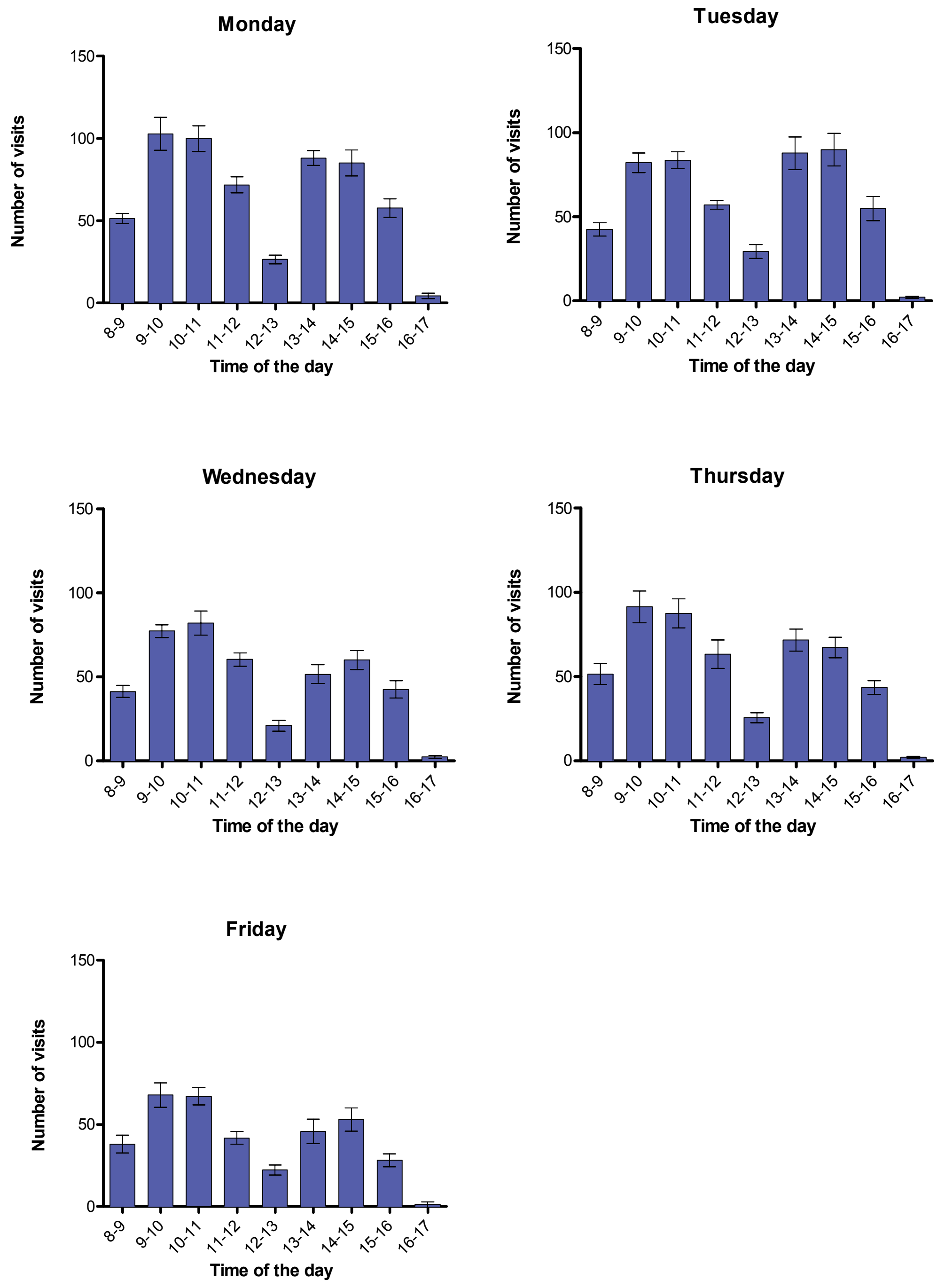


Figure 2.4: The average and 95% CI of the number of appointments scheduled in the OCs during a full working week (data set $\mathbb{A}$).

<table>
<tr><th rowspan="2">Outpatient clinics</th><th colspan="3">Organization of SAD</th></tr>
<tr><th>Inpatient care</th><th colspan="2">Outpatient care</th></tr>
<tr><td>General surgery</td><td rowspan="12">Centralized</td><td rowspan="13">Decentralized</td><td rowspan="7">Collective</td></tr>
<tr><td>G-E/Oncologic surgery</td></tr>
<tr><td>Trauma surgery</td></tr>
<tr><td>Orthopedic surgery</td></tr>
<tr><td>Plastic surgery</td></tr>
<tr><td>Urology</td></tr>
<tr><td>Vascular Surgery</td></tr>
<tr><td>ENT surgery</td><td>Single</td></tr>
<tr><td>Gynaecology</td><td>Single</td></tr>
<tr><td>Neuro surgery</td><td>Single</td></tr>
<tr><td>Ophthalmologic surgery</td><td>Single</td></tr>
<tr><td>Stom. dis./Orthogn. surgery</td><td>Single</td></tr>
<tr><td>Special Care Dentistry</td><td></td><td>Single</td></tr>
</table>

Figure 2.5: The organization of the SADs per specialty.

2.1.3 The ward screening

As described in Chapter 1, not all specialties schedule the ward screening on the same day as the PAC assessment. The bed capacity (and management) at the ward department is differentiated to the various specialties. These specialties all have their own policy of organizing their preoperative process. As a consequence, some specialties screen their patients on the day of hospital admission. The specialties that assess their patients in advance of hospital admission by mean of a ward screening are General, GE-Oncologic, Orthopedic, and Plastic surgery and Urology. These specialties have organized this screening next to the outpatient clinics. All other specialites assess their patients on the same day as hospital admission.

At the ward screening, the patient sees a ward nurse. This nurse performs some basic medical examinations and informs the patient about the procedures concerning his or her surgery and hospital admission. Figure B.2 in Appendix B.1 gives a graphical representation of all acitivites performed during the screening. We do not elaborate on these activities, since the PAC is our primal focus. However, we do remark that the medical examination slightly overlaps with the assessment at the PAC.

By screening patients a couple of days or weeks in advance of hospital admission, the ward department can prepare for the arrival of its patients. Furthermore, when this screening is done in advance of hospital admission, ward nurses do not require extra time for informing patients about the procedures involving their hospitalization, since this has already been taken care of. For the future, management has suggested that the ward screening should be integrated in the PAC visit by default. During our research, there was no definite decission taken regarding the future organization of the ward screening.

2.1.4 The Preoperative Assessment Clinic (PAC)

Patients can only be scheduled for surgery if they are assessed and received approval for surgery. By providing approval, the anesthetist expects that the patient is physically able to undergo surgery. The assessment for a specific type of patients is also performed by trained nurses under the responsibility of a physician, as will be illustrated later.

A patient reports at the PAC either to schedule an appointment or because of a scheduled appointment. In the first case, an appointment is scheduled and the patient leaves the PAC. We remark that not all patients schedule their appointment themselves at the clerk desk, as will be discussed in Section 2.2. In this section, we focus on the activities performed at the PAC.

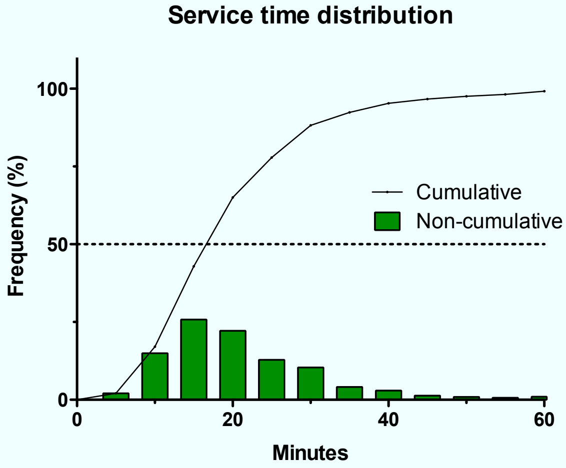
On average, approximately 44 patients are assessed per day (based on data set $\mathbb{D}$ and $\mathbb{E}$). This includes patients with regular, urgent, and urgent ward appointments (see Section 2.1). The ratio between daycare and clinical patients is 3 : 7.

When a patient arrives at the PAC for an appointment, the clerk iteratively performs the following tasks:

1. Checks whether the patient has filled in the health questionnaire. The questionnaire is used to determine the patient's health classification which is subsequently used to determine the provider that sees the patient (nurse or resident).
2. Determines whether the patient requires an ECG. Patients with particular disorders (defined by a protocol) or those that are above 60 years of age currently all require a (recently recorded) ECG. When a patient requires an ECG, and no recent one is available in the central database, the patient is asked to first record an ECG after which to directly return to the PAC.
3. When all required patient information is available, the patients is requested to take place in the waiting room.
4. The clerk digitalizes the questionairre so that it is electronically available for the nurse to determine the patient classification. Recently, the PAC implemented an online questionnaire, which, for the future, should permanently replace the paper forms. Patients can now fill in the questionnaire electronically via the internet. The information is than directly available for the PAC and the clerk is relieved from the time consuming duty of manually digitalizing all paper questionnaires. Currently, not all patients use the online questionnaire, initiating a lot of work at the clerk desk.
5. When the questionnaire is electronically available and the patient has a recently recorded ECG (if requested), the patient's medical file is placed in a bin. Next, the nurse is signalled by means of telephone call.

Here, the time needed for (2) and (4) were registered in our time study as depicted in Figure 2.1.

The nurse collects all medical files that await classification. The questionnaire is used to determine the patient's health status. Based on these results, patients are assigned to either a trained nurse or a resident. The nurse evaluates patients that are considered healthy and undergo regular surgery, indicated by *health status 1*, or HS-1. Physicians serve patients with *health status 2*, HS-2. Patients labeled HS-2 have complicating medical conditions or undergo complex surgery. When the



Number of values	1115
25% Percentile	15.0
Median	20.0
75% Percentile	25.0
Mean	21.4
Std. Deviation	11.0
Std. Error	0.331
Lower 95% CI of mean	20.8
Upper 95% CI of mean	22.1

Figure 2.6: The distribution of the service time at the PAC.

nurse has decided on who attends the next patient, the medical file is placed either in the nurses' or residents' bin, where the FCFS rule is applied.

The first available provider checks the bin for medical files, picks the file, and then prepares the consultation. Hereafter, the patient is called from the waiting room. During consultation, the nurse or physician more thoroughly assesses the medical condition of the patient. The medical history and possible drug prescriptions of the patient are evaluated. The blood pressure is measured and, optionally, a blood test is requested. Furthermore, the patient is informed about anesthesia procedures. If the nurse or resident expects that the patient can undergo surgery, and, in consultation with the patient, has decided on the type of anethesia, an approval for surgery is registered and send to to SAD.

Figure in Appendix B.3 shows a flow chart on the decision making at the PAC.

2.1.5 Service times

The service time was registered in our time motion study. The expected service time, *ES*, refers to the expected time between the patient entering and leaving the consultation room. The service time excludes the time needed to prepare and close a consultation, like reading a patient's medical file and finishing administrative tasks.

Figure 2.6 depicts the distribution of the service time. The plot represents the service time distribution for the total patient population. Most appointments take between 15 and 20 minutes while the expected service time is 21 minutes. The service time for approximately 50% of all patients is less than 20 minutes.

A topic of special interest to the PAC's management are the service time statistics per patient type. It appears that the expected service time per provider type does not significantly differ (21 minutes for nurses compared to 23 minutes for residents). However, the most apparent results are

Table 2.2: The 95% CI of the expected service time, differentiated to patient and provider type.

	Provider type	
Patient type	Nurse	Resident
ECG required	[24.6, 27.8]	[23.0, 26.3]
ECG not required	[17.4, 19.0]	[18.8, 22.3]

obtained when differentiating the patient population to provider and ECG-requirement. As illustrated in Table 2.2, the expected service times significantly differs between patients that require and ECG and those that do not.

We thus conclude that ECG patients require significantly more time than patients that do not require an ECG. This can be explained by the medical complexity of the patient, since ECG patients have a higher age and/or morbidity. Another (additional) explanation is that the ECG for itself might result in a longer service time. Nurses are obliged to consult a resident or doctor for interpreting ECGs and (junior) residents are not evenly practiced in reading ECGs themselves, which both delay the process. During our research, the medical staff indicated that the ECG might not be required anymore in the future, due to its possible lack of medical relevance. A research into this medical relevance of ECGs at the PAC is currently designed.

2.2 The design of the PAC

This section describes the current design of the PAC's AS and capacity planning. At the end of 2008, all outpatient clinics, including the PAC, have been migrated to a new electronic AS, UltraGenda's *UltraGenda Pro*.

2.2.1 The appointment system

In section 2.1.2, we summarized the activities of the SADs. One of the tasks of the SAD is to schedule appointments for the PAC and ward screening. Both the inpatient SAD and the PAC can schedule screening appointments for the PAC, however they are both authorized for different appointment types. Since most clinical patients need a ward screening and assessment at the PAC, these patients are scheduled for *dual* appointments. With a dual appointment, a patient first visits the ward screening and then directly continues to the PAC. Daycare patients only need an assessment at the PAC and are thus scheduled for a PAC visit only, a *singular* appointment. As a result, patients should either schedule their appointment at the SAD or the PAC. In practice, most clinical patients are scheduled for screening at the (inpatient) SADs, while most daycare patients contact the PAC themselves for scheduling an appointment. For some specialties, the SADs also schedule PAC visits for daycare patients. Furthermore, not all patients directly schedule an appointment at the PAC after having received a surgery indication. The expected surgery date determines whether the patient

<table>
<tr><th rowspan="2">Specialty</th><th colspan="2">PAC appointment scheduled by</th></tr>
<tr><th>Clinical patients</th><th>Daycare patients</th></tr>
<tr><td>General surgery</td><td rowspan="7">Inpatient SAD</td><td rowspan="12">PAC</td></tr>
<tr><td>G-E/Oncologic surgery</td></tr>
<tr><td>Trauma surgery</td></tr>
<tr><td>Orthopedic surgery</td></tr>
<tr><td>Plastic surgery</td></tr>
<tr><td>Urology</td></tr>
<tr><td>Vascular Surgery</td></tr>
<tr><td>ENT surgery</td><td>PAC, walk-in</td></tr>
<tr><td>Gynaecology</td><td>OC</td></tr>
<tr><td>Neuro surgery</td><td>SAD and PAC</td></tr>
<tr><td>Ophthalmologic surgery</td><td>PAC</td></tr>
<tr><td>Stom. dis./Orthogn. surgery</td><td>PAC</td></tr>
<tr><td>Special Care Dentistry</td><td></td><td>SAD and PAC</td></tr>
</table>

Figure 2.7: The departments that are responsible for scheduling assessments for the PAC for both daycare and clinical patients.

should visit the PAC on short notice.

We remark this is a general description of the operational activities of the current AS. Figure 2.7 summarizes how the scheduling of assessments at the PAC differs per specialty. Either the PAC or the SAD schedules these appointments, with some slight exceptions: for gynaeocology, the OC schedules PAC appointments; some patient types for ENT surgery are served on walk-in basis at the PAC. Since there are multiple departments involved in scheduling either single or dual PAC appointments, the AS is differentiated over various "user groups", specialties, and appointment types, making it rather opaque. As an illustration, an overview of the PAC's appointment slots available on Mondays is presented in Appendix C.

The first appointment slot is available at 8:15 AM and the last on 3:30 PM. In general, the appointment interval is 15 minutes and regular block size is 2 (there are two slots available per 15 minutes). In the morning, additional slots are available for consultations by phone, making the initial block size 3. Per day, 6 telephone consultations (TCs) are available, however, the clerk can schedule to 120% of this capacity. TCs are used for patients that have recently visited the PAC for which the health status only needs updating before supplying approval for surgery. The appointment slots are differentiated over specialties and appointment types. An appointment type can be a (urgent) dual or single appointment (see Figure C.1 in Appendix C; every color indicates a unique combination of a specialty and an appointment type). The slots can be assigned to patients by either the PAC's or SAD's staff members. We will not discuss the daily functioning of this AS in more detail. The most important aspect of the current AS is the differentiation to specialties and appointment types and the default slot size of 15 minutes.

The number of appointment slots per day lays between 46 and 51 (data set $\mathbb{E}$), which consists

Table 2.3: The average number of assessments (data set $\mathbb{E}$, January 2009−April 2009, $n = 53$) and available appointment slots per day (data set $\mathbb{B}$, July 2008−November 2008).

Patient type	**Average number of assessments**					
	Mon	**Tue**	**Wed**	**Thu**	**Fri**	**Per week**
Regular	46.1	42.6	41.2	38.7	37.1	41.1
Urgent	1.7	1.9	1.5	0.1	1.0	1.2
Urgent ward	2.0	1.3	1.2	1.5	1.1	1.4
Total	49.8	45.8	43.9	40.3	39.2	43.8
	Number of slots available					
Regular and urgent	56	56	55	52	57	55.2

of regular appointments, TCs, urgent appointments, and urgent ward appointments (1, 2, and 3 from Figure 2.2). Requests for urgent appointments have to be complied on the same day. Currently, the AS balances the number of PAC assessment requests during the week. Patients are more or less scheduled evenly over the week, based on the PAC's available capacity per day, number of expected urgent assessment requests, and the preference of patients regarding their day of appointment. Table 2.3 shows the average number of assessments and available slots per day. Mondays are most busy; Fridays most quiet. Data set $\mathbb{E}$ indicates an average of 43.8 assessments per week. The average occupation rate of the AS is smaller than 100% due to the average number of available slots being larger than the average number of appointments per day. We have no clear view on the number of unregistered assessments at the ward. However, staff members indicate that, on average, approximately 1 patient is requested to be seen at the ward per day (without this request being registered at the clerk desk). Then the average number of assessments per day equals $43.8 + 1 = 44.8$. Regardless of the actual number of unregistered ward visits, data set $\mathbb{D}$ and $\mathbb{E}$ indicate an average of 44-45 assessments per day.

Lunch breaks are scheduled in two shifts of 30 minutes between 12AM and 1PM. In this time interval, the AS has 1 appointment slot available.

2.2.2 The current capacity

In section 2.1.4, we described how the role of the trained nurses differs from residents: the nurses serve all HS-1 patients, physicians all HS-2 patients. On regular working days, 2 nurses, 2 residents, and 1 anesthetist is available. The residents perform the tasks of the physicians. Sometimes, an additional nurse is available, however, this nurse mainly performs administrative tasks. The anesthetist only serves as a supervisor and does not assess patients. During busy hours, physicians can also serve HS-1 patients. However, nurses never serve HS-2 patients.

