MASTER THESIS

COMBINING PATIENT-CENTRED PROCESSES AND ANAESTHESIOLOGIC OPTIMISATION FOR THE PREOPERATIVE ASSESSMENT CLINIC

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Combining patient centred processes and anaesthesiologic optimisation for the preoperative assessment clinic

Discovering patient arrivals and facilitating timely screening at preoperative assessment clinic in Amsterdam Medical Centre

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Management summary

The Academic Medical Centre organises the physical pre-operative assessment of elective patients of invasive surgery at an outpatient clinic, the pre-operative anaesthetic clinic (PAC).

The hospital introduced a new hospital information system (EPIC) in October 2016. This allows all specialties to work in the same patient files and share information easily. Together with aging demographics, the increase in comorbidity and polypharmacy and the trend of patient-centred healthcare has led to the improvement project 'Integral pre-operative clinic', which aims to implement a one-stop-shop for patients undergoing invasive surgery. Not all patients have to be screened immediately. A triage (tree) decides which patients qualify for a walk-in screening. Generally, patients who undergo surgery within one month and patients living far from the hospital qualify.

The ideal timing of the physical assessment is not always achieved. Approximately 37% of patients are screened at a moment shorter to surgery then desirable. The project 'Integral pre-operative clinic' relies on patient arrival information and requires capacity management to be implanted successfully.

Goal

The goal of this research is to gain insight in patient referrals to the preoperative clinic and design an efficient schedule blueprint to accommodate timely screening of patients. The research can be broken down to two tasks, the first is gaining insight in the patient arrivals, especially the patients who require immediate screening. The second task is accommodating the timely screening of patients. This again focusses on the patients who have surgery in a within couple of weeks but all patients should be seen in the optimal period for preoperative assessment.

Approach

The project consists of 3 major researches. First an insight in expected patient arrivals is gained. Based on these rates, 5 schedule blueprints are developed and finally assessed on key performance indicators.

Results

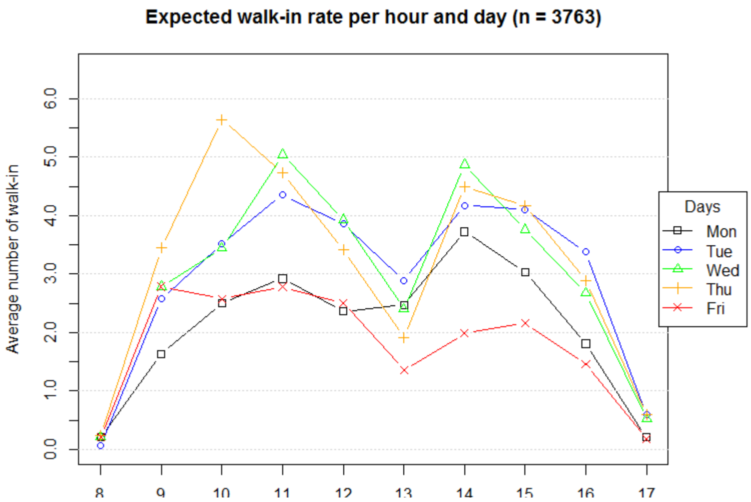
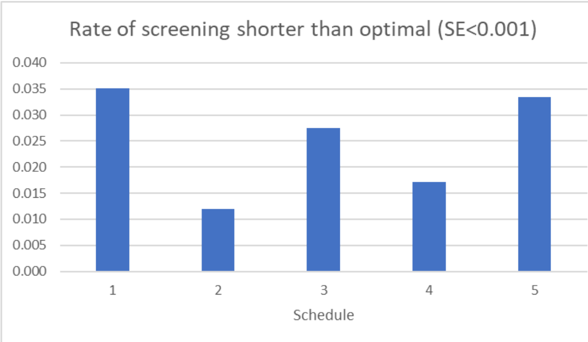


Figure 1 Expected arrival rate of unscheduled patients at PAC

The overview of expected walk-in arrivals at the PAC is shown in Figure 1. Clear is that most days have peaks in the morning and in the afternoon, with a small dip in after the break, and a low rate in the early morning and late afternoon. In general Monday and Friday have much lower rates than Tuesday, Wednesday and Thursday. All rates are approximately Poisson distributed.



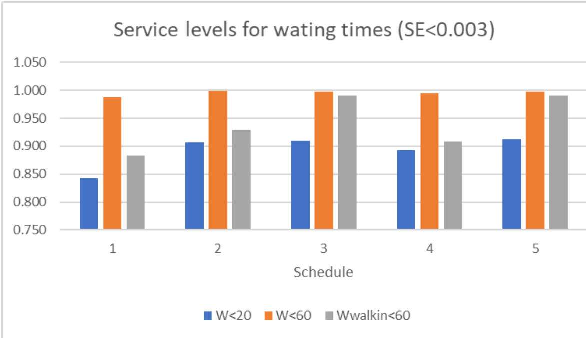


Figure 2 Main results simulation. Rate of patients screened shorter to surgery than desirable and service levels for waiting times for the 5 schedules (SE = highest standard error).

Conclusion

Using the hospital information system, it is possible to gain insight in patient arrivals for the pre-operative anaesthetic clinic. These data are used to generate optimal schedule blueprints. Five schedules with different opening hours, appointment slot length and staffing are determined. A common theme in all schedules is that most appointments are scheduled on times and days that the walk-in rate is low. Under current staffing and opening hours, overtime is inevitable. The overtime is not directly visible to patients, but when taking in account the time required to finish patient files, the available time for anaesthetist is exceeded. The best schedule is schedule 2, displayed in figure. This scores well compared to other schedules and requires only 3 anaesthesiologists.

How to proceed

For practice, this research is a good groundwork for determining what schedule to use for the one-stop-shop. Management of the clinic can alter the schedule however they see fit. It might be possible to schedule more time for patients who are expected to take more time (ASA 3/4) or schedule telephone consults. It should be remembered that the method gives essentially a number of appointments to schedule, and uses remaining time for walk-ins.

There is room for improvement in the Kortbeek et al’s (2014) method. While the method itself is solid, additional features like different appointment lengths, variable staffing, or different opening hours might make the method more suitable for practice.

Value for practice

This research provides great value for practice. It delivers information about what patient arrivals to expect when implementing the one-stop-shop and how to account for these arrivals in the schedule blueprint. Successfully implementing the schedule can improve performance in the outpatient clinic. Waiting times, overtime and late screenings can be decreased, however, opening hours should probably increase to achieve these results. Patients present in the hospital can often (>90%) get a screening the same day as a walk in, increasing patient satisfaction.

The researches that make up this thesis can be redone separately to adjust schedules or update insights. This will proof valuable if changes occur over time because patient arrivals change, patient population changes or new activities are introduced in the process. Therefor this is a relevant tool to

Introduction

adjust the schedule to reflect these changes and maintain a good performance, as long as these changes are noticed timely.

Value for science.

Hospitals generate enormous amounts of data from which interesting insights can be derived. This research shows how it is possible to answer specific questions by combining data and using expert knowledge to relate data and generate new insights. This is not new but given the possibilities of this method it is valuable to show that it is possible to answer logistical questions, based on registrations that are done as part of the patient process.

Science is really good at generating new models for solving problems. This research however shows that excising models can be used with some assumptions, and no new models have to be developed. This research hopefully creates some awareness of these models with the audience they are designed for.

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Chapter 1. Introduction

This research is performed at the preoperative assessment clinic of the Academic Medical Centre. Facing demographic changes and the introduction of a hospital wide electronic patient record has led the department of anaesthesiology to develop a vision for patient centred care in the perioperative proves. This resulted in a concept for an integral preoperative clinic, which faces challenges that need to be addressed before implementation can be considered. A major hurdle is the lack of capacity insight and managing arriving patients. This research aims to create insight in the patient arrivals to expect and how to deal with effectively schedule them.