Three clerks are available at the clerk desk. One of the staff members serves the patients that arrive at the clerk desk. During busy hours, one of the remaining staff members can assist the other. However, the clerk cannot be assisted during the whole day, since this staff member has other administrative tasks to attend. Working hours are from 8 AM to 4 PM.

In the previous section, we concluded that two appointment slots are available per 15 minutes.

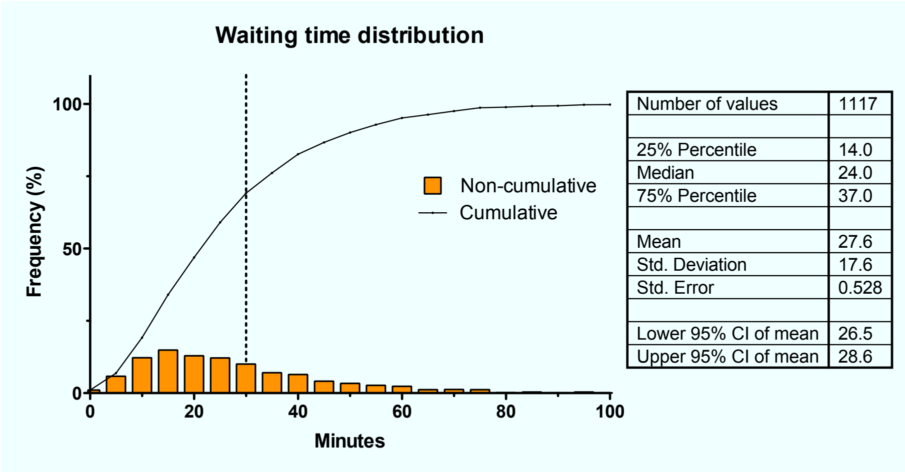


Figure 2.8: The distribution of the waiting time at the PAC.

Since there are 4 providers available (2 nurses and 2 residents), the AS is based on a consultation time of 30 minutes. As a consequence, every staff member, regardless of the patient's health status, has 30 minutes available for consultation. This time frame includes the preparation and finishing of consultations, which we did not register in our time motion study. From the previous section we know that the expected service time is 21 minutes, excluding preparation and finishing consultations. Hence, we question whether an appointment interval of 30 minutes per provider is realistic.

2.3 Performance

We are primarily interested in the waiting times and the rating of the waiting time based on the patient survey. Dexter [9] advocates that, aside from the design of the AS, three additional factors influence waiting times: provider tardiness, patient punctuality, and no-shows. We therefore also discuss these factors. Furthermore, we present the average time needed for making an ECG. This is not directly related to the waiting time, but does seriously affects the length of stay for a PAC visit.

Waiting times

Figure 2.8 shows the distribution of the waiting time (starting time consultation minus arrival time) at the PAC. The plot's tail indicates a large variation. The expected waiting time is 27 minutes and 35% of the patients is not served within 30 minutes. From Figure 2.8 we conclude that 35% of the patient population is not served within 30 minutes and 20% waits longer than 40 minutes.

The most apparent results are obtained when differentiating the patient population to provider. The results are shown in Table 2.4. We see that the average waiting time for patients that wait for a resident is significantly longer than for patients that wait for a nurse: 38 minutes compared to 22 minutes respectively. Management indicated that the fraction of patients that is served within 30

Table 2.4: The waiting time for patients served by nurses and residents (HS-1 and HS-2 respectively).

	Total	Nurse	Resident
EW	0:27	0:22	0:38
Median	0:23	0:20	0:35
N	1,115	728	370

Table 2.5: The results of the patient survey, where patients were asked to rate the waiting time on a ordinal scale from 1 to 5.

Rating	Description	N
1	Very dissatisfied	9
2	Dissatisfied	10
3	Neutral	21
4	Satisfied	50
5	Very satisfied	37

minutes is too small, although a clear alternative was not considered.

We use the data from the patient survey (data set $\mathbb{G}$, period October 2008−December 2008) to determine patient satisfaction regarding the PAC visit. In the patient survey, patients were asked to rate the waiting time on a ordinal scale from 1 to 5. Table 2.5 presents the results of this survey. It shows that most patients rated their waiting time 'satisfied' (rating 4). Management indicated that the waiting times corresponding to patient ratings 1, 2, and 3 (*group A*) should be considered unacceptable. In addition, ratings 4 and 5 (*group B*) should be considered acceptable. Table 2.6 shows the expected waiting times and its 95% confidence interval for group A and B. The confidence interval of group B could be used as a norm for the future situation. However, the expected waiting time for the total population indicates that our sample is not representative for the total population: the expected waiting time for the sample is 24 minutes compared to 27 minutes for the total population. We have no clear indication for this discrepancy. A potential bias could occur if satisfied patients are more likely to respond to the survey compared to dissatisfied patients.

Table 2.6: The expected waiting times for patient group A ($n = 87$) and B ($n = 40$), including the 95% CI of the expected waiting times.

Group	Average $\pm$ st.dev.	95% CI
A	0:33 $\pm$ 0:14	[0:24, 0:35]
B	0:22 $\pm$ 0:14	[0:15, 0:21]
Total	0:24 $\pm$ 0:15	-

Table 2.7: The average starting time of the providers compared to the average arrival time of patients during morning hours (data set $\mathbb{B}$, $n = 9$ per day).

Statistic	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**
Average start time	8:49	8:36	8:30	8:30	8:32
Average arrival time	8:25	8:07	8:11	8:02	8:09
Average waiting time	0:23	0:27	0:21	0:25	0:24

Provider tardiness, patient punctuality, and no-shows

Provider tardiness is a measure for the delay in the starting times of consultations due to the punctuality of the providers (nurse or physician). Table 2.7 illustrates the tardiness of the providers at the PAC. The average start time corresponds to the average time the first patient enters the consultation room. The average arrival time is the average time of the first patient arrival. The expected waiting time corresponds to the expected waiting time for all patients that have an appointment at or before 9:30 AM. Table 2.7 illustrates the effect of provider punctuality on patient waiting times. In theory, all patients that arrive in the early morning should have minor waiting times. However, from Table 2.7 we see that the expected waiting time is 20 to 30 minutes for all patients arriving in the morning. A possible explanation for these relatively high waiting times in the morning are de additional scheduled telephone consultations. Telephone consultation are scheduled in parallel with regular appointment. The providers have to do these calls in between patient visits.

We defined the punctuality as the scheduled appointment time minus the arrival time. Most patients arrive on time for their appointment ($Mode = 0$). The average punctuality is 5 minutes: on average, patients arrive 5 minutes in advance of their appointment. The average number of no-shows is 0.6 patients per day. From Table 2.3 we know that the average number of patients is 45 (data set $\mathbb{E}$). Hence, the percentage of no-shows is 1.3%. We do not expect that this small number of no-shows negatively affects the consistency of the current design of the AS.

Length of stay due to the ECG

Currently, all patients that are over the age of 60 and those with certain disorders require a recent ECG. This currently goes for approximately 40% of all patients and drastically increases their length of stay in the hospital. Currently, the average time required for an ECG is 20 minutes. However, 25% of all patients need more than 25 minutes for making an ECG. Excluding the ECG will then drastically reduce the length of stay (LOS) at the hospital when visiting the PAC.

Patients are not referred to the ECG department if they arrive at the PAC after 3:30 PM. These patients are assessed without an ECG and requested to record one on a later day.

2.4 Conclusion

In this chapter we described the preoperative process and the current design and performance of the PAC. There is a large variation in the number of patient visits the OCs during the weeks. In the future, a fraction of these patients directly continues to the PAC after having visited a physician. We conclude that the estimation of the number of patients that will walk-in at the PAC per hour of the day is complicated by six factors:

1. The number of patients that visits the OCs differs per specialty.
2. The number of patients that visits the OCs differs per day.
3. The number of patients that visits the OCs fluctuates during the day.
4. Only a faction of the patients receives a surgery indication.
5. It is currently unknown what fraction of patients prefers to continue to the PAC directly after consultation at the OC or prefers to make an appointment.
6. If a patient decides to visit the PAC on walk-in, then the time of arrival at the PAC has to be approximated based on the appointment time at the OC.

We conclude that the activities at the clerk desk are very time-consuming, especially the time needed for digitalizing the questionnaires. We advise the PACs management to decide on options that make the majority of patients to fill in their questionnaires electronically. An option currently evaluated, is to attain patient information in an earlier stage in the process. Since all PAC visits are preceded by one or more visits to the OC, the OC would be an ideal location for collecting patient information that is currently collected just before the PAC assessment. However, organizing a walk-in based PAC inherently means patients always have to fill in a questionnaire at the PAC. To minimize workload at the clerk desk, the PAC could then place computers in the waiting room for patients to electronically fill in their questionnaire.

Waiting times are currently to high, especially for patients that are seen by a resident. On average, patients wait 22 minutes to see a nurse and 38 minutes to see a resident. The patient survey indicates that patients accept a waiting time of (approximately) 22 minutes, although the population sample in this survey cannot be considered representative for the total patient population. Regardless of this shortcoming, we conclude that the PAC cannot afford a decline in the current patient service level regarding waiting times.

Regarding the current AS, we question whether a slot size of 30 minutes per provider is sufficient. The time needed per provider to prepare a consultation, assess the patient, and administratively finish the assessment might be more than 30 minutes, which then explains the high waiting times. If so, we have to evaluate the option of larger appointment slot sizes per provider type.

High waiting times might also be explained by the high provider tardiness. Waiting times have the tendency to pile up during working days: if the first patient of the day is served to late, than all succeeding patients experience the delay incurred in the morning. Therefore, it is essential that the providers at the PAC start to see the first patient on time. The additional telephone calls that are scheduled in the morning might cause the current delay. Patient punctuality cannot cause the high waiting times, since most patients arrive on time (5 minutes in advance of their appointment time). Since we have no clear indication about the causes of the high waiting times, we have to resort to the expert knowledge of the staff members to find potential causes.

If the ECG requirement is excluded in the future, the LOS at the hospital will decrease by 20 minutes on average. This is a large improvement in patient service level. Average service times significantly differs between patients that require an ECG and those that do not. This is due to the difference in patient complexity, but we also conclude that reading the ECG takes considerable time. As a result, service times might improve when the ECG requirement is excluded in the future.

Service levels might improve with a more robust AS. In the future, the AS should reserve capacity for walk-in patients without (drastically) deteriorating waiting times. We therefore need to balance workload over the day when combining walk-in and regular appointments.

In the next chapter, we study the literature on organizing walk-in based clinics and reducing waiting times.

CHAPTER 3

Literature

"To keep patients waiting longer than is really necessary is clearly undesirable on humanitarian grounds, and moreover often means a loss of working time which the country can ill afford." [31]

Welch and Bailey [31] pioneered the research on waiting times at hospital outpatient clinics. Although the prime argumentation for lost working hours has nowadays been abandoned, the topic of waiting time reduction and clinic scheduling has drawn attention of various researchers. Welch and Bailey present practical suggestions for the design of an AS, like patient differentiation, variability in consultation time and punctuality of patients and health providers.

Not many works describe clinical settings that take walk-ins or unscheduled visits into account [5, 9, 12, 21, 22, 25, 29, 34]. Fetter and Thompson [12] study the effect of seven variables on patient's waiting time and physicians' idle time. These are: appointment interval, service time, patients' arrival pattern, number of no-shows, number of walk-ins, lateness of physicians, and interruptions in their services. Fetter and Thompson furthermore remark that no-shows cannot simply be considered as the reverse side of walk-ins, since walk-ins tend to differ between clinics compared to no-shows. In our situation, the number of walk-ins will probably fluctuate heavily during the day.

Rising et al. [22] continued on the work of Welch and Bailey and Fetter and Thompson by more specifically focussing on the design of the AS itself. The researcher's AS was designed by balancing workload per day and next balancing appointments to expected walk-ins. The results are reduced throughput times at the clinic, however, waiting times remained the same.

Reilly et al. [21] study a clinic with a high number of unscheduled patient visits. The authors suggest the technique of *delay-scheduling* to deal with this uncertainty while keeping waiting times to a minimum. In delay scheduling, patients that find a queue at the entry of clinic can choose to either wait in the waiting room or return on a later time that day. Patients that choose the latter are given a return time (the *delay*) and are put in front of the queue when they return. The delay is calculated by a mathematical formula that basically evaluates the time needed to process the existing queue. With delay-scheduling, the work load is balanced over the day and patients are not refused service.

Vissers [29] studies the effect of pre-punctuality on waiting and idle times. The authors defines pre-punctuality as the difference between the patient's arrival time and start of the consultation, caused by the patient's punctuality and the physician's lateness. Vissers uses a computer simulation to study the relation between pre-punctuality, waiting, and idle time.

Babes and Sarma [5] discuss a clinic that schedules appointments by providing an appointment date without an appointment time. The number of patients that arrive during the day is thus known in advance, however patients arrive randomly throughout de day. They study the effect of the variability in the number of patients that arrive per day on the expected number of patients in queue, the expected waiting time, and the server occupation rate, while keeping the number of servers constant. Babes and Sarma use an queueing model but conclude that the inherent model assumptions make it inapplicable for comparison to a real-life situation. They argue that simulation provides better means to study the every day dynamics (that incorporates more variables) of a clinic setting.

A small number of authors analyze the scheduling of appointments at the PAC [9, 11, 25, 34]. Here, Dexter [9] provides suggestions for designing an AS. The author discusses how the mean and standard deviation of consultation times, appointment intervals, and patient waiting time are related. Furthermore, Dexter discusses factors that increase patient waiting time and decrease patient satisfaction. These are lack of patient punctuality, provider tardiness, and walk-ins. Dexter suggests to schedule in between appointments for potential walk-ins. Some strategies are proposed to decrease patient waiting times: decrease mean and standard deviation of consultation times and accept substantial provider idle times. As a strategy to improve patient satisfaction, Dexter suggests to provide activities for patients that are waiting.

Both Zonderland [34] and Schoenmakers [25] study high occupation rates that are experienced at their respective PACs. Zonderland discusses a PAC setting where walk-ins form a large proportion of the total number of patients; Schoenmakers studies a PAC setting with mainly scheduled appointments and evaluates the potential of a walk-in PAC. Zonderland uses queueing theory and simulation to analyze the occupation rate at the PAC and provides suggestions for improvement of the preoperative process. According to Zonderland, queueing theory was not reliable for all aspects of the study. When modeling the effect of the lunch break and an AS on the occupation rate at the PAC, a discrete event computer simulation was used. Schoenmakers also resorted to a discrete event simulation model for evaluating an AS that takes walk-ins into account.

Zonderland [34], Schoenmakers [25], and Edward [11] suggest to use ASA classification as a patient differentiation applied within the appointment system. The ASA (American Society of Anesthesiologists) classification is used to classify patients based on their physical condition [2]. The researchers describe that the ASA classes are experienced to have different service times. When implementing this differentiation in the AS, they conclude the PAC's performance can be drastically improved due to a reduction mean waiting time.

Cayirli et al. present a thorough literature review on all relevant studies on outpatient clinic scheduling [7]. The authors also conclude that only a small number of works incorporate walk-ins in clinic scheduling. According to Cayirli et al., the design of an appointment system (AS) involves three major decisions, being:

1. The appointment rule. The appointment rule (AR) consists of three variables: the initial-block size, the block size, and the appointment interval. The block size indicates the number of patients that can receive the same appointment time. Here, the initial-block size only defines the number of patients on the start of the day (the first block). The appointment interval defines the time between subsequent blocks or appointments times. In most cases, the appointment interval is based on the mean consultation time, sometimes including the standard deviation of the consultation time. Any combination of these three variables results in an unique AR.
2. A patient classification. Since the patient population is not homogenous, some patients require a longer consultation than others. Well-designed ASs take into account this variety in patient charateristics by defining a patient classification.
3. Adjustments to deal with no-shows and walk-in patients. No-shows and walk-in patient heavily disturb the clinic's daily routine and affect the performance of its ASs. Therefore, this is an essential element of an AS' design.

Vissers et al. [30] adopt the above description of the appointment rule on an appointment system. They describe how the mean consultation time can be revised to include walk-in and no-shows. However, walk-ins are considered incidental high-priority patients that have to be served between regular appointments. This does not correspond to our situation of walk-ins.

Various studies evaluate different appointment rules but neglect walk-ins [8, 11, 15, 31]. Ho and Lau [14] and Kaandorp and Koole [15] conclude that the famous Bailey-Welch appointment rule is most robust when balancing patient waiting times and physician idle times. With this scheduling rule, the first k patients is given the same appointment time (initial-block size > 0). The appointment times of the other blocks are based on the mean consultation time.

Aside from Zonderland, Su and Shih [27] offer an interesting study of a health clinic in Taiwan where 72% of all patients are walk-ins. In this clinic, patients can either schedule an appointment or visit the clinic as walk-in. Since patients are seen on the *First Come, First Serve* rule, scheduled patients that arrive to late are not put forward in the queue on arrival. Therefore, patients have no incentive to make an appointment, and the majority arrives on walk-in. The researchers evaluate alternative priority rules, with varying priorities for appointments and walk-ins. They conclude that an alternating rule (appointment−walk-in−appointment−...) is most beneficial regarding overall patient throughput time.

An alternative to walk-in based clinics is 'advanced access scheduling', first introduced by Murray and Tantau in 2000 [19]. This concept is founded on the principle that patients should get an appointment on the day they call so that the access time (time between scheduling an appointment and the actual appointment date) to the clinic can be minimized. Advanced access scheduling gained the interest of researchers in recent years [23, 6, 24, 20, 26, 18] and reveals mixed results. Advanced access scheduling is a strategy that can be adopted to reduce access time to the clinic. However, in the context of this research, management decided that access time is to be minimized by implementing walk-ins.

Conclusion

Like other authors, Dexter's definition of walk-in patients involves a small fraction of high priority patients that have to be assessed on short notice. In the context of our research, besides the emergency patients Dexter describes, the PAC additionally has to deal with a large number of regular patients that arrive as walk-ins. The AS then has to reserve more capacity for walk-ins compared to the situation described by Dexter. The appointment rules discussed in literature mostly relate to situations of relatively small number of walk-ins, or walk-ins that are more evenly balanced over the day as in [27]. The uniqueness of our research lays in the fact that a relatively large number of patients arrive on walk-in and that the actual number of walk-ins probably fluctuates during the day. This makes the strategy of Rising [22] to balance the workload per day most suitable for our situation. Differentiating the appointment slots to patient classification (or provider type) should be taken into account. We can base the appointment slot size on the expected service time, which, in our situation, includes the time for preparing a consultation.

The studies of Babes and Sarma, Zonderland, and Schoenmakers exemplify the difficulty in analyzing the everyday dynamics of a clinic setting by means of queueing theory. Besides these authors, others also resort to computer simulation. Most authors focus on more general hospital clinics and specifically on the PAC. In addition to Dexter [9], Zonderland [34], and Schoenmakers [25], Edward [11] studies the design of an appointment system (by using simulation) but this study does not involve walk-ins. In this study, the number of required appointments per day is evaluated to decrease the PAC's access time.

We observe that, where Zonderland already implemented a patient differentiation to ASA classification in the AS, Schoenmakers, and Edward conclude this differentiation as desirable. We acknowledge that a patient differentiation helps in optimizing the AS since different patients might imply different service times. However, to the best of our knowledge and our clinic's management, ASA classification is not ideal for this situation: it is a classification that can only be made after a PAC visit and not on beforehand. Differentiating patients to ASA classification before they visit the PAC is rather inaccurate. We therefore choose not to use the ASA classification in the design of our AS.

CHAPTER 4

Interventions

In this chapter we formulate interventions that might reduce waiting time at the PAC and alternative ASs that facilitate the PAC in reserving capacity for walk-ins. In Chapter 2, we concluded that our data analysis did not result in finding clear causes for the current high waiting times. We therefore use the expert knowledge of the PAC's staff members to find options for decreasing waiting times. In Section 4.1, we discuss the factors that are considered to have the largest impact on reducing waiting times and subsequently suggest 4 process interventions. Section 4.2 presents alternative designs of the AS and related capacity planning. As a starting point, we estimate the expected number of surgery indications provided at the OCs during the day. We then design two alternative ASs that balance workload over the day by combining appointment and walk-in slots.

4.1 Interventions for reducing waiting times

We found relatively long waiting times for patients that wait for a resident. We also concluded that there is a considerable provider tardiness, which might pile up waiting times in the morning and congest the throughput for the rest of the working day. After consulting the staff members of the PAC, we conclude that long waiting times for residents are primarily caused by the following factors:

1. The time needed to prepare a consultation takes considerable more time for residents than for nurses. This is due to the complexity of patients and lack of experience of the residents. For educational purposes, unexperienced residents are frequently scheduled at the PAC. They need more time for preparing and finishing consultations than trained nurses. Note that we did not register these times in our time motion study; we only registered the time the patient is actually seen by a nurse or resident.

2. TCs are scheduled in the morning in conjunction with regular appointments. When unexperienced residents are on duty, TCs take considerable more time, causing a delay in the start of the working day. Nurses indicated that they also incur a delay due to the large number of TCs scheduled in the morning.

3. Residents are contacted directly, without interference of a clerk, by another physician to assess patients that are admitted on the ward department. The resident then temporarily leaves the PAC to visit the respective patient. As described in Chapter 2, we have no clear indication how frequently this occurs but we expect this negatively influences waiting times at the PAC. The PAC's management indicated that a ward visit can easily take 1 hour of the resident's time.

This input of staff members led to a discussion with the PAC's management about the main factors that could negatively influence waiting time at the PAC. The result of this discussion are 5 possible interventions:

Intervention A1: An alternative schedule for TCs. Currently, TCs are not scheduled evenly over the day which might cause provider tardiness in the morning and consequently high waiting times for patients. This intervention balances TCs over the day to reduce workload in the morning.

Intervention A2: Excluding the ECG requirement. During this research, the hospital planned a research into the additive value of incorporating ECGs at the PAC from a medical point of view. Depending on the results of this study, the ECG requirement might disappear in the future. We therefore design an intervention that excludes the current ECG requirement at the PAC.

Intervention A3: Decreasing the (effective) service time at the clerk desk by 50%. The activities at the clerk desk require relatively long time due to the digitalizing of patient questionnaires. We are therefore interested in the effect of reducing throughput time at the clerk desk on waiting times.

Intervention A4: Decreasing the (effective) service time of residents by 50%. The PAC's management is familiar with the problem of unexperienced residents taking more time to assess patients than nurses. To decrease patient throughput time at the PAC, scheduling more experienced medical staff members, like senior residents or doctors, might be a solution. However, this change in scheduling policy currently creates unwillingness among staff members involved. To support the PAC's management and its medical staff members in decision-making regarding this problem, the effect of (frequently) scheduling unexperienced residents at the PAC should be quantified. Furthermore, we should quantify the effect of residents being called from the PAC to assess patients at the ward. Both can be modeled by an intervention that decreases the effective service time of residents.

Intervention A5: Scheduling patients to providers. Currently, patients are assigned to a provider (nurse or resident) after reporting at the clerk desk and handing over their health questionnaire. As a consequence, the PAC can not control the arrival rate of patients that either have to be seen by a nurse or resident. When a patient's health status is available earlier in the process – for example, at the moment of scheduling an appointment – the provider can directly be assigned to the patient. This allows the PAC to differentiate the AS to providers and prevent

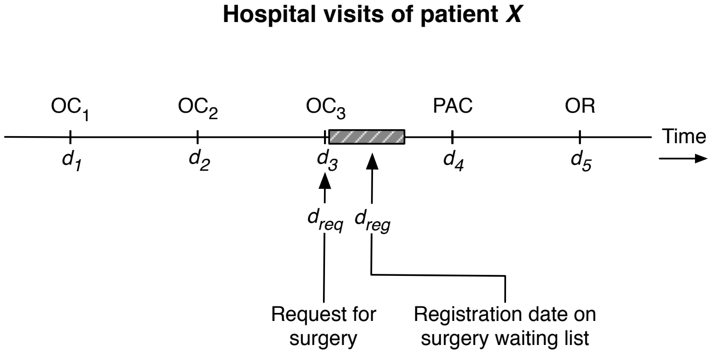


Figure 4.1: The appointment history of a random patient. Based on the historic data (data set $\mathbb{A}$, $\mathbb{B}$, $\mathbb{C}$, and $\mathbb{H}$) , the subsequent visits of a randomly chosen patient can be determined.

fluctuations in arrival rates per provider, which could balance the workload and might reduce waiting times. In intervention B3, we study the situation whereby patients are assigned to providers prior to their appointment. Naturally, this will only apply to appointment patients; the health status of walk-in patients cannot be determined prior to a PAC visit.

In the next section we estimate the future number of walk-ins and design two alternative ASs.

4.2 Alternative appointment systems

To design an AS that reserves capacity for walk-in patients in between regular appointments, we first have to estimate the number of walk-ins at the PAC. Section 4.2.1 explains our computational approach in determining the future number of walk-ins. In section 4.2.2, we present the numerical results and in Section 4.2.3 we design alternative ASs.

4.2.1 Computational approach for estimating walk-ins

We included the data sources (see Chapter 2, page 21) in a *Microsoft Access* database, where data records can be matched based on patient ID. This gives us the ability to depict the pathway per patient ID as illustrated in Figure 4.1, using the following abbreviations:

d_i	Appointment date of appointment i at an OC, $i = 1, \ldots, \lvert d_i \rvert$ (data set $\mathbb{A}$).
t_i	Appointment time of appointment i at an OC, $i = 1, \ldots, \lvert t_i \rvert$ (data set $\mathbb{A}$).
d_{req}	The request date for surgery.
d_{reg}	The registration date on the waiting list.
$d_{\mathbb{C}}$	The time stamp available in data set $\mathbb{C}$.

Suppose a randomly chosen patient that received a surgical treatment first visited the OC at d_1 followed by a second and third visit on d_2 and d_3 respectively and that the last visit resulted in a surgery indication. Then the *request for surgery* date, d_{req}, equals the appointment date d_3. The patient was placed on the waiting list on d_{reg}, which lays somewhere between d_3 and d_4, as indicated by the shaded time interval. At d_4, the patient visits the PAC succeeded by surgery on d_5. In the future, the patient might continue to the PAC directly on d_3.

The request date, d_{req}, is the date the surgery was requested as filled in on the surgery indication form. The registration date, d_{reg}, is the input or mutation date on the waiting list. The time stamp $d_{\mathbb{C}}$ is the variable available in the data set of the waiting list and either indicates the request or registration date (which will be illustrated later on). Our goal is to filter out all appointment dates and times at the OCs a request for surgery was submitted: all appointments dates where $d_i = d_{req}$. Regarding Figure 4.1, d_3 would then be the date of interest since this appointment at the OC could result in a walk-in at the PAC. There are a number complications involved in this methodology:

1. Different information systems are used at the SADs, which complicates data interpretation. For most records that refer to daycare patients $d_{\mathbb{C}} = d_{req}$, while for clinical patients $d_{\mathbb{C}} = d_{reg}$. As a result, for daycare patients, $d_{\mathbb{C}}$ is most easily matched to d_i since most request dates will correspond to an appointment date at an OC. Clinical patients are more difficult to analyze, since for most cases $d_{reg} \geq d_i$ (as indicated by the shaded time interval in Figure 4.1). To match an appointment date to a registration date for surgery for clinical patients, we should thus include a time margin in days, say Δd, that represents the time that passes between the request for surgery and the actual registration on the waiting list. We can then state: if $0 \leq d_{reg} - d_i \leq \Delta d$, a surgery indication was probably provided at appointment i.

2. If a request or registration date matches an appointment date at the OC , we do not know for sure this patient will be a walk-in patient at the PAC at date d_i, due to 2 reasons:

   (a) OC staff members indicate that patients sometimes go home to think the surgical treatment over or request approval with their insurance company. Then the surgery indication form is already filled in and available at the SAD, but the patient will not yet be registered on the waiting list. If a patient successively agrees with the surgical treatment, the surgeon is contacted by phone and the patient is placed on the waiting list by the clerk using the original d_{req} which still refers to d_i. The patient is thus placed on the waiting list with retrospective effect (if the clerk forgets to input the request date, the computer program automatically enters the registration date). Yet, this patient will not visit the PAC at d_i in the future, since at d_i no definite decision was made regarding surgical treatment. The same problem occurs when having matched d_i to d_{reg} for clinical patients.

   (b) Alternatively, delay in registration can occur due to the service time at the SADs. A clerk at one of the inpatient SADs indicated that patients are sometimes processed a week later. Then, although $d_i \neq d_{reg}$, the patient might have decided to visit the PAC on walk-in on date d_i.

(c) Not all patients will decide to visit the PAC on walk-in; some might prefer to return with an appointment. The patient's emotional or physical condition might result in the patient choosing to return to the PAC with an appointment.

We have no data that can be used to filter our these three types of delay in waiting time registration.

3. If a request or registration date cannot be matched to an appointment date at the OC, a patient can still decide to walk-in at the PAC on the date of an appointment at the OC. A doctor might suggest a surgical treatment along with a request for additional medical tests before surgery can take place. Since a PAC assessment has a validity of 6 months, the patient might be advised to visit the PAC in advance of the actual registration for surgery. Then the patients visits the PAC and is placed on the surgery waiting list afterwards.

4. We are specifically interested in the number of walk-ins per hour of the day. When $d_i = d_{\mathbb{C}}$, we also have appointment time t_i available. If the patient continues to the PAC, the time that passes between the appointment time at the OC and the arrival time at the PAC has to be estimated.

Complication (1) is dealt with by incorporating a margin for matching the surgery request date to an appointment date at the OC. For daycare patients, the majority of patients is placed on the waiting list on the same day the patient visits the (outpatient) SAD with a surgery indication. However, we expect a one day delay in registration if a patient arrives at the SAD at the end of the day. If the clerk plans a patient for surgery one day after the request and subsequently forgets to register the request date, the computer program automatically fills in the registration date, resulting in the situation $d_{\mathbb{C}} = d_{reg} = d_{req} + 1$. To account for these situations, we select all appointments within a one day margin of the request date: $0 \leq d_{\mathbb{C}} - d_i \leq 1$.

At the inpatient SADs, patients are registered on the waiting list within a 7 day margin after their surgery request according to the SADs clerk. For clinical patients we thus select the appointment that follows the condition of a 7 day margin for registration: $0 \leq d_{\mathbb{C}} - d_i \leq 7$.

For Complication (4), we estimate the moment of walk-in by analyzing the case of daycare patients. These patients schedule their PAC appointment at the clerk desk after having received a surgery indication. The registration time for this appointment, $t^{PAC}_{reg,i}$, is available in data set $\mathbb{B}$. The time that passes between the appointment time at the OC and the moment of scheduling the PAC appointment at the PAC's clerk desk then equals $t^{PAC}_{reg,i} - t_i$ for all cases where $0 \leq d_{\mathbb{C}} - d_i \leq 1$.

Complication (2) and (3) cannot be solved by means of the current data. Due to (2), our estimation of the number of walk-in patients might result in an overestimation compared to reality, contrary to (3) that might result in an underestimation. We expect both Complications to balance one another and that our estimation thus remains reliable.

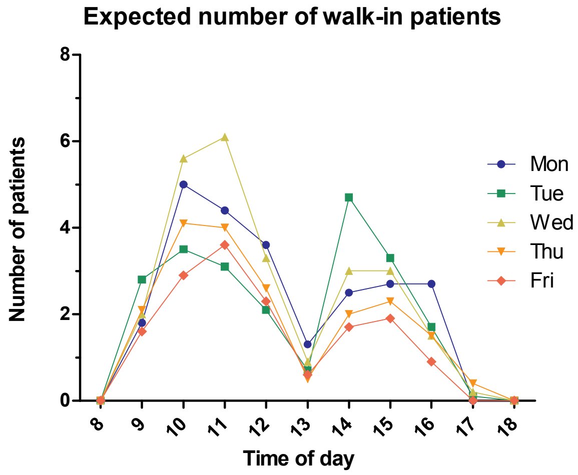


Figure 4.2: The expected number of patients that arrive as walk-in at the PAC, daycare and clinical, based on combining data sets $\mathbb{A}$, $\mathbb{C}$, and $\mathbb{H}$ ($N = 4,113$).

4.2.2 Number of walk-ins

We design a database query that merges the OC appointments (data set $\mathbb{A}$) with waiting list mutations (data set $\mathbb{C}$) and elective surgeries (data set $\mathbb{H}$) covering the period October 2007−November 2008. We exclude the PAC appointments (data set $\mathbb{B}$), since the time period of this data set is too small for comparison. As a replacement, set $\mathbb{C}$ includes a variable that indicates the presence of an anesthetist, which is an indicator for a preoperative assessment at the PAC: if an anesthetist was present during surgery, anesthesia was administered, which means the patient was assessed at the PAC. We statistically verified the correlation between this indicator of $\mathbb{C}$ against the actual assessments registered in $\mathbb{B}$ using the Kappa test. The resulting $\kappa = 0.86$ indicates strong agreement between the two data sets (see Appendix D for the results).

The average time between the appointment time at the OC and the arrival time at the PAC is approximately 1 hour. Figure 4.2 shows the resulting number of walk-ins per hour, per working day after adopting the computational approach explained in the previous section. The reader is referred to Appendix E for a numerical overview of the number of walk-ins per hour per working day, differentiated to daycare and clinical patients.

4.2.3 Alternative designs

Intervention A1 in Section 4.1 deals with an alternative schedule for TCs. In this section, we exclude the scheduling of TCs and focus on the remainder of appointment types − both regular and urgent − in combination with walk-ins.

The capacity per hour of the day, N^t_{cap}, is allocated to both walk-in and scheduled patient visits, based on working hours from 8 AM to 4 PM. Time t corresponds to one hour time intervals during the working day, where $t \in 8,9,..,15$ so that $t = 8$ equals the time interval from 8 AM to 9 AM, $t = 9$

Table 4.1: The capacity and appointment slots available per hour for AS B1.

(a) The number of patients that can be served per hour, based on the number of providers and the slot size.

	Capacity	**Slot size**	**Max N^t_{cap}**
Nurse	2	30 min.	4 patients
Resident	2	30 min.	4 patients
Total	4	-	8 patients

(b) The number of slots, N^t_{app}, available per hour for regular appointments.

Hour	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**
8-9	6	6	6	6	6
9-10	6	5	6	6	6
10-11	3	4	2	4	5
11-12	4	5	2	4	4
12-13	0	0	0	0	0
13-14	7	7	7	7	7
14-15	5	3	5	6	6
15-16	2	2	2	2	2
Total	33	32	30	35	36

the time interval from 9 AM to 10 AM etcetera.

Let $N^t_{walk-in}$ be the number of slots reserved for walk-in patients and N^t_{app} be the number of appointment slots available on time t. Figure 4.2 gives us the expected number of walk-ins per hour. For every walk-in patient we reserve a walk-in slot in the AS. Then $N^t_{walk-in}$ equals the expected number of walk-in patients per hour depicted in Figure 4.2. The remainder of the capacity is available for scheduling appointments, resulting in $N^t_{app} = max\{0, N^t_{cap} - N^t_{walk-in}\}\ \forall t$.

N^t_{cap} is defined by the slot size and the number of providers available per hour. Based on the findings presented Chapter 2 regarding the service and preparation time and discussion with the PAC's management, we decided on two alternative ASs based on two different slot sizes for residents:

Alternative B1– Slot size of 30 minutes: We use the default slot size of 30 minutes per provider as currently used by the PAC. Per hour, 2 residents and 2 nurses are available and working hours are from 8 AM to 4 PM. Then total capacity is 8 patients per hour as summarized in Table 4.1a . Table 4.1b shows the number of appointment slots (N^t_{app}) available per hour per working day. No appointments can be scheduled during the lunch break (12 AM and 1 PM) since capacity is then temporarily reduced to 50% while walk-ins are still expected.

Alternative B2 – Slot size of 40 minutes for residents: We set the slot size for residents to 40 minutes due to the relatively long time needed for preparing a consultation.Working hours

Table 4.2: The capacity and appointment slots available per hour for AS B2.

(a) The number of patients that can be served per hour, based on the number of providers and the slot size.

	Capacity	**Slot size**	**Max N_{cap}^{t}**
Nurse	2	30 min.	4 patients
Resident	2	40 min.	3 patients
Total	4	-	7 patients

(b) The number of slots, N_{app}^{t}, available per hour for regular appointments.

Hour	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**
8-9	6	6	6	6	6
9-10	5	4	5	5	5
10-11	2	3	1	3	4
11-12	3	4	1	3	3
12-13	0	1	1	1	1
13-14	6	6	6	6	6
14-15	4	2	4	5	5
15-16	4	4	4	4	4
Total	30	30	28	33	34

are from 8 AM to 4 PM. Since 2 residents are available per day, a maximum of 3 HS-2 patients can be served per hour. The slot size for nurses remains unchanged (30 minutes). Nurses can thus serve 4 patients per hour, which results in a total capacity of 7 patients per hour. Table 4.2a summarizes the capacity per hour in the new AS and Table 4.2b shows the number of appointment slots (N_{app}^{t}) available per hour per working day. Compared to B1, this schedule allows less appointments per hour (7 versus 8). To slightly compensate for this capacity reduction, additional appointment slots are available during the lunch break.