Section 1.1 Background

This research is performed at the preoperative assessment clinic (PAC) of the Academic Medical Centre (AMC), a large university hospital in Amsterdam. The preoperative assessment clinic is established with the goal to collect information about the patient prior to the day of surgery, to assess the physical condition of patients and identify possible risks of morbidity and mortality during the perioperative trajectory. Furthermore, the consult at the preoperative assessment clinic is an important moment to inform patients and receive informed consent for intended medical procedures (Oei, 2017).

The Academic Medical Centre is a large teaching hospital where yearly 17.000 surgeries are performed under anaesthesia or local sedation. Those patients whom are undergoing elective surgery are required to have their physical condition assessed. The Dutch Association of Anaesthesiology require the assessment of elective patients in their guidelines (NVA, 2007). Accurately performed assessment is shown to reduce risk of surgery cancelation due to condition of the patient (Ferschl, Tung, Sweitzer, Huo, & Glick, 2005). The AMC, like most hospitals, organise the assessment at an outpatient clinic.

Since the new electronic patient record and hospital information system (EPIC) is introduced in October 2015, physicians of all departments have access to the same patient records. However, historically grown logistic processes hinder beneficial collaboration in the perioperative trajectory.

Together with aging population and expected increase in comorbidity and polypharmacy that challenge caregivers, the department of anaesthesiology started a project to revise the preoperative process for patients. The main goal is to create an integral preoperative outpatient clinic, a one-stop-shop, for all preoperative consults. This should lead to more collaboration and a better service to patients, as they require only one visit to the hospital and are central in this process, instead of the departments the patient has to visit.

Another major goal of that project is not directly related to improve collaboration, but in improving patient's condition. The preoperative assessment is not only the moment to gather patient information, but also the ideal position to optimally prepare the patient for surgery. This is especially beneficial for patients who have several conditions and a variety of medications, who have a higher risk of complications during the perioperative process.

The preparation of the patient requires some time. Anaesthesiologists consider a period of 2 to 4 weeks optimal. It allows for enough time to adjust medication and diet, and other interventions aiming to improve the condition of patients before surgery. A shorter period would reduce the effects of interventions and a longer period might cause the condition to differ to much between the screening and surgery, causing the gathered information to be less reliable.

A triage tree for patient paths in this process has been designed by anaesthesiologist, to determine which patient to screen immediately, at the same day as the consult with the operator. Patients who have surgery within 2 weeks are eligible for same-day screening, regardless of their physical condition. Patients who have between 2 weeks and 4 weeks before surgery are not considered healthy are allowed for same-day screening as well. Healthy patients will have a telephone consult. Patients who have their surgery in more than 4 weeks, are scheduled for appointments within 2 to 4 weeks before surgery. An exception is made for patient living far away from the hospital. As a tertiary hospital, a substantial share of patients live far away. Having to travel an addition time for the preoperative assessment is a big nuisance.

Section 1.2 Problem description

In the current setting the target of 2 to 4 weeks between screening and surgery is often not achieved. Different causes are suggested, like the lack of walk-in appointment availability, the unfamiliarity of walk-in appointments at referring departments and scheduling policies. As seen in Table 1, slightly over half of all patients vising the preoperative anaesthetic have their surgery not within 5 days, and more than a quarter has surgery the next day.

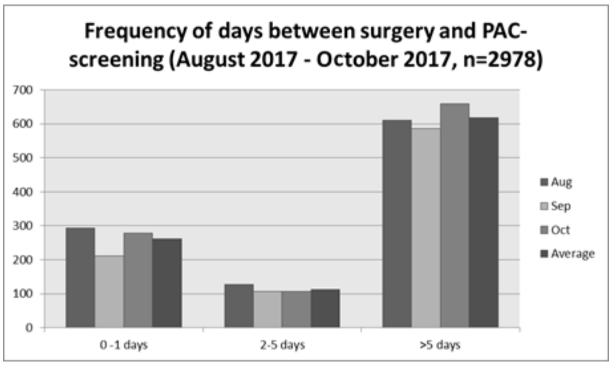

Figure 3 Frequency of days between PAC screening and surgery

Table 1 Days between surgery and PAC screening

	Days between surgery and PAC-screening			
Month	**0 -1 days**	**2-5 days**	**>5 days**	**Total**
Aug	293	127	611	1031
Sep	211	106	586	903
Oct	279	106	659	1044
Average	261	113	619	993
Total	783	339	1856	2978
	26%	11%	62%	100%

Implementing the described integral preoperative clinic depends on sturdy capacity analysis to be successful. Moreover, complete implementation is yet far away. However, the department of the anaesthesiology is exploring how to improve preoperative trajectory with the same goals in mind, and testing concepts in pilot studies with their preoperative assessment clinic. The department wants to provide immediate assessment consults to patients who have surgery within 4 weeks or live far away from the hospital.

In order to successfully implement facilitating these screenings, sufficient walk-in appointments have to be available. Current issues with walk-in appointments is that patients tend to arrive in peaks and few spots are available to walk-in. An overview of the timing of expected arrivals and corresponding appointment schedule are necessary for facilitating preoperative screenings that allow enough time for optimisation of patient's condition.

Section 1.3 Research goal

The goal of this research is to gain insight in patient referrals to the preoperative clinic and design an efficient schedule blueprint to accommodate timely screening of patients. The research consists of two parts, the first is gaining insight in the patient arrivals, especially the patients who require immediate screening. The second part is accommodating the timely screening of patients. This again focusses on the patients who have surgery in a within couple of weeks but all patients should be seen in the optimal period for preoperative assessment.

Section 1.4 Research questions

In order to achieve the stated goal, the underlying researches have been identified. This thesis covers all posed research question that make up the problem at hand. The following research questions are identified:

What is the current process at the preoperative assessment clinic and what is its performance?

This question seeks to provide context to the processes at the preoperative assessment clinic. An overview of processes is given and important characteristics and performance measures are derived. The limitations and constraints for the schedule are assessed as well. This research question is covered in Chapter 2.

What relevant research is already performed?

This research explores relevant literature on dealing with unscheduled arrivals and efficient scheduling of patients in a preoperative assessment clinic. This literature study is covered in Chapter 3.

What is the flow of referred patients to the preoperative assessment clinic?

The goal of this research is to find the arrival rate of patients who are referred to the preoperative assessment clinic. Primary target is discovering arrival patterns of patients who require immediate screening, according to the developed triage model. Besides the arrival rate, another useful result is the distribution of referrals from the different departments. This insight allows for closer collaboration and pilot studies with selected specialty departments. This research is presented in Chapter 4.

What schedule can be designed to facilitate timely assessment of patients referred to the preoperative assessment clinic?

This research covers the design of the optimal schedule blueprint for the preoperative assessment clinic, given the goals and restrictions imposed. Important feature is the facilitation of same-day appointments for walk-in patients. Based on the results of the preceding research in arrival patterns, an optimal schedule is proposed that meets the goals set by the department of anaesthesiology. The performance of the schedule regarding the goals and performance indicators is assessed in a simulation study. The design of schedules is covered in Chapter 5 and the simulation study to assess performance is covered in Chapter 6.