For both alternatives, the lunch breaks are scheduled in two shifts between 12 AM and 1 PM, corresponding to the current situation. As can be seen from the schedules, more patients are scheduled during the lunch break for intervention B2 compared to B1. In our model implementation, we will take into account the current differentiation of workload over the week. For example, on Mondays considerably more patients are assessed than on Fridays. As a result, the alternative ASs are evaluated with the same occupation rates as in the current situation.

CHAPTER 5

Computational approach

The effects of the interventions presented in the previous chapter will be assessed by means of a discrete-event simulation model designed in *Tecnomatix eM-Plant v.7*. To design this simulation model, we have to decide on various model characteristics, like its conceptual design (number of stations and their functions), input parameters, and probability distributions. Figure 5.1 illustrates our approach in designing the simulation model and the outline of this chapter.

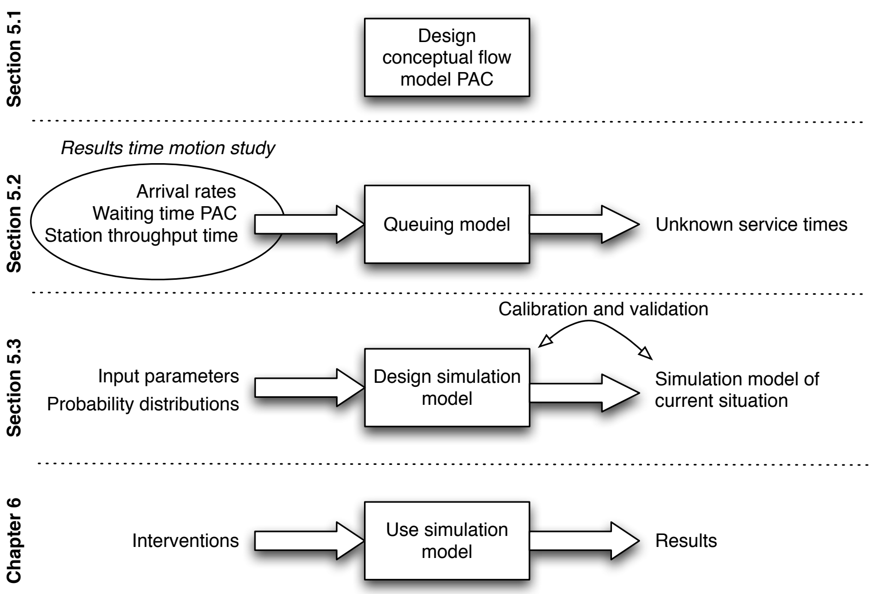


Figure 5.1: The computational approach used for designing the simulation model together with the outline of this chapter.

Section 5.1 describes how the PAC can be represented in a flow model that incorporates all activities performed at the PAC. These activities were presented in Section 2.1.4 and result in waiting time for the patient. The time motion study gives us the total waiting time for a PAC visit, however, the actual time needed for a number of activities is unknown. Knowing these times is essential when designing a simulation model that realistically simulates daily activities at the PAC. Hence, we have to derive these expected service times. In Section 5.2, we introduce a queuing model that models the patient throughput at the PAC. Using Microsoft Excel's build-in solver tool, we approximate the unknown expected service times.

When all expected service times are known, the simulation model's input parameters are available and we can decide on probability distributions that represent these service times. We use *Math-Wave EasyFit v.5* to verify the data of our time motion study against various probability distributions. EasyFit fits a large number of distributions using Maximum Likelihood Estimators and ranks the distributions based on their goodness-of-fit according either the Kolmogorov-Smirnoff, Anderson-Darling, or Chi-squared test. We use the graphical output of EasyFit (histogram, PP, and QQ plots), the ranking according to the goodness-of-fit test, and the availability of the distribution in EM-plant for selecting the distributions that best fit the data. Hereafter, the simulation model is calibrated and validated to obtain a model that realistically simulates the PAC's current situation.

The simulation model then allows us to study the effect of the interventions presented in the previous chapter.

5.1 Conceptual flow model

In our time motion study, we registered the sojourn time of two activities – the administrative activities at the PAC's clerk desk and the time needed for making an ECG – and the service time of an assessment by either a nurse or a resident. However, from Section 2.1.4 we know that there are two additional activities for which no times have been registered in our time motion study: the time it takes for the nurse to assign a patient to a provider and the time needed to prepare a consultation. These activities induce waiting time for the patients and can thus not be excluded in our simulation model. Therefore, we have to be derive the time needed for these activities from the data.

Figure 5.2 shows a conceptual flow model of the PAC where the stations represent the activities performed that result in waiting time for patients. The total waiting time the patient incurs for all these activities was presented in Section 2.3. This total waiting time is the result of the sojourn times at stations 2, 3, 4 and/or 6 and are related to the processing of the patient's medical file. After arriving at the clerk desk, the patient enters the waiting room and leaves his or her medical file. When the medical file enters station 5 (nurse) or 7 (resident), waiting ends and the consultation starts. The end of processing the patient's medical file thus corresponds to the patient entering the consultation room.

Figure 5.2 encompasses the following activities and assumptions:

Dummy station "Arrival at PAC": Represents the time needed for welcoming patients and redirecting them to either the ECG or waiting room. We neglect the short time that is needed for these activities. The first station therefore has zero service time and only functions as a *redirecting* station.

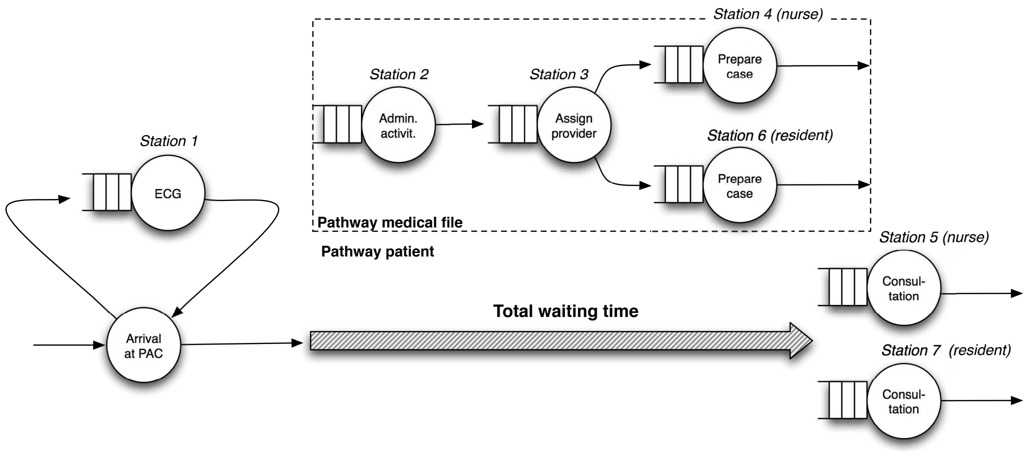


Figure 5.2: The conceptual flow model of the PAC: the stations represent various activities.

Station 1: Represents the time needed to make an ECG. The sojourn time ($EW + ES$) at station 1 consists of the sum of the time to continue to the department, to record the ECG, and return at the PAC. When a patient arrives at the PAC, it is decided whether an ECG is needed. Patients that do not need an ECG directly continue to the waiting room.

Station 2: At station 2, the patient's medical file is processed at the clerk desk, which often requires the patient's questionnaire to be digitilized. This represents task (4) described in Section 2.1.4 on page 31. Medical files are processed according the FCFS rule.

Station 3: Represents the time it takes for the nurse to get the patient's medical file and assign it to a provider based on the questionnaire.

Station 4 and 6: Respectively represent the time of the nurse and resident to prepare the consultation by studying the medical file.

Station 5 and 7: Represents the consultation of the nurse and resident respectively. Service at these stations starts when the patient is called from the waiting room.

Assumptions: In this representation, stations 4 & 5 and 6 & 7 are considered unrelated regarding available capacity. In reality, capacities are directly related since the provider that prepares the case subsequently sees the patient. We use this simplification to be able to more easily determine the input parameters of our queuing and simulation model. We return on the validity of this assumption in Section 5.2.

From the time motion study, the expected sojourn time at station 1 and 2, the expected service time at station 5 and 7, and the expected total waiting time for a patient is known. For example, we know patients have to wait an average of 8:35 minutes before the medical is processed at station 2. We interpret this as an expected sojourn time of 8:35 minutes at station 2. For the design of out simulation model, we also need the sojourn times at stations 3, 4, and 6. These have to be approximated based on the data.

5.2 Queueing model

In this section, we derive the service times of stations 1, 2, 3, 4, and 6 by using a queuing model. This queuing analysis supports us in approximating the (unknown) expected service times for the simulation model.

Our queuing analysis is based on the queuing theory discussed by Zijm [33]. We design a Multi-Class Open Queueing Network (OQN) using the Kendall-Lee notation for queuing systems along with the following notations:

k	Patient class, for distinguishing patients that need an ECG and those that do not need an ECG
i, j	Station ID, $i,j \in \{1,..,7\}$
$\gamma_i^{(k)}$	External arrival rate of patient class k at station i, patients per hour
$\lambda_i^{(k)}$	Internal arrival rate of patient class k at station i, patients per hour
$\mu_i^{(k)}$	Service rate of patient class k at station i, patients per hour
$P_{j,i}^{(k)}$	Fraction of patients of class k at station j that is referred to station i (only when splitting)
c_i	Number of parallel servers at station i
$EA_i^{(k)}$	Expected inter-arrival time of patient class k at station i in hours, where $EA_i^{(k)} = 1/\lambda_i^{(k)}$
$SCV_{A,i}^{(k)}$	Squared Coefficient of Variation of the arrival time of patient class k at station i
$ES_i^{(k)}$	Expected (effective) service time of patient class k at station i in hours, where $ES_i^{(k)} = 1/\mu_i^{(k)}$
$SCV_{S,i}^{(k)}$	Squared Coefficient of Variation of the service time of patient class k at station i
$SCV_{D,i}^{(k)}$	Squared Coefficient of Variation of the departure time of patient class k from station i
$EW_i^{(k)}$	Expected Waiting time (of patient class k) at station, hour i
$ET_i^{(k)}$	Expected sojourn time (of patient class k) at station i in hours
ρ_i	Occupation rate at station i, where $\rho_i = \lambda_i / c_i \mu_i$

Based on the findings from Chapter 2, we distinguish between patients that need and ECG and those that do not, since we know this patient differentiation influences service times per station. We assume the system is stable, therefore $\rho_i < 1 \; \forall i$. The model of Figure 5.2 is adjusted to benefit our analysis, which result in the queuing model shown in Figure 5.3. The type of queues are indicated per station. In queuing terminology, Figure 5.3 is called a queuing network composed of 7 stations with $c_i \geq 1 \; \forall i$ [33]. Corresponding to Figure 5.2, the total waiting time the patient experiences is due to the sojourn times of stations 2, 3, 4, and 6.

For analyzing a Multi-Class OQN we use the complete reduction method which comprises 3 steps (see [33] for a complete description of the method) :

1. Reduction of the given K class OQN to a single class OQN by aggregating the K classes.

2. Analysis of the single class OQN

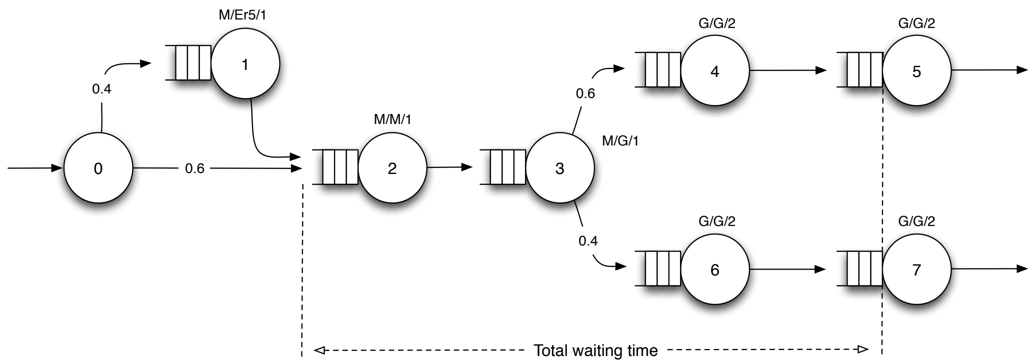


Figure 5.3: The queuing model of the PAC: a queuing network consisting of 7 stations.

3. Disaggregation to obtain the performance measures per class for the given K class OQN.

In our analysis, we start at step (2) using the results from our time motion study without differentiating to ECG requirement (aggregated scale). Step (2) involves the following relations:

$$\lambda_i = \gamma_i + \sum_{j=1}^{M} \lambda_i P_{j,i} \tag{5.1}$$

$$ET_i = EW_i + ES_i \tag{5.2}$$

Here, (5.1) gives that the arrival rate at station i equals the external arrival rate at i plus the sum of all departures from station j to i (inter-arrivals) and (5.2) states that the expected sojourn time equals the sum of the expected waiting and service time.

The expected waiting time per station type is defined by the following relations:

$$EW_i(M/M/1) = ET_i - ES_i = \frac{\rho}{\mu_i(1-\rho_i)} \tag{5.3}$$

$$EW_i(M/G/1) = \frac{1}{2}(1 + SCV_{S,i})\frac{\rho}{\mu_i(1-\rho_i)} \tag{5.4}$$

$$EW_i(M/M/c) = \frac{1}{G_i}\frac{(c_i\rho_i)^{c_i}}{\rho_i!}\frac{1}{(1-\rho_i)^2}\frac{1}{c_i\mu_i} \tag{5.5}$$

$$EW_i(G/G/c) = \frac{SCV_{A,i} + SCV_{D,i}}{2} EW_i(M/M/c) \tag{5.6}$$

For the $M/G/\infty$ queue (which is a generalization of the $M/Er/\infty$ queue), no queues exits and therefore waiting times are zero [32]. The sojourn time then equals the service time. Regarding (5.5), G is the normalization constant defined by:

$$G_i = \sum_{n=0}^{c_i-1} \frac{(c_i\rho_i)^n}{n!} + \frac{(c_i\rho_i)^{c_i}}{(1-\rho_i)c_i!} \tag{5.7}$$

Since we are dealing with a serial system, the inter-departure process at station i determines the arrival process at (succeeding) station j, which is defined by the relation:

$$SCV_{A,j} = SCV_{D,i} = \begin{cases} (1-\rho_i^2)SCV_{A,i} + \rho_i^2 SCV_{S,i} & for\ c_i = 1 \\ 1 + (1-\rho_i^2)(SCV_{A,i}-1) + \frac{\rho_i^2}{\sqrt{c_i}}(max[0.2, SCV_{S,i}]-1) & for\ c_i \geq 1 \end{cases}$$

These mathematical relations can be used to determine aggregated waiting and sojourn times based on the service time per station. In our approach, we derive the aggregated service times based on the waiting and sojourn times. Hereafter, we need to disaggregate the service times to the 2 patient classes (ECG and non-ECG), following the condition that the waiting time does not differ per patient class, (5.8), and the difference in sojourn time is due to and only due to differences in service times between patient classes, (5.9):

$$EW_i^k = EW_i \quad \forall i,k \tag{5.8}$$

$$ET_i^k = EW_i^k + ES_i^k = EW_i + ES_i^k \quad \forall i,k \tag{5.9}$$

From the aggregated waiting and sojourn times (data set $\mathbb{F}$) we can thus derive the disaggregated service times based per patient class. This leaves us to characterize the stations (see Figure 5.3) and quantify the input parameters per station:

Dummy station: Currently, the PAC uses an AS to balance the work load over the day. One would expect deterministic arrival times due to the AS, however, inter-arrival times are exponentially distributed, probably due to patient unpunctuality (see Appendix F for an illustration). On average, approximately 45 patients visit the PAC per 8-hour working day, resulting in an expected arrival rate of 5.625 patients per hour.

Station 1: Approximately 40% of all patient that arrive at the PAC need an ECG, which takes them approximately 20 minutes before returning at the PAC ($ET_1 = 0.33$). Patients return at he clerk desk with exponential inter-arrival times and the sojourn time for station 1 fits an Erlang-5 distribution. As a result, the station 1 can be represented by an $M/Er_5/\infty$ queue (or, alternatively, as a station with 5 serial servers with exponential service times [4, 16]).

Station 2: 60% of all patients that arrive at the PAC directly continue to the waiting room. On average, patients wait 8:35 minutes before their medical file is ready for processing at station 3, which makes $ET_2 = 0.14$. ES_2 is unknown and has to be derived from ET_2. One clerk is available, therefore $c_2 = 1$. Arrival rates are exponentially distributed. The station is represented by an $M/M/1$ queue.

Station 3: Both ET_3 and ES_3 are unknown. Staff members indicate that a service time of 1 minute is realistic so that $ES = 0.017\ hour$. Capacity equals 1 server ($c_3 = 1$), referring to one nurse. The station is represented by an $M/G/1$ queue.

Table 5.1: The main parameters per station based on the expected values of the total patient population (aggregated scale), where * indicates an estimated value and blanks refer to unknown values that have to be derived.

Station i	λ_i	$SCV_{A,i}$	ES_i	$SCV_{D,i}$	EW_i	ET_i
1	2.475	1	0.33	1	0	0.33
2	5.625	1		1		0.14
3	5.625	1	0.017*	1*		
4	3.375	1		1*		
6	3.375	1	0.35	0.26		
5	2.25	1		1*		
7	2.25	1	0.38	0.26		

Station 4 and 6: ES_i and ET_i are unknown for both stations. Capacity equals 2 servers per station: 2 nurses at station 4 ($c_4 = 2$) and 2 residents at station 6 ($c_6 = 2$). Both stations are represented by $G/G/2$ queues.

Station 5 and 7: We discussed the expected service times in Section 2.1.5, indicating differences per patient type (ECG requirement) and provider type (nurse or resident). Service time at station 5 is 26.2 minutes for ECG patients and 18.2 for patients without an ECG. At station 7, service time is 24.8 minutes for ECG patients and 20.6 for patients without an ECG. Like station 4 and 6, 5 and 7 also have 2 servers per station available: 2 nurses and 2 residents respectively. Stations are represented by $G/G/2$ queues.

Before we can calculate the service times, we additionally need to know $SCV_{S,3}$, $SCV_{A,4}$, $SCV_{S,4}$, $SCV_{A,6}$, and $SCV_{S,6}$. For the preceding stations this is no issue, since we know throughput at these stations follows a Poisson process (exponential arrival and service times, thus $M/M/1$ or $M/M/\infty$ queues). Yet, stations 3, 4, and 6 have general service (and arrival) times, which means we need to determine $SCV_{D,i}$ to characterize the inter-arrival pattern in between these stations. We have no data for estimating any of these parameters and set $SCV_{D,3}$, $SCV_{D,4}$, and $SCV_{D,6}$ to 1.

Table 5.1 summarizes the values of the parameters per station. The table does not distinguish between patient classes; only the expected values for the aggregated patient population are shown. The blanks indicate unknown values. When splitting occurs, Figure 5.3 indicates the fraction of patients that is referred to the respective station. As a result, we know the arrival rate, λ_i, at every station. Some of the blank values can be calculated directly (stations 3, 6, and 7), others have to be derived based on the target value of the total waiting time (stations 2, 4, and 5). Regarding this waiting time, we know $ET_2 + ET_3 + ET_4 + EW_5 = 0.23$ for patients that visit a nurse and $ET_2 + ET_3 + ET_6 + EW_7 = 0.49$ for patients that visit a physician.

We implement the queuing model in Microsoft Excel using the parameters of Table 5.1. We design a solver macro that (iteratively) derives the expected service time for stations 2, 4, and 5 that result in either the registered waiting or sojourn time. Table 5.2 shows the results of our queuing analysis. The table shows the expected service time per station, per patient class.

Table 5.2: The results of our queuing analysis, showing the service times in minutes, where * indicated a derived service time; $^\diamond$ means *estimated prior to analysis*.

	$ES_1^{(k)}$	$ES_2^{(k)*}$	$ES_3^{(k)\diamond}$	$ES_4^{(k)*}$	$ES_5^{(k)}$	$ES_6^{(k)*}$	$ES_7^{(k)}$
ECG	20.0	2.0	1	4.6	24.6	26.2	24.7
no ECG	-	6.0	1	1.6	14.4	18.2	20.6
Aggregated	20.0	4.5	1	2.8	19.6	20.8	23.0

Table 5.3: The service time distributions per station.

Parameter	Distribution
$EA^{(k)}$	Exponential
$ES_1^{(k)}$	Erlang-5
$ES_2^{(k)}$	Exponential
$ES_3^{(k)}$	Exponential
$ES_4^{(k)}$	Exponential
$ES_5^{(k)}$	Exponential
$ES_6^{(k)}$	Log-normal
$ES_7^{(k)}$	Log-normal

In Section 5.1 we advanced the assumption that stations 4 & 5 and 6 & 7 do not share capacity despite the fact that these tasks are performed by the same providers. This assumption cannot hold if the sum of the occupation rates concerning these stations becomes to high ($\rho > 0.85$). Our queuing model gives $\rho_4 + \rho_5 \approx 0.74$ and $\rho_6 + \rho_7 \approx 0.82$, which means our assumption is justified from the perspective of occupation rates.

Table 5.3 shows the service time distribution per station (data set $\mathbb{F}$ using MathWave's EasyFit). We assume exponential service times for stations 2, 3, 4, and 5; fit an erlang-5 to station 1; and fit a lognormal distribution to stations 6 and 7 (see Appendix G for the results of the goodness-of-fit test). We now have all input parameters and arrival and service time distributions available to design the simulation model.

5.3 Simulation model design

In the previous section we determined the parameters and distribution of the service time per station and inter-arrival time at the PAC. We use these data to design our simulation model. Figure 5.4 shows the model design in EM-Plant. Compared to the queuing model of the previous section, our simulation model also incorporates the TCs discussed in the previous chapter.

The simulation model consists of 4 parts:

1. The **Control** section is used to set the run length and monitor the simulation during a run. A single simulation run replicates a pre-defined number of working weeks, the run length. We

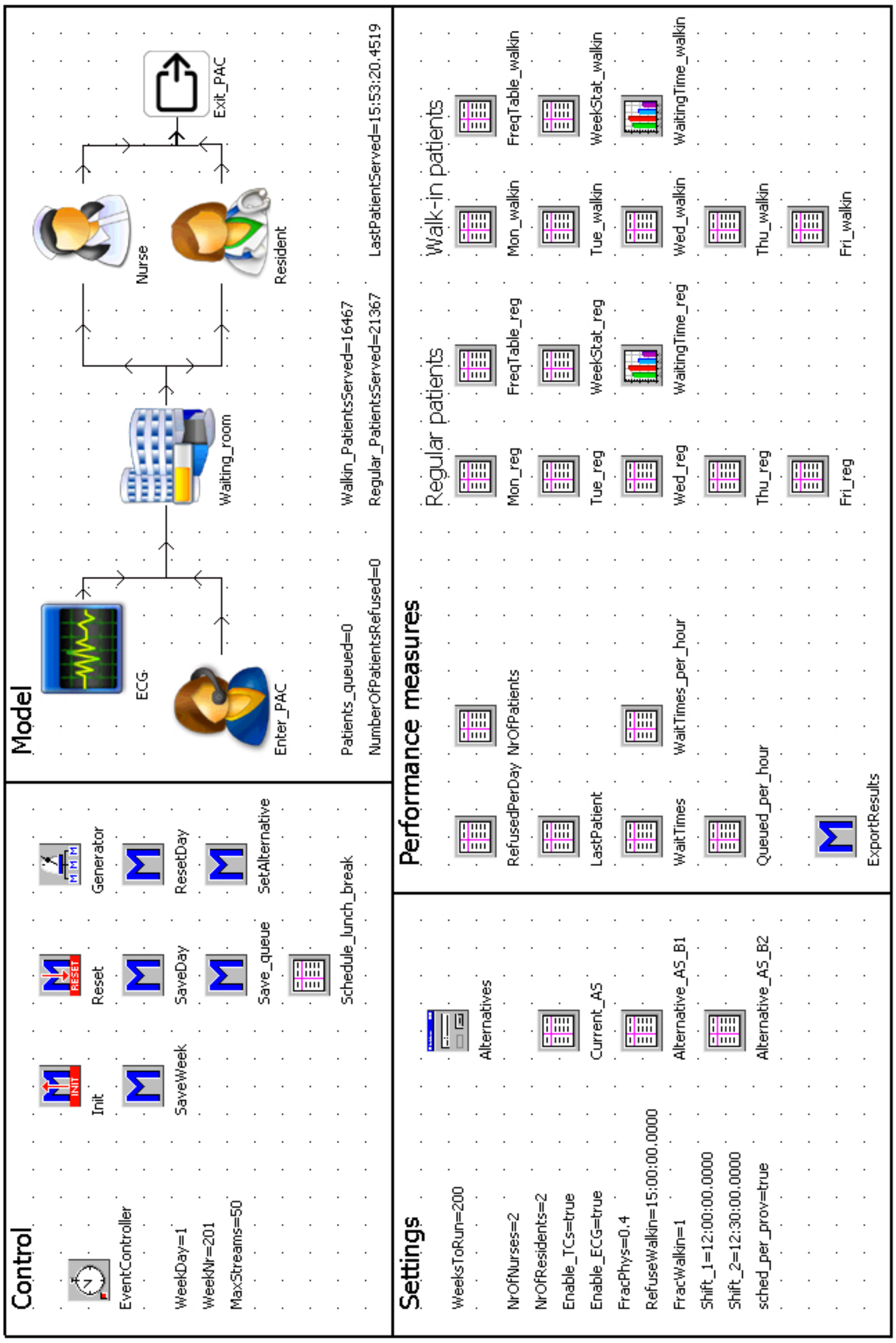


Figure 5.4: The design of the simulation model in TecnoMatix EM-Plant.

distinguish the working days of the week, i.e. Monday to Friday. Every run starts at Monday 8 AM, week 1.

2. The **Settings** section is used to set a number of variables. The variables that can be adjusted are:

   (a) The run-time length.

   (b) The inclusion or exclusion of TCs and ECGs.

   (c) The capacity, i.e. the number of nurses and residents available per day.

   (d) The fraction of patients served by a resident, currently 40%.

   (e) The time at the end of a working day when walk-in patients are not allowed to enter.

   (f) The fraction of patients that chooses to visit the PAC on walk-in after visiting an OC. Since no information is available about the patient's preference, we set this variable to 1.

   (g) The lunch break schedule, i.e. the time of lunch shift 1 and 2.

   (h) The appointment schedule used by the PAC, differentiated to the number of slots available per hour per day.

   These settings can be used for configuring interventions.

3. The **Model** section holds the model of the PAC conform Figure 5.3.

4. The **Performance measures** section is used to register all relevant data of patients that exit the PAC, like service and waiting times, number of patients served per day, fraction served within 30 minutes, and the average time of the last patient that leaves the PAC. The model also provides a plot of the waiting time distribution.

The AS is included in the model and used to generate the number of patient arrivals per hour of the day. For every simulation weekday, the AS includes an occupation rate variable that can be used to calibrate the number of patients that the model generates per working day.

Every simulation day (Monday to Friday), the number of patients and the waiting and service time are registered in the *Performance section*. It should be clear that the total number of alternative configurations that can be tested are far larger than the alternatives considered in this research. Our simulation model is not only designed to test the alternatives suggested in this research, but also to support the PAC's management in decision-making regarding various aspects of the PAC's operational design.

5.3.1 Calibration and validation

As described, the simulation model includes a variable that can be used to calibrate the AS so that the number of patient arrivals per day match the real life situation at the PAC. The arrival rate of patients is controlled by the number of slots available in the AS and this "occupation rate" variable. We calibrate the model so that the average number of patients generated per working day equals the actual number of assessments as specified in Table 2.3 on page 35.

We next validate our model on 3 criteria:

1. The expected waiting time for patients served by a nurse and resident: when simulating the current process, average waiting times of (approximately) 22.2 and 37.8 minutes should be obtained for nurses and residents respectively.

2. The fraction of patients served within 30 minutes after arriving at the PAC should be around 65%.

3. The average closing time (time of the last patient finishing service) should be around 4 PM, since working hours are from 8 AM to 4 PM.

The simulation model is successfully validated concerning these 3 criteria. However, waiting time and closing time variance was considered too large. We put an upper bound on the service times generated by our simulation model to decrease waiting time variance. The upper bound is based on the maximum values registered in our time motion study. Variance in waiting time showed a slight reduction, but remains higher than reality. Especially in-day variance in closing time remains higher than reality (approximately 1 hour compared to 30 minutes in reality).

Table 5.4 shows the values of the validation criteria of our simulation model and reality. The mean values indicate a close fit to the real life situation. The model was presented to the staff members and management for validation who indicated that the simulation input, process, and output are modeled conform reality. Although in-day variance of the closing time is too large, we consider our simulation model a good representation of reality.

Table 5.4: The simulation model results after calibration and correcting for the large waiting time (and closing time) variance (run-length $= 50$).

	Nr. of patients served	**Waiting time nurse**		**Waiting time resident**		**Fraction < 30 min.**	**Closing time**
		$mean \pm stdev$	95% CI	$mean \pm stdev$	95% CI		
Reality	≈ 44	22.5 ± 13.7	[21.4, 23.7]	37.7 ± 20.2	[35.7, 39.8]	0.65	$\approx$ 4 PM
Simulation	44.8	22.6 ± 20.6	[22.4, 22.8]	37.4 ± 28.4	[37.0, 37.7]	0.65	4:10 PM

CHAPTER 6

Results and implementation

The simulation model allows us to study the effect of the interventions proposed in Chapter 4. In Section 6.1, we discuss the simulation results regarding the process interventions of Section 4.1 that focus on reducing waiting times. In Section 6.2, we elaborate on the simulation results regarding the alternative ASs designed in Section 4.2. We summarize our finding in Section 6.3. The implementation of the results and the strategies that can be used to support implementation of the AS are discussed in Section 6.4.

6.1 Process interventions

Our simulation model is characterized as a *terminating* simulation [16] where a single replication corresponds to one working week. The run length is set to 50 weeks – which equals 250 working days – for all four interventions discussed in this section. The process interventions are evaluated on the resulting waiting times. The main performance indicators are:

1. The expected waiting time per provider, which should be smaller than the current waiting times.
2. The fraction of patients that is served within 30 minutes, which should be higher than the current 65%.

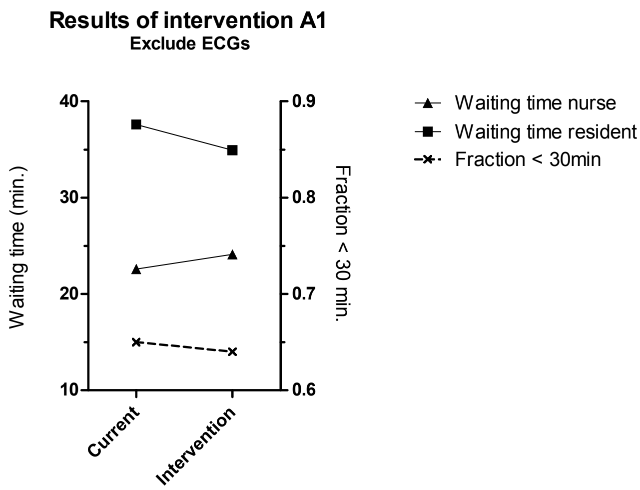
We statistically verify the differences in performance indicators between the current situation and the intervention by using a two-sided paired t-test ($\alpha = 0.05$). The simulation results can be used to support decision making with respect to process improvements at the PAC.

6.1.1 Intervention A1: Exclude ECGs

During this research, the medical staff decided to plan a study into the medical relevance of requesting patients to record an ECGs prior to their PAC visit. The results of intervention A1 give an indication of waiting time improvements that can be realized when excluding the ECG requirement at the PAC. We remark that the savings only refer to the waiting time. However, the time needed for a visit to the PAC will drastically reduce if patients are not requested for to get an ECG since this takes an average of 20 minutes (see Section 2.3).

Figure 6.2 shows the results: the expected waiting time for a nurse slightly increases ($P < 0.05$), the expected waiting time for a resident decreases by almost 3 minutes ($P < 0.05$), and the fraction of patients served within 30 minutes slightly decreases. The 95% CI on the reduction of the expected waiting times is [-1.9, -1.2] and [2.0, 3.3] for the nurse and resident respectively.

We expected that the waiting time for both the nurse and resident would decrease. This is inherently related to the design of our simulation model since we differentiated the service times per station analogous to the values in Table 5.2. As a result, patients that do not require an ECG have considerable shorter service times. We therefore have no clear explanation for the fact that the expected waiting time for a nurse increases. A possible explanation could be that the ECG requirement currently has a balancing effect on the workload over the day. The ECGs result in a fraction of patients being redirected to the ECG department and to return at the PAC later than their original appointment time. Consequently, their appointment time is delayed so that the ECG indirectly alters patient arrival rates during the day. Excluding the ECG might thus result in higher (maximum) arrival rates during certain hours of the day, which increases workload and would explain the higher expected waiting time for a nurse. However, one would then expect that the waiting time for a resident also increases, although this is not the case. We can thus not provide a clear explanation for the results. Overall, excluding the ECG does not drastically improve waiting times.



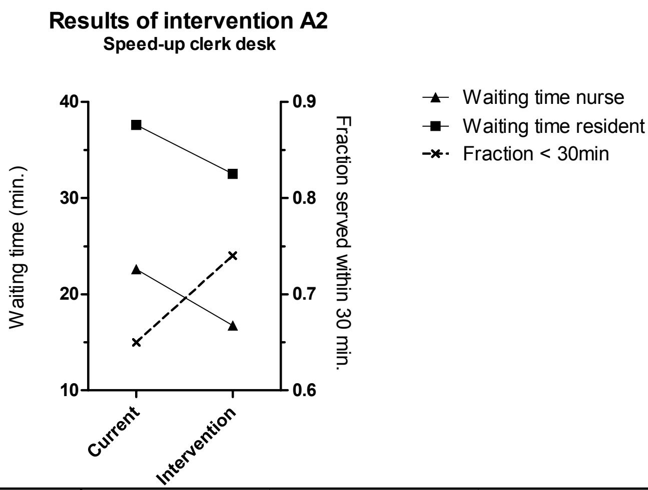
	Waiting time nurse	Waiting time resident	Fraction < 30min
Current	22.6	37.6	0.65
Intervention	24.1	34.9	0.64

Figure 6.1: The simulation results when excluding the ECG requirement ($P < 0.05$).

6.1.2 Intervention A2: Decrease throughput time at clerk desk

With this intervention, we decrease the expected processing time with 50% which (by approximation) corresponds to the situation where more patients hand-in their questionnaires electronically. The clerk currently needs to digitalize many questionnaires since a lot of patients hand in their questionnaire on paper. This hampers patient throughput at the PAC. If the questionnaires do not have to be digitalized, the medical file is available earlier, and delay at the clerk desk can be minimized.

Figure 6.2 shows the results of decreasing the processing time at the clerk desk from 4 to 2 minutes. Waiting times are reduced by 5 minutes on average ($P < 0.05$). The 95% CI on this expected reduction is [5.6, 6.1] for nurses and [4.7, 5.5] for residents. The fraction of patients served within 30 minutes increases to 74%. Improving the processing time at the clerk desk thus greatly improves waiting times.



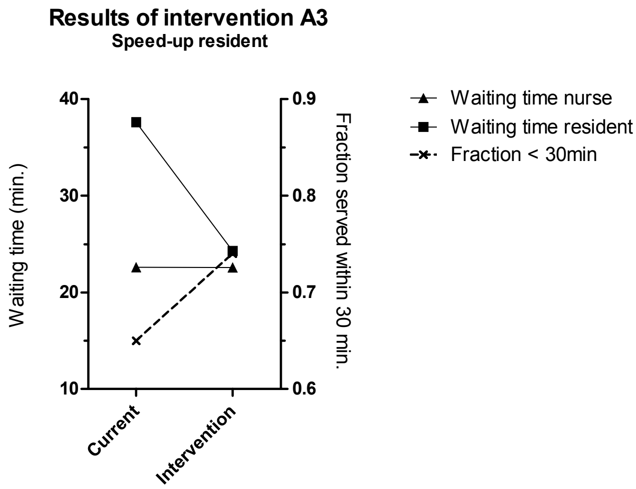
	Waiting time nurse	Waiting time resident	Fraction < 30min
Current	22.6	37.6	0.65
Intervention	16.7	32.5	0.74

Figure 6.2: The expected waiting time when the processing time at the clerk desk decreases to 50% ($P < 0.05$),

6.1.3 Intervention A3: Decrease throughput time for preparing assessment

Currently, residents are called away from the PAC to assess patients at the ward and unexperienced junior residents are frequently scheduled for shifts. Both issues are experienced to delay patient throughput and consequently increase the expected waiting times for a resident.