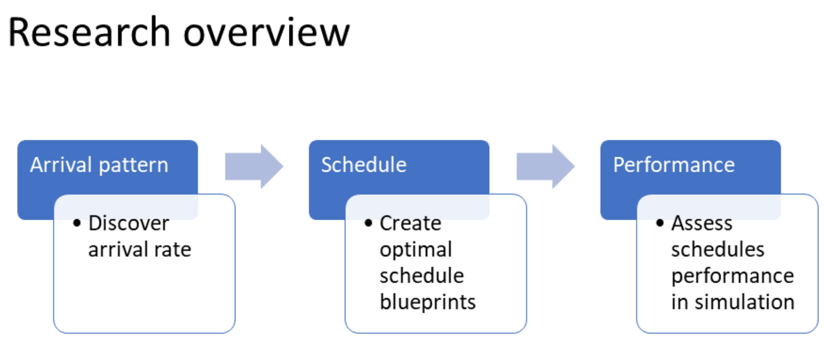

Figure 4 Research overview

Section 1.5 Scope

The preoperative process covers many subjects. This research is limited to the preoperative assessment clinic. The process at the specialty department, neither the process at the day of surgery is included in this research.

The final chapter, Chapter 7, concludes how this research covers the stated goal of the research. A discussion of the results is provided and the relevance and impact of this thesis is discussed as well.

Chapter 2. Context analysis

This chapter covers all relevant aspects of the context of this research. An overview of the processes at the preoperative assessment clinic is given and the performance of these processes. The patient mix will be analysed and a capacity analysis is performed. Important performance indicators are determined and finally implications and directions for the following researches are described. This chapter should provide a complete overview of the situation and activities at the clinic.

Section 2.1 Process description

Patients undergoing invasive surgery are required to have their physical condition assessed before surgery. The screening is part of the preoperative trajectory, which is part of the perioperative process. The preoperative trajectory covers all aspects between indication and the surgery. The preoperative screening is performed at the outpatient anaesthesiology clinic. Patients that are indicated for invasive surgery, and are not emergency patients, are redirected to the clinic. During the screening an assessment is made on their physical condition and the anaesthesiologist determines an anaesthesia plan for the surgery. The patient is informed about the procedure and consent to the discussed procedure. Additionally, prehabiliation is discussed if necessary and additional testing might be requested. Finally, the anaesthesiologist gives fiat to the surgery if no issues arise. This concludes the screening and the patient is ready to move forward in the preoperative process. The position in the chain from indication to release is displayed in Figure 5.

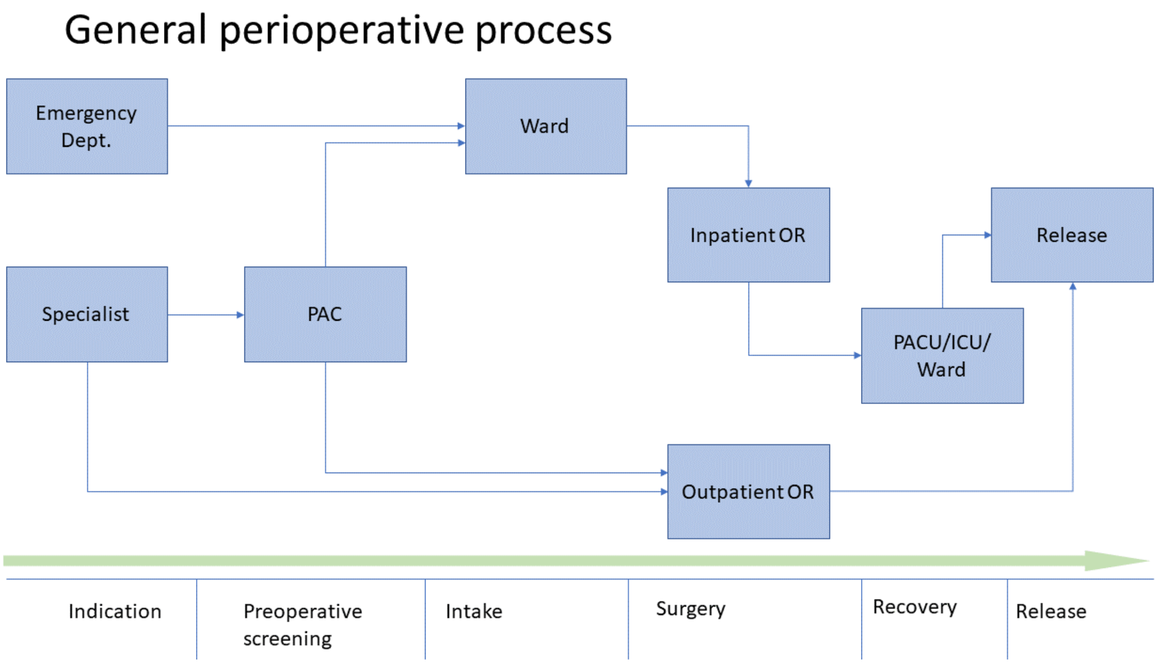

Figure 5 Overview of general perioperative trajectory. The path depends on the patient

There are a few ways a patient gets referred to the clinic. Patients are instructed that they can visit the desk and check if there is a walk-in appointment slot free or make an appointment at the desk. Not all patients go to the desk, some of them do not receive the information, decide not to go there or are not in the hospital on some cases. These patients are put on a worklist, a backlog of patients that require screening and have to be scheduled. When a patient is scheduled a letter is sent with the appointment information, a questionnaire regarding general physical condition and a request to bring a recent list of all medication. Patients are requested to arrive at least 15 minutes before their appointment time. Some have not filled in the questionnaire and are required to complete it while waiting.

The consult is divided in two parts. First a consult with the physician's assistant where the patient is prepared for the second consult, with the anaesthesiologist. The goal of the first consult is to get a general overview of the patient's physical condition and the medications the patient uses. During the consult with the physician's assistant some general patient characteristics are measured and entered in the hospital information management system. The patient is asked to give a brief summary of its physical condition and endurance. The current medication of the patient will be checked and registered. Finally, patients are instructed what will be discussed during the consults with the anaesthesiologist. Questions the patient, or present family and caregivers, might have will be answered and the consult with the physician's assistant is concluded.

The consult with the anaesthesiologist requires some preparation. The physician has to get acquainted with the patient record and the upcoming surgery. The anaesthesiologist creates a plan to safely admission the appropriate anaesthesia. This depends on many variables, like the location of surgical site, the duration of the surgery, possible allergies and interaction with other medication. This is not definite yet and will be discussed with the patient during the consult.

The consult with the anaesthesiologist has several goals. The greater goal is an optimal preparation of the patient for surgery. Another important goal of the consult is the informed consent of the patient. The patient receives all information regarding the anaesthetic procedures used during surgery, and possible adjustments can be discussed if requested by the patient. The patient and anaesthesiologist agree to a certain anaesthetics plan. Fastening for surgery and some general information regarding surgery will be explained as well. Depending on the physical condition of the patient, the presence of comorbidities and polypharmacy, preparation might be necessary to reduce the risk of complications during surgery. Prehabilitation might consist of stopping, changing or reducing of medication or special diets. The patient can receive more information and questions are answered. Some additional testing might be necessary. The consult is concluded and the patient can go to the laboratory if required.

The anaesthesiologist has to process the results of additional tests and can acquire more information from specialists. The details of the preparations are laid out and necessary arrangements can be made. Finally, the anaesthesiologist releases the patient for surgery. This means that the patient can be operated given the plan and surgery. This release is valid for six months and for this specific surgery. A patient undergoing different surgeries requires more screenings and releases. The process will be smoother often as some steps can be skipped and the patient is more familiar with the process.

At the preoperative assessment clinic there are three types of anaesthesiologists who consult patients. Inn order of training and experience they are: the specialised nurse is a nurse who specialised in administering anaesthesia to patients. Then there are two types of residents, a young resident is a medical specialist in training and the senior resident is a specialist in anaesthesiology.

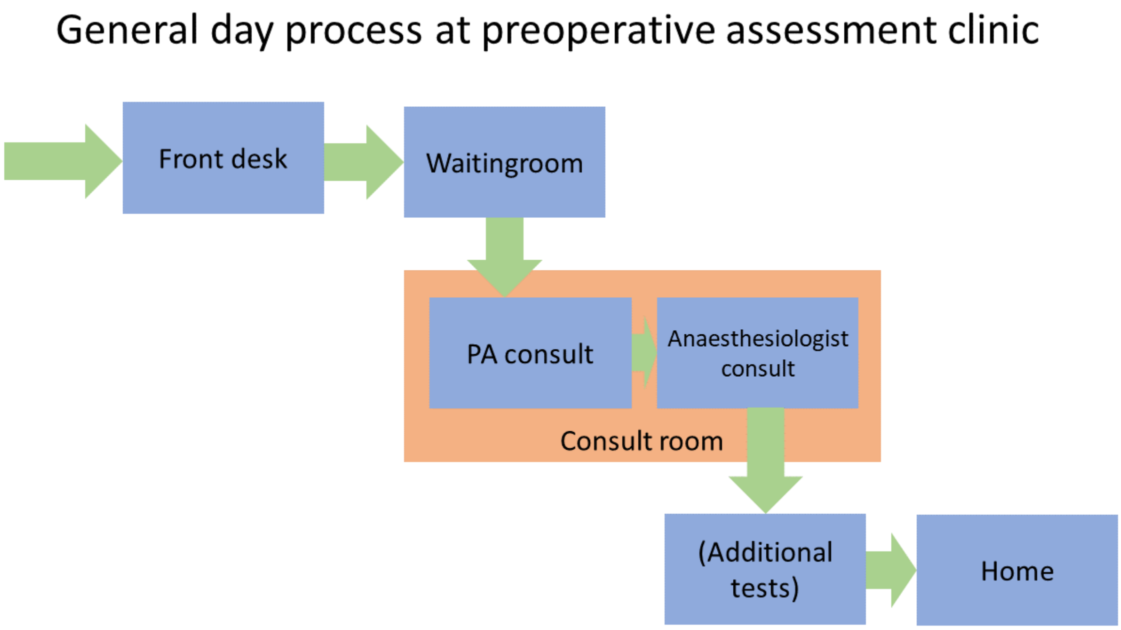

Figure 6 General day process at the PAC

Since January 2018 the preoperative assessment clinic in the AMC changed its layout and made a change to the process, to provide better service to patients and become more flexible Usually the caregivers reside in appointed room and the patients visit the appropriate room, while waiting in the waiting room in between. In the new situation the consult rooms are now assigned to patients and the caregivers move to the specific room. This has a few consequences. Travelling time, although it looks minor, for patients is reduced. Especially for patients who require assistance with walking or moving, the saved time adds up. The waiting room could be crowded at times when patient brought several family members or caregivers, now patients only wait when no spare room is available. They still have to wait in case the anaesthesiologist is not available yet but the patients stay in the consult room. The caregivers now work in a shared office space where there is more interaction among them for sharing information and questions. The patient path is displayed in Figure 6.

Another change is the assignment of patients, and schedules, to the anaesthesiologists. Before the change an anaesthesiologist was assigned a schedule, often based on the complexity of the patient and experience of the physician, and had to assess all the assigned patients that day. This often resulted in notable differences in workload, where the anaesthesiologist with the 'easy' patients was idle half the time and the schedule with the more difficult patients was delayed and often had to work in overtime. Another issue is the difficulty of assigning patients to the corresponding schedule. Some patients turned out to be more complex than expected, resulting in broken consults because help of a, sometimes already busy, experienced anaesthesiologist was required. In the new situation, the anaesthesiologists do not have an assigned schedule and patients but work on the available patient at that moment. This balances the workload of the anaesthesiologists during the day and no major differences are expected at the end of the day. Inexperienced physicians consulting the complex patients should be less of an issue as they can simply discuss the patient in advance, and help is always available in the work space.

Currently there are 3 types of appointments, Appointments for scheduled patients, which are appointed 20 or 30 minutes, appointments for walk-in patients, which all take 30 minutes, and telephone consults. Telephone consuls, sometimes called paper consults, are used if the patient is expected to be in good health. The relevant information is discussed over phone with the patient, so no extra traveling to the hospital is involved. The patient should be considered health, besides the reason for surgery, so no additional testing or examining long medication lists are required. The Dutch Association of Anaesthesiologists recommends the use of paper consults for relative healthy patients, as it is more convenient for patients and the load on the clinic is decreased.

The physician's assistants are responsible for scheduling patients to appointment slots. They are scheduled from the worklist of a day earlier. There is no clear scheduling strategy. Often patients are scheduled on a free spot in the near future. There is however a strategy for determining the type of appointment. The assistants examine the patient records and determine if the patient is in good health. There is no clear indication, so a variety of characteristics are used, such as age, type of surgery, number and type of medication, distance to hospital and medical record. When patients are required to be assessed in the near future, but no appointments are available, they are scheduled in walk-in spots.

Section 2.2 Process performance

In this part the process characteristics are described and measured. This covers the service times of both consults, waiting times and the distribution of appointments. As the collecting of data on consult and waiting times is time consuming and can be disruptive, results from earlier measurements are used. In these measurements the patients are tracked and the timestamp of beginning and ending of events are captured. The consult times and waiting times from individual patients can be tracked. There are two previous measurements available, one which is performed in August 2017, were 204 patients were tracked, and the other is performed in February and March 2017, with 306 patients.

Because the measurements are from the previous layout, there are some considerations. As the activities of the anaesthesiologists is not different, the consult times are considered representative. A Kolmogorov-Smirnov test does not reject that these measurements are taken from the same distribution, indicating that there is consistency between the two measurements. The activities for the physician's assistants are different for the two measurements. In February and March of 2017, a pilot ran on the preoperative assessment clinic, were the patients evaluated the medication list with a pharmacist. This task was assigned to the assistant again and therefore the two measurements differ significantly. As the activities now are comparable with the activities in August, only the results of that measurement are used in the analysis of consult time of the physician's assistant.

The waiting times from the measurements are not representative of the waiting time at the current clinic, as the layout and process are changed. These will not be analysed extensively.

Consult time anaesthesiologist

For the analysis of the consult time of anaesthesiologists the measurements of 495 patients are used to derive a distribution. The data is analyses in a *Cullen and Frey* graph to check for common distributions, and distribution parameters are derived.

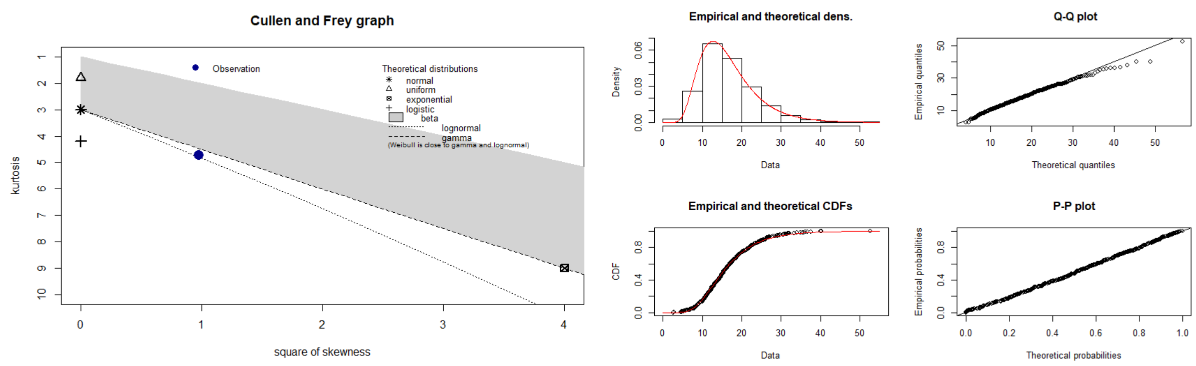

Figure 7 Distribution analysis of anaesthesiologists consult time

Table 2 Distribution overview of anaesthesiologists consult time

Consult times anaesthesiologists (N = 495)	
Mean	15.4 minutes
Median	16.6 minutes
Distribution	Lognormal
μ	2.73
σ	0.398

Consult time physician's assistant

For the analysis of the consult time of the physician's assistants the measurements of 195 patients are used to derive a distribution. The data is analyses in a *Cullen and Frey* graph to check for common distributions, and distribution parameters are derived.