With this intervention, we study the impact of scheduling more experienced residents and improving the resident's availability. This availability can be improved if residents are not called away from the PAC to assess patients at the ward. Figure 6.3 shows the result of decreasing the effective preparation time by 50%. The results indicate that waiting time for a resident can then be reduced



	Waiting time nurse	Waiting time resident	Fraction < 30min
Current	22.6	37.6	0.65
Intervention	22.6	24.3	0.74

Figure 6.3: The expected waiting time when the (effective) preparation time for residents decreases to 50% ($P < 0.05$).

by 13 minutes on average ($P < 0.05$, 95% CI is [12.7, 14.0]). The fraction of patients that is served within 30 minutes after arrival is also drastically improved.

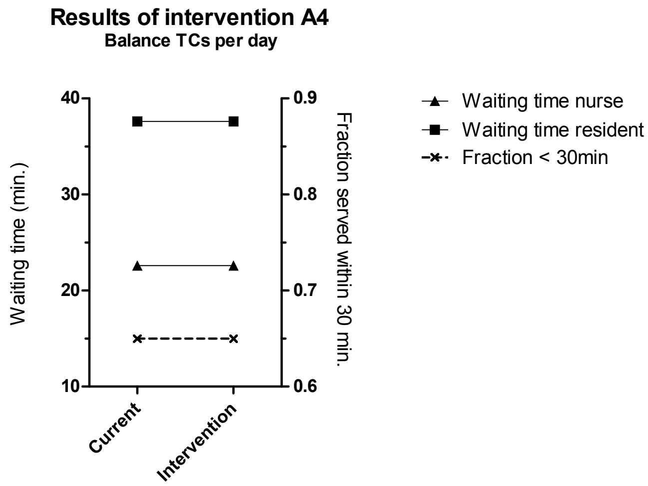
6.1.4 Intervention A4: Balance TCs over the working day

Staff members indicated that the high provider tardiness presented in Section 2.3 could be explained by the high number of TCs scheduled during morning hours alongside regular appointments. With this intervention, we evaluate this potential cause by balancing the TCs evenly over the working day. The results depicted in Figure 6.4 indicate that waiting times do not improve. Based on these results, we thus question whether the scheduling of TCs influences waiting times at the PAC.

6.1.5 Intervention A5: Scheduling patients to providers

With this alternative, we evaluate the future option of differentiating appointment slots to providers (nurse or resident). Given that patients that schedule an appointment have already supplied their medical information, they can directly be assigned to a provider in the AS. This way, the type of patient that visits the PAC is known in advance, fluctuations in provider work load are reduced, and waiting times might improve.

Figure 6.5 indicates that the expected waiting time and fraction of patients served within 30 minutes can be reduced ($P < 0.05$). From the figure we see that the expected waiting time for both nurses and residents can be decreased. The 95% CI for the reduction in waiting time is [1.5, 2.9] for nurses and [3.5, 5.9] for residents. The number of patients served within 30 minutes increases to



	Waiting time nurse	Waiting time resident	Fraction < 30min
Current	22.6	37.6	0.65
Intervention	22.6	37.6	0.65

Figure 6.4: The simulation results when TCs are scheduled evenly over the day.

70%. This makes it very beneficial to assign patients directly to a providers, if this would be possible for the near future.

6.1.6 Combining A2, A3 and A5

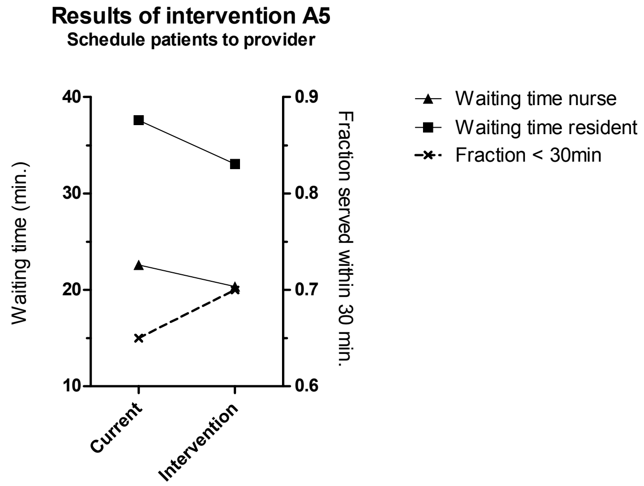
Since interventions A2, A3, and A5 all improve waiting time at the PAC, we are interested in the combined effect of these interventions on waiting times. Figure 6.6 shows the results. Waiting times are reduced to approximately 15 minutes per provider ($P < 0.05$). The 95% CI on waiting time reduction is [7.2, 8.5] for a nurse and [21.1, 23.1] for a resident. Almost 90% of all patients is served within 30 minutes. These results indicate that the combined effect of the interventions equals the sum of the individual interventions.

6.2 Alternative appointment systems

In this section we discuss the results of the alternative ASs and evaluate the effects of walk-ins on the expected waiting time. Regarding the process at the PAC, we include two conditions:

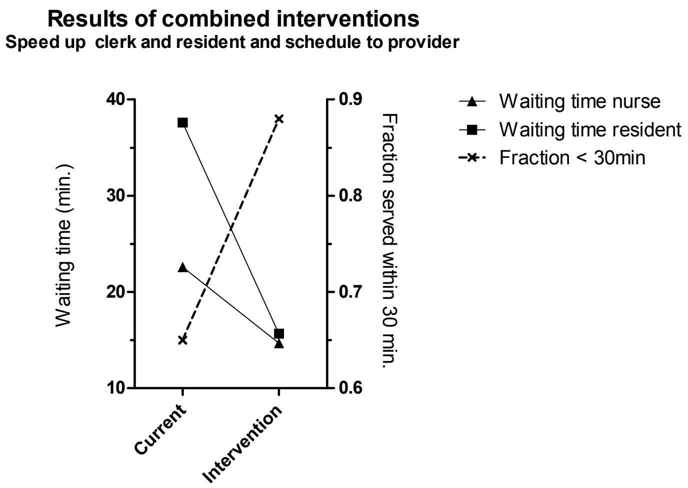
1. No walk-in patients are accepted after 3 PM as to minimize the chance of over-time. In the future, these patients will be offered an appointment on another day.

2. Appointment patients have a higher priority than walk-in patients. This means that appointment patients are put forward in queue the moment their medical file is processed at the clerk desk.



	Waiting time nurse	Waiting time resident	Fraction < 30min
Current	22.6	37.6	0.65
Intervention	20.4	33.0	0.70

Figure 6.5: The expected waiting times if the PAC would be able to directly allocate a patient to a provider when scheduling an appointment ($P < 0.05$).



	Waiting time nurse	Waiting time resident	Fraction < 30min
Current	22.6	37.6	0.65
Intervention	14.7	15.7	0.88

Figure 6.6: The simulation results when combining interventions A2, A3, and A5 ($P < 0.05$).

Table 6.1: The results of the simulation runs for alternative B1 and B2. * indicates a statistically significant difference between B1 and B2.

	EW nurse		*EW* resident		**Frac.** $<$ 30 **min.**	**Exp. closing time***
	Appoint.	Walkin	Appoint.	Walkin		
AS B1	19.6	25.7	33.7	37.6	0.70	4:23 PM
AS B2	18.0	26.1	33.9	38.2	0.71	4:15 PM

Table 6.2: The average closing time per working day for alternative B1, B2, and current situation based on simulation results.

	Mon	**Tue**	**Wed**	**Thu**	**Fri**
AS B1	4:32 PM	4:24 PM	4:22 PM	4:21 PM	4:14 PM
AS B2	4:32 PM	4:26 PM	4:00 PM	15:59 PM	15:59 PM
Current	4:25 PM	4:10 PM	3:56 PM	4:03 PM	3:43 PM

The results are evaluated on the expected waiting time for a nurse and a resident. Since we take walk-ins into account, we differentiate the patient population into appointment and walk-in patients. We are furthermore interested in the fraction of patients served within 30 minutes and the average closing time (equals the average time the last patient leaves the PAC).

For the moment, we assume that the average number of patients assessed per day remains the same in the new situation. Hence, both alternative B1 and B2 are calibrated on the current number of patients assessed per day.

Since we are also interested in the closing time statistics, which show a large in-day variance (see Section 5.3.1), we set the run-length to 200 to maximize the precision of the performance criteria's values.

6.2.1 Intervention B1 and B2: two alternative ASs that incorporate walk-ins

Alternative B1 has appointment slots of 30 minutes per provider, B2 has appointment slots of 30 minutes for nurses and 40 minutes for residents. Both alternatives incorporate walk-in patients by reserving capacity for the expected number of walk-ins per hour. Table 6.1 shows the results on the performance criteria. The waiting time performance measures show no significant differences between both alternatives. The expected closing time significantly differs with 7 minutes (unpaired t-test using Welch's correction, $P < 0.05$).

Based on the results of Table 6.1 we conclude that both alternatives result in the same waiting times and that waiting times can be improved for appointment patients due to the priority rule. A topic of special interest to the PAC's management are the closing times per day and the expected waiting time per hour of the day. Management cannot afford much longer working hours for staff members than currently realized. Table 6.2 indicates how the average closing time differs per day of the week.

Alternative B2 clearly outperforms B1 on Wednesdays, Thursdays, and Fridays. For both alter-

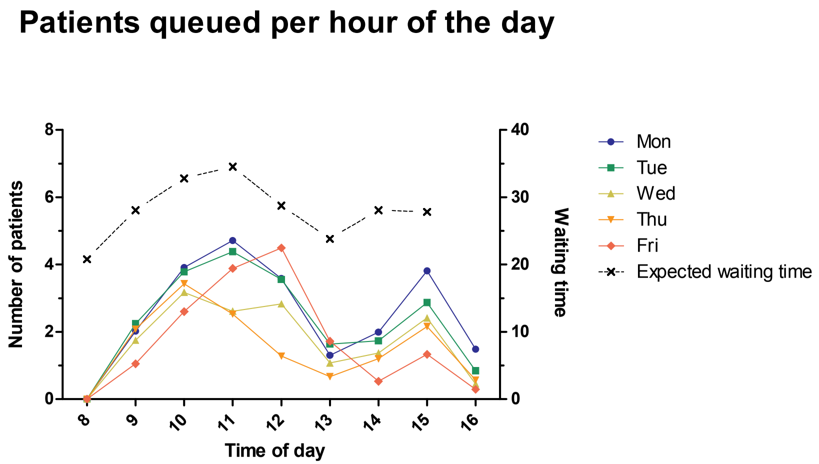
Table 6.3: The revised appointment system of alternative B2 and its resulting closing times.

Hour	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**
8-9	7	7	7	7	7
9-10	5	4	5	5	5
10-11	2	3	1	3	4
11-12	2	4	1	3	3
12-13	3	3	3	3	3
13-14	3	3	3	3	2
14-15	1	1	1	1	1
15-16	1	1	1	1	1
Total	24	26	22	25	26

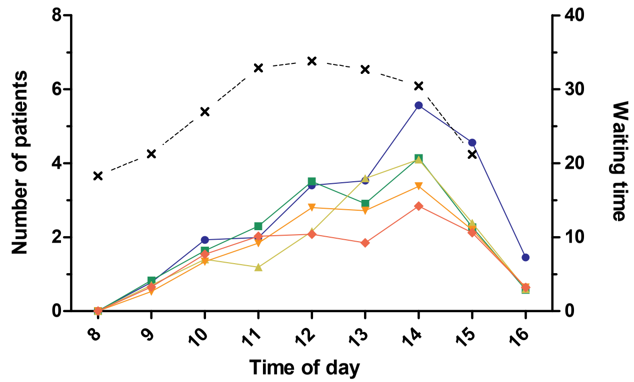
natives, Mondays and Tuesdays can be considered critical. The (high) closing times for alternative B2 can be explained by Figure 6.7, where the number of patients queued and expected waiting time is plotted against the time of day the patient enters the PAC. For ease of comparison, we also included a figure of the current situation. From Figure 6.7 we see – for figures (a) to (c) – that Monday (blue line) is located at the top of the graph indicating a relatively high number of patients queued in the waiting room, especially at the end of the working day. In general, a high number of patients queued at the end of the day will greatly increase the chance of working in overtime. Note that the graphs also include the expected waiting time (averaged over all days). Suppose a patient enters the PAC at 15 PM on Monday, than according to alternative B2 in Figure 6.7c, the patient finds 4 other patients already waiting and incurs an expected waiting time of approximately 22 minutes. For controlling the closing time per working day, it is therefore essential to keep the number of patients queued to a minimum at the end of the day. The AS can support in realizing this: the number of appointments at the end of the day should be minimal and the number of patients assessed per day should be (more evenly) balanced over the week. Alternative B2 performs relatively well on this point. However, the schedule for Monday should be improved.

Figure 6.7 also clearly illustrates the effect of the expected walk-ins. In the current situation, only a small number of patients is queued during lunch hours. For both alternatives, this cannot be realized due to walk-in patients that arrive between between 12 AM and 1 PM.

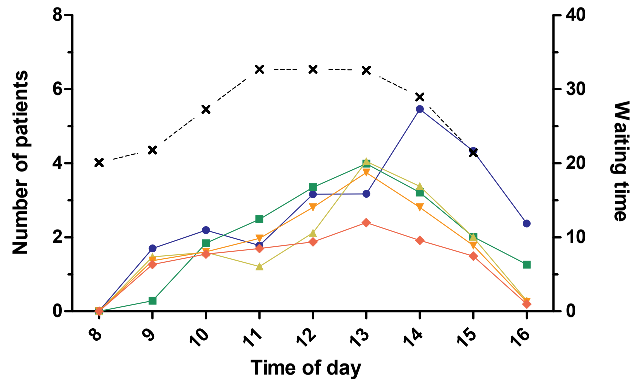
In the introduction to this section, we remarked that the alternatives were calibrated on the current workload per day. We now abandon this assumption. As noted above, the results of Figure 6.7c indicate that most appointments should be scheduled in the morning and that workload should be balanced more evenly over the week. We therefore revise alternative B2 to take these conditions into account, resulting in the AS depicted in Table 6.3. The AS is calibrated to balance workload over the week, i.e. an average of 44 assessments per day. As can be seen from Table 6.4, the expected closing times per day are improved: all closing times are before 4 PM. Figure 6.8 depicts the expected number of patients that wait in the waiting room per hour of the day. As can be seen from the this figure, the number of patients queued at the end of the day is substantially reduced. This confirms our finding that most appointments should be scheduled in the morning. Furthermore, the PAC is strongly advised to more evenly balance the workload over the week when implementing walk-in.



(a) Current situation: appointment patients only.



(b) AS B1: appointment and walk-in patients; slot size 30 minutes per provider.



(c) AS B2: appointment and walk-in patients; slot size of 40 minutes for residents and 30 minutes for nurses.

Figure 6.7: The expected number of patients queued and the expected waiting time per hour of the day. The hour of the day corresponds to the time the patient enters the waiting room.

Table 6.4: The expected closing time as a result of the appointment system depicted in Table 6.3.

Hour	Mon	Tue	Wed	Thu	Fri
Closing time	3:54 PM	3:48 PM	3:47 PM	3:44 PM	3:43 PM

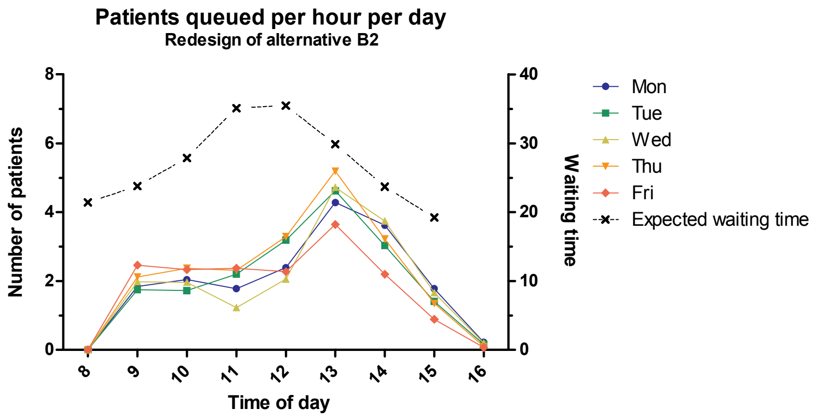


Figure 6.8: The expected number of patients queued and the waiting time per hour after applying the AS depicted in Table 6.3.

6.2.2 Combining process improvements and walk-ins

We found the main criteria for designing an AS that reserves capacity for walk-ins, resulting in the AS of Figure 6.3. In Section 6.1, we discussed which interventions reduce waiting time. We now combine these results and simulate the PAC under walk-in conditions, using the AS of the previous section and the combined interventions of Section 6.1.6 (run-length=200).

The results in Table 6.5 show that waiting times can be drastically reduced, even under walk-in conditions. In addition to these results, the fraction of patients served within 30 minutes increases to 91%. The average closing time per day is 3:31 PM, with only a minor deviation between working days.

These results demonstrate that, given that the interventions are attainable and a robust AS is implemented, large improvements can be made regarding the patient service level: the PAC can offer services on walk-in and still improve waiting times.

Table 6.5: The simulation results when combining the process improvements, walk-ins, and alternative AS.

	Waiting time nurse		Waiting time resident	
Patient type	*mean* ± *stdev*	95% CI	*mean* ± *stdev*	95% CI
Appointment	12.0 ± 12.2	[11.8, 12.2]	15.3 ± 12.4	[15.0, 15.5]
Walk-in	16.3 ± 15.9	[16.0, 16.7]	17.8 ± 14.3	[17.5, 18.2]

6.3 Conclusion

Summarizing our main findings, we conclude that excluding ECGs does not greatly improve waiting times at the PAC. Moreover, balancing TCs over the working day has no effect on waiting times. The greatest improvements can be obtained when improving throughput at the clerk desk and decreasing the preparation time for residents. Regarding the first, patients have to be encouraged to fill in their questionnaires electronically, either at home or at computers located at the PAC. The high preparation time for residents is probably due to their unavailability and lack of experience. If availability can be improved or more experienced can be scheduled for shifts at the PAC, then waiting time for residents can be significantly improved. If patients can be scheduled directly to a provider, then waiting time can be reduced even more. When combining these improvement, we expect waiting time can be reduced by 7 to 8 minutes for nurses and 21 to 23 minutes for residents.

Regarding the ASs, we consider appointment slot sizes of 40 minutes for residents as most effective for controlling waiting times. We demonstrated that is essential to schedule most appointment in the morning and balance workload over the week. This substantially reduces the risk of overtime. The priority rule − appointment patients have a higher priority than walk-ins − enables the PAC to keep waiting times for appointment patients to minimum. This is an important aspect of the (future) patient service level: for the future, patients that schedule an appointment have the advantage over walk-ins that they have a smaller expected waiting time.