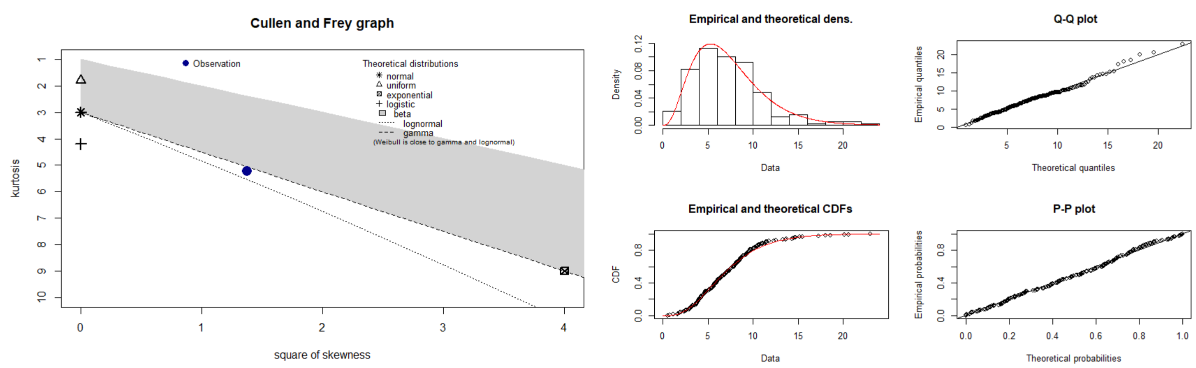

Figure 8 Distribution analysis physician's assistant consult time

Table 3 Distribution overview physician's assistant consult time

Consult times physician's assistant (N = 195)	
Mean	6.8 minutes
Median	7.3 minutes
Distribution	Gamma
Scale	3.645
Shape	0.502

Waiting times

The construct waiting time is open for multiple interpretations. The waiting time can be split in a voluntary waiting time, the time the patient from arriving until the scheduled start of the appointment. The involuntary waiting time is the time the patient waits before he is seen by the physician. In the case of the preoperative assessment clinic, things are more complicated. The scheduled start time is the time the consult with the anaesthesiologist is supposed to start. This time is also communicated to the patient, where they are also requested to be at least 15 minutes early because they also have a consult with the physician's assistant. The waiting time is split in two waiting times, the waiting time prior to either consult. In the time-measurement of May 2018, the average waiting time before entering a room is 19:47 minutes and the average waiting time in the room waiting for anaesthesiologists to arrive is 10:48 minutes.

Section 2.3 Patient mix

As stated all patients undergoing (semi-)elective invasive surgery are screened on the preoperative assessment clinic. Because the patients of many different specialty departments there is a large variety in patients as well. Based on the production of the clinic last year, 2017, some characteristics of the patients are gathered. The prediction is that production will be stable next period, so these characteristics are also used as forecast for the scheduling period. In 2017 a total of 13.432 had a completed screening. Because no major changes in number of patients are expected, the expected number of total arrivals is 13.500 patients per year.

The most obvious characteristic is the ASA class of patients. The ASA Physical Score describes the physical condition of the patient(ASA, 2014). The lower the score, the healthier the patient and vice versa. The ASA score is a good predictor of the consult time. A patient in bad physical condition, and often comorbidities, regularly has a longer consult as there is simply more to discuss and diagnose. However, the ASA score is only determined by the anaesthesiologist during the consult.

Table 4 Overview of ASA PS of patients at the PAC in 2017

ASA PS	N	N(%)
I	3453	29,8%
II	5150	44,5%
III	1941	16,8%
IV	106	0,9%
blank	934	8,1%

The majority of patients screened has an ASA score of II (44,5%). The next largest group has ASA PS I (29,8%). The group with score III makes up 16,8% of the patients and the group IV is small with less than 1% patients. This not unexpected, as the score IV represents patients with a constant threat to life, and those patients are low in number and more often need non-elective surgery so they do not visit the PAC. Also, their physical condition limits them in visiting, so these screenings are regularly performed in the ward by a visiting anaesthesiologist.

Specialty departments

Another differentiation can be made in the referring department. The hospital houses many different specialties, most of them send patients to the assessment clinic. There is no clear data record of the referring specialty of patients visiting the PAC, so this data is not readily available. This insight is gained in Chapter 4, the patient arrival research.

The same holds for the time between indication and surgery. This measure is not recorded at the PAC and can often only be measured retrospectively because at the moment of surgery request, no certain surgery date can be given. An indication is made and communicated back. The referring specialist can however often make an educated guess based on the urgency of the surgery and the backlog for other surgeries. This allows the referring specialist to still use the triage tree to decide which patients are allowed for walk-in. A complete overview of the retrospective intervals for all patients is also given in Chapter 4.

At the moment most patients are seen on appointment base. This has a few reasons, with the current (un)availability of walk-in slots as main reason. About a quarter of appointment slots (87 out of 301) are indicated for walk-in patients, and occasionally these slots are scheduled in advance anyway. Another major reason is that the referring departments are inconsistent with sending patients to the desk of the PAC, for diverse reasons. Some send all their patients, of which a share gets rejected because they do not meet the criteria for walk-in, and even if allowed, there is not always a walk-in slot free. Then there are departments that do not send patients to the desk and these patients have to be scheduled to appointment slots anyway, regardless of their surgery date.

Triage tree

A major requirement for the proposed integral preoperative clinic to succeed is a clear and common understanding which patients should be scheduled and which patients are eligible for walk-in. The anaesthesiology department developed a triage list, a decision support tool, to unambiguity decide which patient allows and which do not. The referring specialist is required to fill in a short questionnaire, specified to the specialty, with general indications about the condition of the patients. Originally the concept was to base the decision on ASA score, but as this score is decided during the consult, the questions are designed to reflect the expected ASA score. In the data research the original concept is used, as the retrospective data contains ASA scores, and no information regarding patient conditions or perceived condition.

There is a mix of necessity and service to patients which determines who is eligible for walk-in. The optimal interval screening patients is within two to four weeks before surgery. This is however not necessary for healthy patients, which do often not require any prehabilitation. These patients, assigned ASA score I, can be seen on shorter notice and the clinic management rather reserves walk-in appointments for those that need it most. These patients considered healthy are appointed walk-in slots if their surgery is within 2 weeks.

The last indication if a patient is eligible for walk-in appointments is the distance it lives from the hospital. As a large academic hospital, patients are referred from all over the country for some specific diseases. As service to those who require a long traveling time, walk-in appointments should be available for them as well, regardless of condition or waiting time for surgery. Often because these patients live far away, their willingness to wait for a free appointment slot is also higher than patients living nearby. The analysis of distribution of the distance for patients is derived in Chapter 4 as well. A distance of more than 35 kilometres is considered far, however the perception differs between patients.

As in most service industries no-shows do occasionally occur. An appointment that is registered as a no-show is when a patient does not show for the appointment, without informing the clinic. Else it is registered as a cancelation. No shows account for 383 of registered screening appointments. The total number of cancelations is 4009. There are many reasons for cancelling appointments, most common is a rescheduling because the patient is unavailable or the surgery is rescheduled. The no-shows account for 2% to 3% of all completed screenings. Historically this figure has been around 2% for some time.

Section 2.4 Capacity analysis

This part covers an analysis of the capacity at the preoperative assessment clinic. The opening hours of the clinic are currently from 8:00 to 16:00, with a break from 12:00 to 13:00. The exception being Wednesday, where the clinic opens at 9:00 because a weekly meeting for all anaesthesiologists. This yields a total weekly opening time of 34 hours. Every day there are four anaesthesiologist presents, of which three have a schedulable appointment agenda. The fourth anaesthesiologist is a senior resident who helps out the other anaesthesiologist in case advise or feedback is required.

With 3 schedulable resources the total available appointment time is 102 hours per week. When the clinic is open for 51 weeks a year, this averages 265 patients per week and 2.60 patients per schedulable hour. Capacity seems sufficient with an average consult time of 15:24 minutes per patient, however, significant waiting times and are reported and overtime is common. There is a total of 301 appointments available per week.

Besides the anaesthesiologists there are also physician's assistants working on the department. Their activities vary, but most important to this research are the consults they perform prior to the patient's consult with the anaesthesiologist. There are always two physician's assistants available for this task.

Section 2.5 Performance indicators

This section covers the performance indicators management considers important in monitoring and evaluating the performance at the clinic. For specific indicators a goal is set on what is desirable or minimum.

Arguably the most annoying feature of visiting the hospital are waiting times. Waiting time is often time wasted, as the patient is unable to spend the time meaningful and instead just waits till the patient is requested for consult. Actual waiting times since introducing the new layout and process in the clinic are not available. Measurements from august indicate an average of 19:24 minutes total waiting time. The goal of the clinic is in line with hospital wide guidelines. For at least 80% of patients waiting time should not exceed 20 minutes, and 95% should wait less than 60 minutes.

The occupation rate of staff is a common measure, as it is good indicator of the workload. A high occupation relates to a low idle time and thus induce long waiting times for patients. There is no clear goal for what occupation rate is acceptable. A good indication would be as high without exceeding the norm for waiting times, as they are related.

Another common performance measure is the access time, the time between the request for service and the appointed start of the service. This measure is not very relevant in this definition for the PAC, as the access time is ideally defined by the moment of surgery. A more meaningful interpretation would be the time to the first available appointment slot not reserved for walk-in. This data is not collected however. The hospital guidelines prescribe a maximum access time of 10 days for at least 95% of patients.

No performance measure for referred walk-in patients is monitored now. The acceptable goal is a referral rate less than 5%. The idea is that only patients who require an immediate screening are eligible, and rescheduling could disturb the ideal screening timing.

Overtime is not constantly monitored, but from the measurements it is not uncommon and more often than not the las patient leaves after closing time.

The staff and opening hours are preferred to stay unchanged. Effect of slight changes are examined however.

Table 5 Overview of performance indicators and targets

Performance indicator	Target
Waiting time	80 % within 20 minutes
	95 % within 60 minutes
Waiting time for walk-in	95 % within 60 minutes
Occupancy rate	
Access time	95 % within 10 days
Referral rate walk-in patients	Less than 5 %
Overtime	
Rate of timely screened patients	

Section 2.6 Further information

During the research another time measurement was performed at the preoperative assessment clinic, in May 2018. The results for consult times are not significantly different. However, the new layout of the clinic reveals some hidden work time. When patients were assigned to a fixed schedule, the corresponding physician usually prepares the consults in advance, often in own time the evening before. Since it is not certain which physician will consult which patient, the preparation is done during opening hours of the clinic, often after arrival of the patient. This leads to more work that has to be done, resulting in higher occupation rates and longer waiting times. The case for finishing patient files is still unchanged. This is ideally done immediately after the consult but that is not always possible. Eventually, this is often done during idle time, or outside opening hours.

The results are based on self-reported times. The average of preparation is 6:42 minutes (N = 168), and the average of finishing files is 8:01 minutes (N=164).

This is important for determining proper reserved consult duration time, as a proper indication for consult duration is all time spend on a patient, including the preparation and finishing files. This is further covered in chapters 5 and 6, where the schedules are designed and validated.

Chapter 3. Literature study

This chapter describes findings of a literature study that identifies relevant topics and methods to the research problem. Key issues are identified and related to the research problems and possible solution designs are explored. First general positioning of the research is done. Relevant topics for this research are scheduling at outpatient clinics, the preoperative clinic and one-stop-shop design. The chapter closes with the implications for this research, on which further chapters are based.

Section 3.1 Healthcare

Health care is complex. A good start for planning research in healthcare would be positioning the research. The framework described by (Hans, van Houdenhoven, & Hulshof, 2012) offers a valuable tool in differentiating research in healthcare context. The tool for planning and control consist of a 4x4 table (Figure 9) representing the managerial areas horizontally and hierarchical levels vertically. Managerial areas like medical planning consists of determining what treatments to perform and how to perform them. The resource capacity planning determines all decisions made regarding the use of non-renewable resources like staff and facilities. Material planning involves the renewable resources, like medications and instruments. Financial planning regards the finance of operations. The hierarchical levels indicate a planning horizon and detail. The strategical level is the highest the hierarchy and consist of broad goals over a long period, that reflect the goals of the organisation. The planning horizon is typically one or more years. The tactical level represents the decisions that have to be made to reach the goals and have a typical horizon of a month to a year. The operational hierarchy deals with operational decisions made on a day by day (offline) or ad hoc (offline) basis. These are typically monitoring the operation and reactive to unforeseen events.

	Medical planning	**Resource capacity planning**	**Materials planning**	**Financial planning**
Strategic	Research, development of medical protocols	Case mix planning, capacity dimensioning, workforce planning	Supply chain and warehouse design	Investment plans, contracting with insurance companies
Tactical	Treatment selection, protocol selection	Block planning, staffing, admission planning	Supplier selection, tendering	Budget and cost allocation
Offline operational	Diagnosis and planning of an individual treatment	Appointment scheduling, workforce scheduling	Materials purchasing, determining order sizes	DRG billing, cash flow analysis
Online operational	Triage, diagnosing emergencies and complications	Monitoring, emergency coordination	Rush ordering, inventory replenishing	Billing complications and changes

← managerial areas →

↑ hierarchical decomposition ↓

Figure 9 Healthcare planning and control framework (Hans et al., 2012)

This thesis research focusses on the resource capacity planning. Designing schedules is a typical tactical planning activity. However, operational decisions are taken into account for the simulation study and are considered in the recommendations.

Section 3.2 Appointment scheduling

Appointment scheduling has been a key issue in managing outpatient clinics in hospitals since early 1950's. Bailey and Welch (Welch & Bailey, 1952) were the first to investigate the relation between patient waiting time, physician's load and appropriate defined appointment systems. They note

"Although very many hospitals now use some kind of appointment system for outpatients, anybody entering the waiting-rooms of most outpatient departments will at once be impressed by the large number of people waiting." Since then, many things have been researched and improved, but the goal of all studies is finding a way to balance the waiting time for patients and the idle time of physician's (Cayirli, Veral, & Rosen, 2006; Dexter, 1999; Ho & Lau, 1992). These two characteristics are always inversely related (Fetter & Thompson, 1966). As in increased idle time lowers the expected waiting time (Zonderland, Boer, Boucherie, de Roode, & van Kleef, 2009).