6.4 Implementation

This research is based on an extensive data analysis and, to the best of our knowledge, provides the best means available to estimate the number of walk-ins per hour, per working day. Our research suggest an AS that should be able to control patient arrivals and waiting times. However, the robustness of the AS is revealed after implementation. In the implementation phase, it therefore is essential that unreliabilities in our data analysis are revealed as soon as possible so that we are able to quickly adjust model parameters and re-evaluate the PAC's process. At the time of publication of this report, implementation had not yet started. We support the future implementation in two ways:

1. The ASs are presented to the PACs management and clerks to discuss which AS is desired and whether minor alterations are needed. The effect of possible alterations can then be easily verified in our simulation model.

2. We designed a practical computer tool designed in Microsoft Excel that can be used at the clerk desk. The tool is used to register all patients arrivals per day so that our estimation of the number of walk-ins can be easily verified. If major deviations in the expected number of walk-ins are noticed, preventive actions can be planned to control waiting times and provider occupation rates at the PAC.

3. We created a project team of staff members and management that will coordinate implementation.

Currently, the PAC has no means available to determine the patient's health status in advance of a PAC visit. We can therefore not control the number of HS-1 and HS-2 patients that arrives during the day. Improving the preparation time of residents cannot be expected in short notice, since this requires a policy change at the PAC that requires commitment of all anesthetists.

If waiting times cannot be reduced under walk-in conditions, than the PAC can decide on the option of delay-scheduling as described in literature. With this scheduling policy, a walk-in patient that arrives at the PAC is then given an appointment time and is requested to return later that day. This "delay" can be 1 or 2 hours later, depending on the queue length.

CHAPTER 7

Conclusions & recommendations

Patients that currently visit the PAC of UMCU experience high waiting times. For the near future, walk-ins are allowed alongside regular appointments. With this research, we studied how a walk-in based PAC can be organized while keeping waiting times to a minimum.

Chapter 2 elaborates on the current organization of the preoperative process, the current organization of the PAC, and the PAC's current performance. A major aspect of our research is an extensive data analysis involving eight data sources, which enabled us to quantify patient pathways. Data records from these data sets could be matched based on patient ID by which it became possible to relate appointment data of outpatient clinics and the PAC to mutations on the waiting list and performed surgeries. We designed a time motion study to monitor patient sojourn times at the PAC. In combination with data from multiple information systems, we were able to quantify the preoperative process in general, and that of the PAC in particular. Our conclusion is twofold:

1. The number of patients that visit the OCs heavily fluctuates per day as well as during the day. In the future, a fraction of these patients might directly continue to the PAC if they are planned for surgery. However, this actual number of walk-ins depends on the ratio of the patients that is planned for surgery in combination with the preference of the patient to visit the PAC on walk-in.

2. The waiting times are currently too high, especially for patients that wait for a resident: patient wait an average of 22 minutes for a nurse and 38 minutes for a resident; 65% of all patients is served within 30 minutes. The causes for these high waiting times remained rather unclear, although we found that:

   (a) Digitalizing the questionnaires at the clerk desk requires too much time.

   (b) The current design of the appointment system is not transparent due to the differentiation to specialties, user-groups, and appointment types.

   (c) An appointment slot size of 30 minutes might not be sufficient. The service time now leaves an average of 8 minutes for finishing the consultation and preparing the next.

   (d) Service times differ between patients that need an ECG and those that do not. This can be explained by the medical complexity of the patient and the fact that the interpretation of ECGs takes additional time.

(e) Appointments in the morning start with a delay (high provider tardiness). If the first patient is served to late, than successive patients incur additional waiting time that cannot be easily caught up. We advise the PACs management to remind staff members of the consequences of late starting times on waiting times during the day.

(f) The patient survey indicated that an average waiting time between 15 and 20 minutes is acceptable, although we do not consider the survey's population sample representative for the total population (the average waiting time of the patients that responded is smaller than the average waiting time registered in our time motion study).

Chapter 3 presents the literature on organizing walk-in clinics and controlling waiting times. Most researchers interpret walk-in patients as high priority patients that have to served in between regular appointments. The fraction of appointment slots reserved for walk-ins is then considerably smaller than in our situation, which make these theories less applicable. Some researchers describe the need to balance appointments over the day and agree that simulation is a useful technique to model the dynamics of a hospital clinic. Various studies suggest a patient classification that is used in the appointment system helps to control waiting times, and suggest the ASA classification. We advocated that we do not expect that the ASA classification is the right classification, since a patients ASA classification can only be determined after consultation, not prior to it.

Chapter 4 describes interventions that might reduce waiting times and alternative appointment systems that should reserve capacity for walk-ins. The interventions are the result of a discussion with staff members and management about the possible causes of the high waiting times. We suggested 5 interventions that focus on process improvements at the PAC:

1. Intervention A1: An alternative schedule for TCs.
2. Intervention A2: Excluding the ECG requirement.
3. Intervention A3: Decreasing the (effective) service time at the clerk desk by 50%.
4. Intervention A4: Decreasing the (effective) service time of residents by 50%.
5. Intervention A5: Scheduling patients directly to providers.

We determined the expected number of walk-ins per hour of the day and designed two appointments system that supports the PAC in reserving capacity for walk-in patients. The first is based on an appointment slot size of 30 minutes per provider; the second is based on an appointment slot size of 30 minutes for nurses and 40 minutes for residents.

In Chapter 5, we designed a simulation model that allows the PACs management to study various process interventions. A queueing model was used to derive unknown service times based on the waiting and sojourn times registered in the time motion study. The simulation model was successfully validated and gives a good representation of patient processing times and waiting times at the PAC. The model also supports management in designing an AS.

The simulation results were presented in Chapter 6. We evaluated the process interventions and the alternative appointment systems under walk-in conditions. Our main findings are:

1. Excluding ECGs and balancing TCs over the day does not (greatly) improve waiting times.
2. Decreasing the processing time at the clerk desk by 50% reduces the expected waiting time by 5 to 6 minutes on average.
3. Decreasing the preparation time of residents by 50% reduces the expected waiting time for a resident by 13 to 14 minutes on average.
4. Assigning patients directly to providers when scheduling appointments reduces the expected waiting time by 2.5 to 3 minutes for nurses and 4 to 6 for residents.
5. The combined effect of (2), (3), and (4) equals the sum of the individual interventions. Waiting times can be reduced by 7 to 8 minutes for nurses and 21 to 23 minutes for residents.
6. An appointment system that incorporates a 40 minute slot size for residents slightly outperforms one than incorporates 30 minutes for residents.
7. Under walk-in conditions, it is essential that most appointments are scheduled in the morning and that workload is evenly balanced over the week. If these criteria are not met, the PAC risks that staff members need to work in overtime (after 4 PM).
8. An appointment system based on the criteria of (7) in combination with the process intervention of (5) suggest that the PAC can be successfully organized on walk-in and at the same time drastically reduce waiting times.

The following shortcomings are experienced in the process of our research:

- The results of the patient survey regarding experienced waiting times can not be considered valid from a statistical point of view. The patients population that responded to the survey does not correspond to the population registered in our time motion study.

- After having performed the time motion study, it appeared that not all activities at the PAC had been registered. This led us to derive the processing times of these activities based on available waiting and sojourn times. The simulation model could be improved if the (processing) time of these activities is known.

- Matching the appointments at the OC to request dates for surgery per hospital location is complicated due to differences in registration methods and information systems used. Matching these appointments is essential for successfully approximating the expected number of walk-ins per hour of the day.

- We do not know whether patients prefer to visit the PAC on walk-in if they just received a surgery indication. In this study, we assumed all of these patients choose to directly continue to the PAC, i.e. to visit the PAC on walk-in. Therefore, the expected number of walk-in patients presented in this research can be considered a ‘worst-case’ scenario.

Our research resulted in a large data set that can be used for further research. The simulation model provides extensive options for evaluating interventions at the PAC. Although the model is build for simulating activities at the PAC, some slight modifications allow it to be used as a simulation tool for other outpatient clinics.

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APPENDIX A

Data sources

The data used in this research covers different time spans, which has consequences for our data analysis. Figure A.1 illustrates these differences. The data source *Appointments outpatient clinics* is differentiated to the various OCs.

Table A.1 gives an overview (in Dutch) of all variables that are available from the data sets. All data sets are imported in a *Microsoft Access* database so that records can be merged based on patient ID.

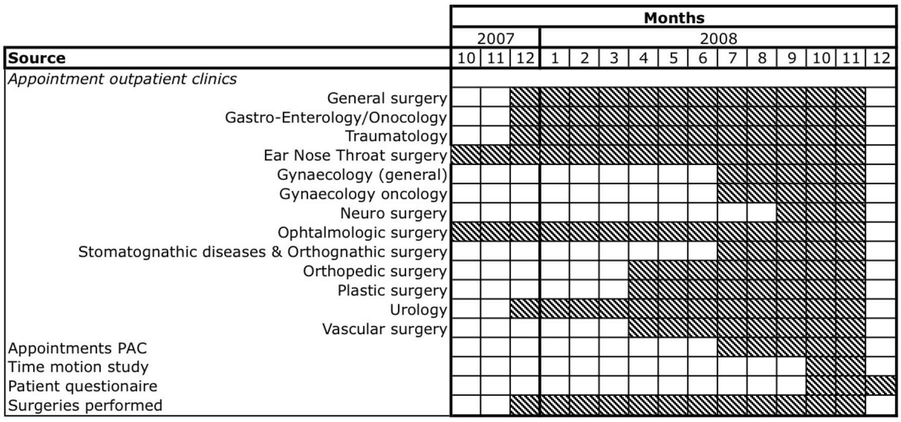


Figure A.1: The time range per data set.

Table A.1: The variables available per data set (Dutch).

Data set A	Data set B	Data set C (dagb.)	Data set C (klinisch/F4)	Data set D	Data set E	Data set F	Data set G	Data set H
Afspraken poli's	**Afspraken POS**	**Wachtlijst F2**	**Wachtlijst F4**	**Vierkleurenpen**	**Papieren registratie POS**	**Tijdstudie**	**Enquete**	**Ingrepen F2 en F4**
Patientnummer	patientnummer	AanvraagDatum	Patientnummer	case_id	Datum	Dag	Datum invoer	Operatienummer
Ziekenhuis	afdeling	OperatieDatum	Ziekenhuislocatie	patient_id	Dag	Datum	Datum bezoek	Lokatie
Locatiecode	agendacode	AnaesthesietechniekCode	Opnametype	ok_nr	POS patienten	AZU-nr	Enkel of combi afspraak	Hoofdspecialisme
Kostenplaatscode	contacttype	Patientnummer	Omschrijving	begindatum_tijd	Afdelingspatienten	Inlogcode	Behandelaar	Datum_aanvraag
Kostenplaats	afspraaktype	Patientnaam	Specialismecode	begindatum		Tijdstip afspr.	Ontvangst	DagvdWeek_aanvraag_d
Afdeling	boekingsdatum	Specialisme	Omschrijving	OK_dag		Aankomst afspr.	Wachttijd	Week_aanvraag_d
Agendacode	jaardag	Operateur	Tracercode	dossiernummer		Dossier klaargelegd	Tel. bereikbaarheid	Maand_aanvraag_d
Agenda	maandnummer	Urgentie	Omschrijving	episode_nummer		arts/vpl	Pers. aandacht	Jaar_aanvraag_d
Contacttypecode	maand	Herkomst	Opvoerdatum	episode_datum		Aankomst spreekkamer	Deskundigheid	Operatiedatum
Contacttype	maanddag	Bestemming	Afvoerdatum			Vertrek spreekkamer	Duidelijkheid	Operatiedatum2
Afspraaktypecode	weeknummer		Wachtdagen			Vertrek ECG	Verwachting bezoek	DagvdWeek_operatie_d
Afspraaktype	weekdag					Retour ECG	Te linken?	Week_operatie_d
Programmacode	dag						Locatie invoer	Maand_operatie_d
Programma	boekingstijd						Code	Jaar_operatie_d
Boekingsdatum	afspraakdatum						Inlogcode	Anesthesie_code
Bezoekjaar	afspraaktijd							Anesthesie_omschr
Bezoekdatum	consultduur							Patientnummer
Bezoektijd								OK
								Prioriteit_code
								Prioriteit_omschr
								SoortOpname_code
								SoortOpname_omschr
								ASA
								Aantal_AM
								Discrepantie
								Patient_op_OK
								Patient_uit_OK
								Datum_patient_op_OK
								Tijd_patient_op_OK

APPENDIX B

Flow charts

B.1 The SAD process

There are numerous administrative tasks that have to be performed at the SAD before a patient can finally be scheduled for surgery. The clerk at the SAD is responsible for managing and controlling the process for all patients and ensuring that patients are processed as quickly as possible. The clerk at the inpatient SAD schedules patients for the ward screening and PAC visit, schedules additional medical tests requested by the surgeon, registers patients on the waiting list, and – for some specialties – allocates patients to available operating room slots.

The flow diagram in Figure B.1 shows the tasks performed when a patient should be planned for surgery and the information systems involved. The diagram is based on the activities of the general surgery department, one of the largest SADs. It therefore is representative for most patients in the preoperative process.

B.2 The ward screening process

Figure B.2 shows the tasks concerning the ward screening. Only clinical patients of a number of specialties are screened by the ward in advance of hospital admission. For most patient, the ward screening is then combined with an appointment at the PAC.

B.3 The PAC assessment

Figure B.3 shows a flow chart of all tasks performed at the PAC concerning patient assessments. The flow chart also illustrates which information systems are involved at various moments in the process. The left part of the flow chart refers to the tasks of the clerk; the right side refers to the tasks of the providers (nurse or resident).

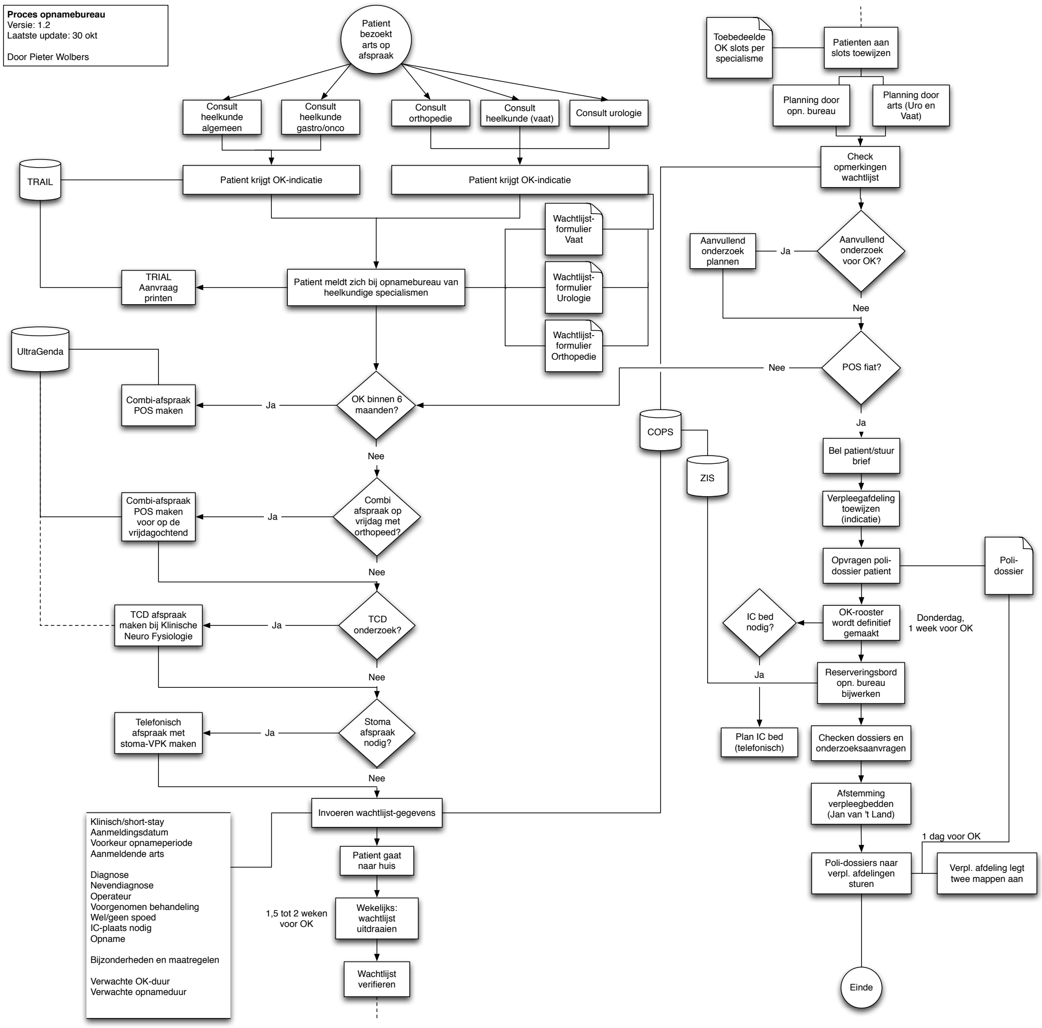


Figure B.1: Flow chart of all tasks involved when a patient is planned for surgery (in Dutch).

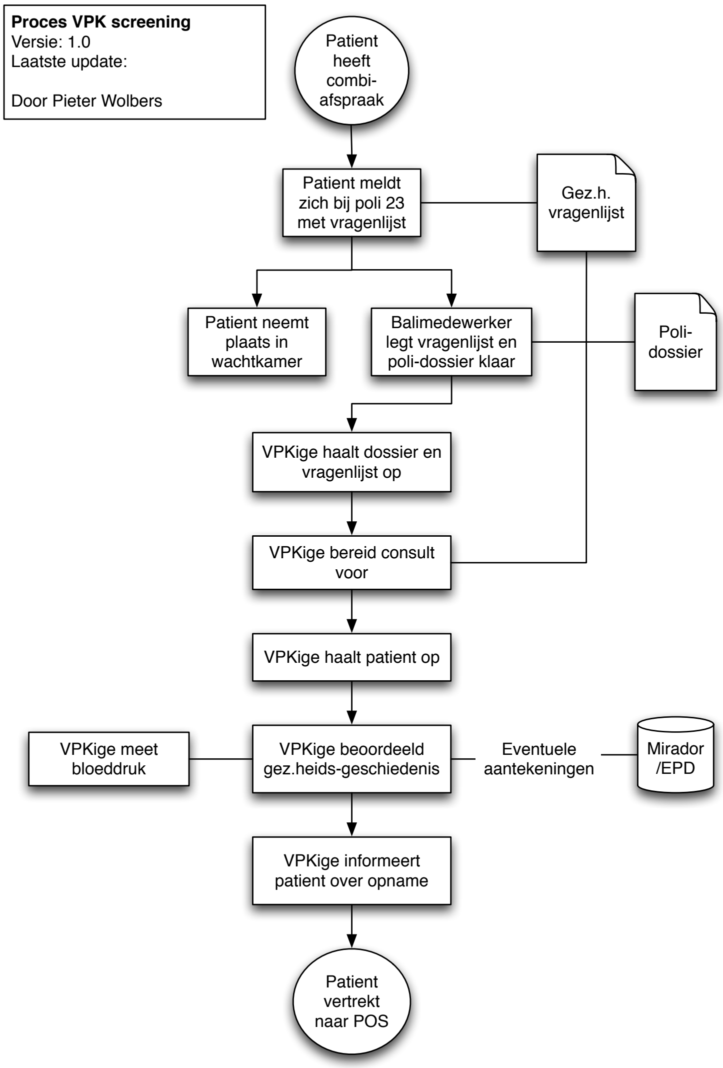


Figure B.2: Flow chart of all tasks involved for the ward screening of clinical patient (in Dutch).