Scheduling is one of the few tools available to balance the variation in workload. According to Pinedo (Pinedo, 2016) scheduling can be described as assigning resources to tasks over a given time period, in order to achieve on or more goals. As described in the stochastic setting of outpatient clinics, this involves two conflicting goals, raising challenges to scheduling and invokes reflecting what performance is acceptable. As publicly funded institutions, hospitals have a limited budget to finance the activities, and are expected to deliver good service to patients. This causes the need to balance the idle time of (expensive) staff and the service for patients, of which waiting time is an important factor.

Operations research models for designing schedules for outpatient setting using either assume a discrete time or continues time representation of activities. The advantages of discrete time events are a reduced complexity and focussing on other stochastic events (Ahmadi-Javid, Jalali, & Klassen, 2017).

Open access, or sometimes called advance access scheduling is appointing patients to see their physicians within a couple of days. Open access offers clear advantages, like reduced access and no-show rate and increase in productivity of providers (Mallard, Leakeas, Duncan, Fleenor, & Sinsky, 2004). Many researches on open access is already performed but often the focus is on policies to deal with sudden high arrival rate(Rising, Baron, & Averill, 1973), or policies to deal with patients with different urgency's (Patrick, Puterman, & Queyranne, 2008). Characteristics of the clinic that identify success of open-access scheduling are(1) the fraction of patients being served on open access, (2) the scheduling horizon for patients on longer term appointment scheduling, (3) provider care groups, and (4) overbooking (Kopach et al., 2007).

A complete open access is not appropriate in the setting at the PAC, as there is a clear time-window in which the screening remains valid. If the screening is performed earlier, it has to be done again, introducing waste. Another downside of open-access scheduling is that in practice there is a variation in arrival rate of patients throughout the day and week. Rising et al (Rising et al., 1973) described a method to compensate this. Schedule the appointments for scheduled patients in the moments during the day where expected arrivals are lowest.

Kortbeek et al., (2014) build on this idea, and introduces a method to design a cyclic schedule, considering different arrival rates and days. The proposed model connects the appointment making process, resulting in the access time, with the day process in which referral rate determines performance. Appointment schedules are built by first assigning number of appointment slots to days, and then by assigning the appointment slots over days. Both an exact method and a heuristic are being described.

Section 3.3 Preoperative assessment clinic

Research in planning at the pre-operative anaesthetics clinic often focusses on the day process, where the main goal is to reduce waiting times and idle time. A popular approach is using queuing theory models for capacity dimensioning or analytically deriving process characteristics. The one-stop-shop is often described for multi-disciplinary conditions and diseases, where cancer is a popular topic as multiple specialist have to be seen often (Kadouch et al., 2015; Romero et al., 2013; Sella et al., 2013).

Some simulation studies discerning scheduling guidelines for scheduling at the PAC (Edward et al., 2008) recommend using different appointment lengths based on the ASA score of patients. This would give better estimations of the realised appointment duration. It however induces more complexity with designing schedules and with the appointment scheduling itself.

Section 3.4 Conclusion

As the project regarding the one-stop-shop implementation of the pre-operative process is not in a stage where integral scheduling is realisable or desirable, the focus in this research will focus on scheduling at the preoperative assessment clinic. Arguable, patients who require immediate (same day) screening do not necessarily need an appointment in advance if an effective appointment system is implemented. The goal regarding timely screening therefor does not have to be reached by appointment scheduling over multiple departments but is still something one should aim for eventually. A good solution would be to optimize the matching between unscheduled arrivals and available appointment slots for these arrivals. This would allow patients from the specialty departments to complete their preoperative the same day, if necessary. This essentially achieves the same goal, serving patients by reducing the number of hospital visits.

Given the variety in the patient population, regarding both health and the time to surgery, some choices have to be made. The triage tree presented in the previous chapter deals with what patients to be seen as walk-in patients and who to schedule later.

The goals of the model for designing cyclic appointment schedules from Kortbeek et al align with the perceived goals of the required schedule. However not all patients have to be seen in a short time, a short access time implies that when necessary patients do not have to wait long for an appointment. This is especially beneficent to referred walk-in patients, who have surgery within a couple of weeks. At the core of the model is assigning appointments to time slots to in order to reduce the number of expected referred patients. This is essential for implementing an integral preoperative clinic. In this research project the method of Kortbeek et al will be used to design schedules for the desired preoperative assessment clinic. Some assumptions have to be made, but this is disclosed in Chapter 5, where the appointment schedule design is described.

Chapter 4. Patient arrival research

This Chapter covers the research in arrival moments for unscheduled patients. A data research is presented which results in an overview of the expected arrival times for walk-in patients based on the triage tree. An overview of the origin of patients is derived as well, gaining information in the waiting times patients from different specialties face before surgery.

Section 4.1 Introduction

A main objective of this thesis is to gain insight in when patients arrive at the clinic in the future situation. This cannot simply be measured by counting and interviewing people at the desk. Not only is it time consuming and possibly bothering to patients, it is also incomplete. Currently there are no clear guidelines for which patients are send to the clinic, and referring specialists are inconsistent in who they refer to the preoperative assessment clinic. Some specialists send all their patients because it has to be done anyway so why not today, and some do not send patients at all because there is almost never time available.

The goal of the project integral preoperative anaesthetics clinic is to work more together between specialties and the anaesthetics clinic. It is therefore necessary to get an insight in when and how many patients to expect in order to accommodate the timely assessment of these patients. In order to achieve this information relevant data is extracted from the hospital information system (EPIC) and the proposed triage tree is used to determine which patients are eligible for a walk-in screening.

Section 4.2 Research goals

The main goal of this research to determine the arrivals of unscheduled patients at the preoperative assessment clinic. The insights gained with this research can be used to design schedule blueprints for the clinic. A secondary goal of this research is to get an overview of the share of patients from specialties and the distribution of access time of these patients. This is not necessary the main goal of the thesis but it provides useful insights for implementing pilots with integral scheduling and can be used to verify results.

Section 4.3 Research design

The research is performed using data from the hospital information system. First it is necessary to set the preferred outcomes so it is easier to define what steps to take when analysing data. For the main research question the preferred outcome is an expected number of patients at a given time period and if possible a distribution of these arrivals. A resolution of an hour gives enough accuracy for implementations. For the secondary goal the number and distribution of time to surgery of patients for each specialty is determined. For both results the focus will be all patients with a surgery request in the year 2017.

Section 4.4 Data

For this research several data sets are available, all extracted from hospital information systems. Three data sets are used. The first set of interest is an overview of all surgeries and interventions in the hospital from January 1st 2017 to January 24th 2018. This file has 32,598 records. An overview of the attributes is given in Table 6**Error! Reference source not found.**. The second file is a list of all outpatient clinic appointments, in the period January 1st 2017 to December 28th 2017.The file contains 206,580 instances. The attributes of these instances are displayed in Table 7. Finally, a list of all appointments at the preoperative assessment clinic between January 1st 2017 and December 28th 2017 is available. This file has 17,971 records, and its attributes are shown in Table 8. This data is used for determining the share of patients who live far from the hospital, finding the GI-patients who require screening, the expected number of screenings and the no-show rate (Chapter 2).