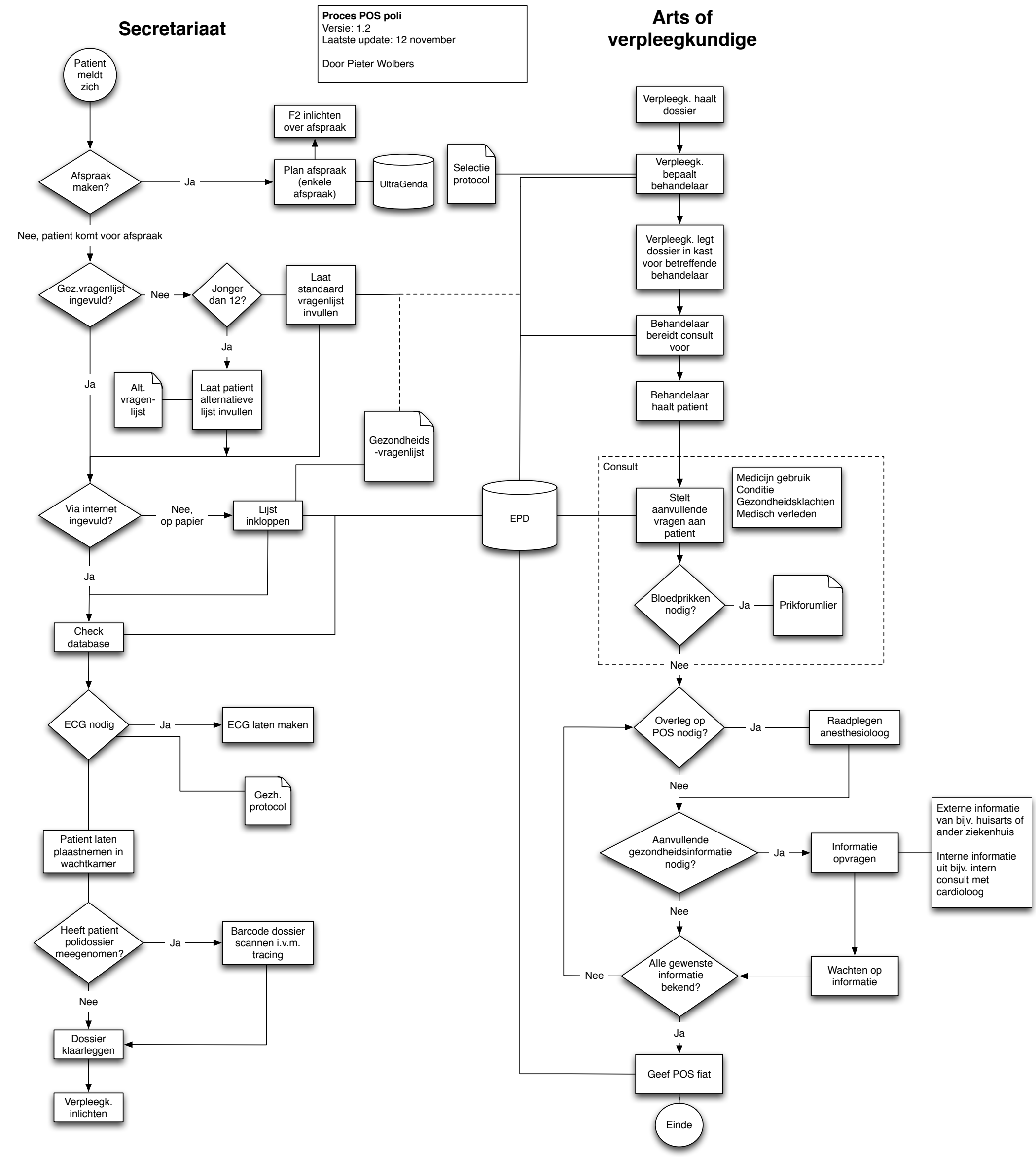


Figure B.3: Flow chart of the tasks performed at the PAC (in Dutch).

APPENDIX C

Current design of the appointment system

Figure C.1 gives an overview of the appointment slots available on Mondays. Default appointment interval is 15 minutes, initial block size is 3 (including telephone consultations), and regular block sizes are 2. Six additional slots are available for consultations by phone.

Dag	Tijdstip	Slot 1	Slot 2	Slot 3	Slot 4
Ma	08:00				
Ma	08:15	Neuro	Oogheelkunde		Telefonisch
Ma	08:30	Chirurgie	Oogheelkunde		Telefonisch
Ma	08:45	Oogheelkunde	PLAN spoed		Telefonisch
Ma	09:00	Chirurgie	Gynaecologie		Telefonisch
Ma	09:15	Neuro	PLAN		Telefonisch
Ma	09:30	Gynaecologie	Nieuw INLO		Telefonisch
Ma	09:45	Chirurgie	Nieuw INLO		
Ma	10:00	Chirurgie	Nieuw INLO		
Ma	10:15	Nieuw INLO	BT		
Ma	10:30	Gynaecologie	Chirurgie (spoed)		
Ma	10:45	Chirurgie	Neuro (spoed)		
Ma	11:00	Neuro (spoed)	Neuro		
Ma	11:15	Chirurgie	Nieuw INLO		
Ma	11:30	Chirurgie (spoed)	PLAN		
Ma	11:45				
Ma	12:00	Chirurgie			
Ma	12:15				
Ma	12:30				
Ma	12:45				
Ma	13:00	Spoed INLO			
Ma	13:15	Gynaecologie	Nieuw INLO		
Ma	13:30	Chirurgie	Chirurgie (spoed)		
Ma	13:45	Gynaecologie	Oogheelkunde		
Ma	14:00	Chirurgie (spoed)	Oogheelkunde		
Ma	14:15	Chirurgie	Oogheelkunde		
Ma	14:30	Chirurgie	Oogheelkunde		
Ma	14:45	Oogheelkunde	PLAN		
Ma	15:00	Chirurgie	Nieuw INLO		
Ma	15:15	Gynaecologie	Nieuw INLO	BT	
Ma	15:30	Chirurgie			
Ma	15:45				
Ma	16:00				
Ma	16:15				
Ma	16:30				

Figure C.1: Overview of the appointment slots in UltraGenda available on Mondays. The colors indicate unique combinations of specialty–appointment types.

Correlation between presence anesthetist and PAC assessment

Figure D.1 shows the SPSS output of the Kappa test performed on data set $\mathbb{B}$ and $\mathbb{C}$ to determine the agreement between the presence of an anesthetist during surgery and a registered PAC visit of the patient. The Kappa value indicates strong agreement ($\kappa > 0.8$). The presence of an anesthetist during surgery can therefor be used as an indicator for an assessment at the PAC.

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Anesth. present* Assessment at PAC	24039	100,0%	0	,0%	24039	100,0%

Anesth. presence* Assessment at PAC Crosstabulation

Count

		Assessment at PAC			Total
			yes	no	
Anesth. present		3850	0	0	3850
	yes	0	14743	539	15282
	no	0	1119	3788	4907
Total		3850	15862	4327	24039

Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Measure of Agreement	Kappa	,867	,003	180,852	,000
N of Valid Cases		24039			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Figure D.1: Results of the Kappa test on the presence of an anesthetist during surgery versus a PAC assessment.

APPENDIX E

Expected number of walk-ins

Table E.1a and E.1b respectively show the estimated number of daycare and clinical patients that will visit the PAC per hour per day. Table E.1c shows the sum of both patient groups. The first patients are expected around 9 PM since patients have to continue to the PAC from the outpatient clinic. Data shows that, on average, 1 hour passes between a patient's appointment time at the outpatient clinic and his or her arrival time at the PAC. This constitutes the waiting time and service time at the outpatient clinic, administrative activities after leaving the surgeon, and walking over to the PAC.

Table E.1: The estimated number of walk-in patients that arrive at the PAC per hour per working day.

(a) Daycare patients

Hour	Mon	Tue	Wed	Thu	Fri
8-9	0	0	0	0	0
9-10	0.7	2.1	0.2	0.4	0.8
10-11	2.6	1.2	1	1	0.9
11-12	1.7	1	1.4	1.5	0.6
12-13	1.5	0.7	0.9	1	0.6
13-14	0.1	0.3	0.4	0.2	0.4
14-15	0.8	2.4	0.9	0.5	0.4
15-16	0.8	1	0.8	0.6	0.2
16-17	0.5	0.7	0.5	0.3	0
17-18	0	0	0.1	0.3	0
Total	8.7	9.4	6.2	5.8	3.9

(b) Clinical patients

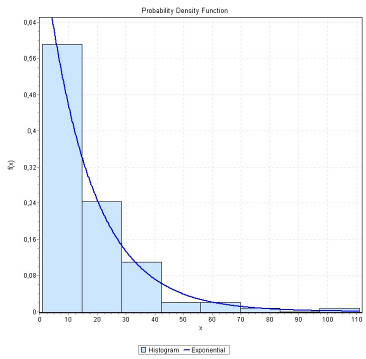
Hour	Mon	Tue	Wed	Thu	Fri
8-9	1.1	0.7	1.8	1.7	0.8
9-10	2.4	2.3	4.6	3.1	2
10-11	2.7	2.1	4.7	2.5	3
11-12	2.1	1.4	2.4	1.6	1.7
12-13	1.2	0.4	0.5	0.3	0.2
13-14	1.7	2.3	2.1	1.5	1.3
14-15	1.9	2.3	2.2	1.7	1.7
15-16	2.2	1	1	1.2	0.9
16-17	0	0.1	0.1	0.1	0
17-18	0	0	0	0	0
Total	15.3	12.6	19.4	13.7	11.6

(c) Total

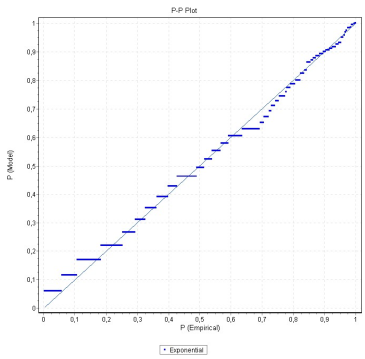
Hour	Mon	Tue	Wed	Thu	Fri
8-9	0	0	0	0	0
9-10	1,8	2,8	2	2,1	1,6
10-11	5	3,5	5,6	4,1	2,9
11-12	4,4	3,1	6,1	4	3,6
12-13	3,6	2,1	3,3	2,6	2,3
13-14	1,3	0,7	0,9	0,5	0,6
14-15	2,5	4,7	3	2	1,7
15-16	2,7	3,3	3	2,3	1,9
16-17	2,7	1,7	1,5	1,5	0,9
17-18	0	0,1	0,2	0,4	0
Total	24.0	22.0	25.6	19.5	15.5

Verification of poisson arrivals

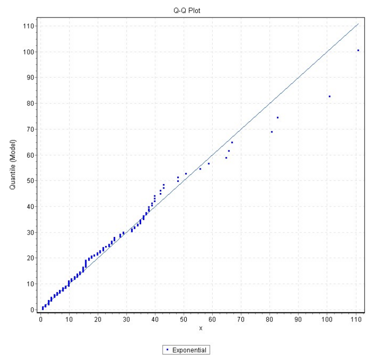
Figure F.1a, F.1b, and F.1c respectively show the resulting probability distribution plot, PP, and QQ plot after fitting the exponential distribution to the current patient inter-arrival times at the PAC under the conditions of an appointment system. The graphs illustrate a good fit. In addition, the Chi-Square test indicates a good fit between the sample and the exponential distribution: $\chi^2 = 8.22 \leq \chi^2_{7,0.95}$.



(a) Probability distribution function



(b) PP plot



(c) QQ plot

Figure F.1: The MathWave Easyfit output when fitting the exponential distribution to the inter-arrival rate at the PAC (Data set $\mathbb{F}$, n=247, df=7).

APPENDIX G

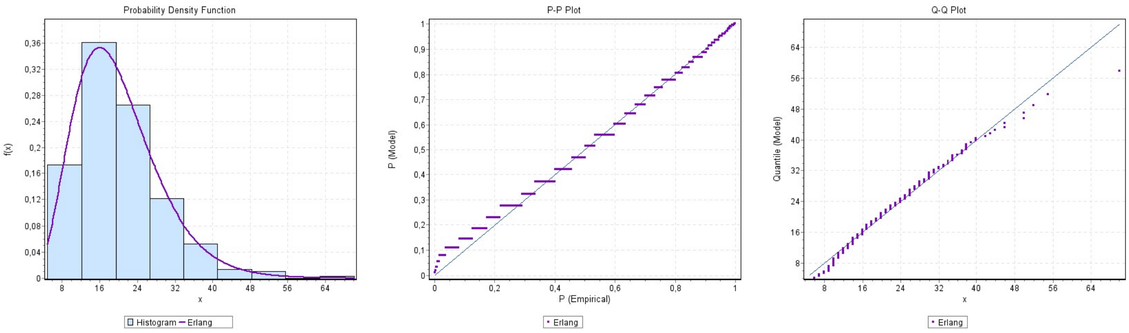
Fitted distributions

Figure G.1, G.2, and G.3 respectively show the results of fitting a distribution to the time a patient needs to record an ECG and return to the PAC (erlang distribution), the service time of a nurse (lognormal distribution), and the service time of a resident (lognormal distribution). All figures show a distribution density plot, a PP-plot, and a QQ-plot.

The figures indicate a reasonable fit between the respective distribution and the sample data. However, the goodness-of-fit tests (Chi-Square, Kolmogoroff-Smirnov, and Anderson-Darling) give mixed results: for some levels of significancy the H_0 hypotheses are rejected indicating a poor fit. However, for practical reasons − we need to select distributions that are compatible with Tecnmatix EM-Plant − we accept the distributions (and distribution parameters) as plotted in figures G.1, G.2, and G.3. Table G.1 summarizes the distribution characteristics for the ECG time, service time of the nurse, and service time of the resident. The distributions and parameters depicted in Table G.1 are used in our simulation model.

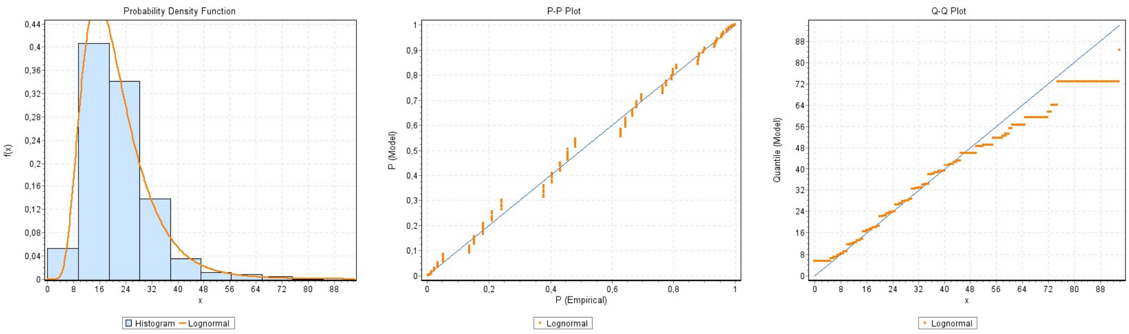
Table G.1: The distributions and distribution parameters used in our simulation model for the ECG sojourn time and service time of the nurse and resident.

Sample set	Distr. of $\widehat{F}$	Param. of $\widehat{F}$
Sojourn time ECG	Erlang-5	$k = 5,\ \lambda = 4$
Service time nurse	Lognormal	$\mu = 21, \sigma = 11$
Service time resident	Lognormal	$\mu = 23, \sigma = 12$



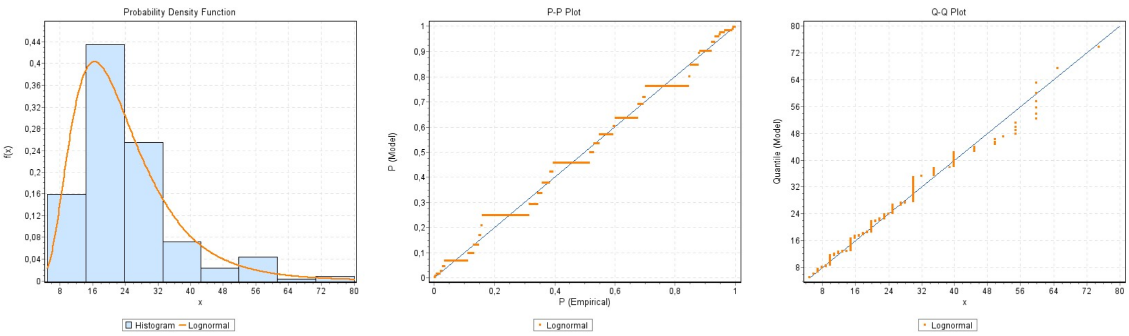
(a) Probability distribution function *(b)* PP plot *(c)* QQ plot

Figure G.1: The MathWave Easyfit output when fitting the erlang-5 distribution to the time it takes for a patient to record an ECG and return at the PAC (Data set $\mathbb{F}$, n=247).



(a) Probability distribution function *(b)* PP plot *(c)* QQ plot

Figure G.2: The MathWave Easyfit output when fitting the lognormal distribution to the service time of the nurse (Data set $\mathbb{F}$, n=840).



(a) Probability distribution function *(b)* PP plot *(c)* QQ plot

Figure G.3: The MathWave Easyfit output when fitting the lognormal distribution to the service time of the resident (Data set $\mathbb{F}$, n=251).