Table 6 Overview of attributes of OR record data

OR records (32,598)			
Attribute name	**Description**	**Type**	**Comments**
MDN*	Patient record number	number	Unique identifier to patient
Leeftijd	Age	text	Not used in analysis but used for validating and checking results
OperID**	Surgery Identifier	number	Unique identifier to surgery
Chirurgen	Surgeon	text	Name(s) of surgeon(s) performing the surgery
Specialisme	Specialty	text	Specialty of (first) surgeon
Verrichtingen	Medical procedures	text	List of procedures performed during research
ASA	ASA-score	number	ASA physical score of patient
Anes Type	Anaesthetics type	text	Global description of anaesthetics admissioned during surgery
Anes Type2	Anaesthetics type	text	More detailed description of anaesthetics
Operatieclassificatie	Surgery classification	text	Measure of urgency of emergency or (semi)elective
Datum	Date of surgery	date/time	Date of surgery realised
Verw opname datum en tijd	Expected surgery date and time	date/time	Used for informing patients and surgeons for upcoming surgeries
Annuleringsdatum	Cancel date	date/time	Date of cancelation (in case)
Status	Status	text	Current surgery status
Aanvraagdatum	Request Date	date/time	Date of surgery request
Aanmaakgebruiker	Request User	text	User who filed request
POS info	PAC information	text	PAC information
*) Unique to patient. Not unique to table **) Unique to surgery and to table			

Table 7 Overview of attributes of outpatient appointment record data

Outpatient Clinic records (206,580)			
Attribute name	**Description**	**Type**	**Comments**
MDN*	Patient Record number	number	Unique identifier to patient
Afdspecialisme	Department specialty	text	Specialty of department
Zorgverlener/resource	Caregiver	text	Scheduled caregiver for the appointment
Afsprtype	Appointment type	text	Description of type of appointment, departments use different codes or abbreviations
Datum	Date	date/time	Date of appointment
Afspraaktijd	Appointment time	date/time	Time of appointment
Afsprduur	Appointment length	number	Duration of appointment

Table 8 Overview of attributes of PAC appointment record data

Preoperative assessment consults (17,971)			
Attribute name	**Description**	**Type**	**Comments**
Afspr.type	Type of appointment	text	20 or 30 minute or telephone
MDN*	Patient record number	number	Unique identifier to patient
Zorgverlener	Caregiver	text	type of staff
Datum	Appointment date	date/time	
Afspraaktijd	Appointment time	date/time	
afspraakstatus	Appointment status	text	Current appointment status
Wachttijd(dagen)	Waiting time in	number/text	Time between referral and appointment

Section 4.5 Method

One of the requirements is that the software this research is performed in is available in the hospital. Therefor this research is performed using Microsoft Access and Microsoft Excel. Access allows manipulation of instances in lists through SQL-queries and Excel allows easy calculations and counting of instances.

The first steps are performed in Access and combines data from the first two tables, the OR records and the specialty clinic records, to shape a resulting table which can be analysed. As the goal of the research is to find the moment patients arrive at the PAC, the moment patients finish their consult where they are being informed of their surgery is a good outcome for the analysis. This is achieved by combining all surgeries with all appointments at the specialties outpatient clinic with the patient. This yields many possible combinations and the challenge is to find the correct combinations. These steps are explained in more detail in the following paragraphs.

First, we filter the surgeries which require a preoperative assessment. As described emergency patients do not require the screening at the clinic, so these instances (4,496) are removed first. They are indicated by a *Surgery classification* of S1 to S4. Non-invasive interventions or mildly invasive interventions, either without or with anaesthetics but not administered by anaesthetists, do not require a screening at the PAC. These are identified as the *Anaesthetics type* attribute describes that none or mild anaesthetics are used, or they are administered by specialized nurses. These account for 9,653 records. These are not all that do not require screening, as there are many patients for endoscopies and gastroscopies present in the list but do not require the screening. The registration of anaesthetics is often inconsistent in this group. Some of these patients do require a screening but are difficult to differentiate. One way would be using the procedures during surgery, but it requires a lot of effort to determine the right combinations of procedure. Eventually, the surgery entries with patients who were screened at the preoperative anaesthetics clinic (data Table 8) are not removed.

The next step is to combine the data from the two sets. This is done with an outer merge on patient file identifier. All records from the one table, the surgery records, are combined with every possible combination of appointments at the clinic from the corresponding patient. Surgery records with no corresponding patients form the appointment table remain. Patients with appointments at the specialty clinic but no surgery record are discarded. This generates a total of 87,492 records. The surgeries without consults are moved to another table and used for finetuning the research. After the removal 82,708 records, of which 13,664 unique surgery records remain.

The next step is to determine the interval between the surgery request date and the appointment date. The surgery request is not always made on the same day as the appointment. Sometimes it is already known that a patient requires surgery before the actual appointment and it is also not uncommon to wait with requesting surgery for a patient when laboratory results are required. The patient is informed of the surgery, but the request is made later. An interval of two weeks in either direction is reasonable to determine that an appointment and a surgery request are linked. All combinations outside this interval are removed, leaving 15.851 instances.

These remaining instances might share the same surgery identifier, as the patient could have more than one appointment in the 4-week interval. A measure of how likely the combination of surgery request and the appointment is introduced. This is a combination of a score for the mentioned interval and a score if the surgery request is made by the same caregiver of the appointment. There are many exceptions, as general user accounts or secretaries and assistants can request surgeries as well, but it is the best measure given the available data. The specialty of the department and surgeon might seem like a good comparison measure as well but there are some issues. The specialties for departments and surgeons do not always correspond. This is discussed later this chapter. Another issue is that when more surgeons are performing procedures in a surgery, only the specialty of the first surgeon is recorded. The likeliness score awards up to 14 points for how short the interval is and 5 points if the caregiver is the same as the user who made the surgery request.

This resulting data file is exported to Excel, where the first step is sorting the list on surgery identifier and next decreasing on likeliness. All surgeries with more than one linked appointment are grouped, with the most likely combination highest. Next the remove *duplicates function* of excel is used with the surgery identifier as criterium, so only the most likely combination of each surgery remains. The reason this is done in Excel is that a relational database does not necessary store the records sorted and removing duplicates might inadvertently remove the wrong instances. At the end of this step 9,480 surgeries remain, with a linked appointment at the outpatient clinic.

Table 9 Overview of steps in data analysis

Steps in data research	Records remaining
Filter for screening	18,449
Combine with specialty appointment	87,492
Remove unmatched	82,708
Remove out of interval	15,851
Select best matching	9,480

Section 4.6 Analysis

With the moments known when patients are in the hospital and presumably being informed about their upcoming surgery, it is possible to derive when they arrive at the preoperative assessment clinic. With the information from the appointments it is possible to calculate the expected end of the appointment and derive an arrival time. Assumed is that the consult is not delayed or takes more time and that the patient requires 15 minutes traveling time within the hospital.

Table 10 Analysis steps data research

Analysis steps
Find moment of walk-in for patients with surgery within 2 weeks
Find moment of walk-in for patients with surgery within 4 weeks (ASA 2-4)
Extrapolate for expected walk-ins for patients living far from hospital
Extrapolate for expected number of patients

Now the arrival times from this group of patients can be derived. However, it is not desirable that all patients go to the PAC after their consult. As discussed earlier the ideal assessment timing is between 4 and 2 weeks before surgery. Therefore, some measures that allows further analysis are introduced. A classification if the appointment is within two weeks, two to four weeks or more than four weeks before surgery is determined. From the appointment date the day and week number are determined, and the expected arrival time is truncated to the full hour.

From here two analyses are performed with this data. The first determines the arrival times of walk-in patients over the week and the second determines the distribution of patients between walk-in and appointment request. The latter analysis is explained first, but a minor addition to the data is made. As the goal is to determine the distribution of patients at the PAC over 2017, also the patients with a surgery scheduled in 2017 but a surgery request, and consult with the surgeon, from before 2017 should be included. These are mostly not walk-in patients, only 178 out of a total count of 2104 patients.

The actual arrival pattern is derived by counting arrival occurrences for every week and hour of each day. Only the patients who are considered walk-in, according to the triage tree and their time to surgery and ASA score are counted. The result is corrected for patients living far from the hospital in a later stage. The frequency of these occurrences is calculated. From the frequency a cumulative distribution is derived. Because the measure is a number of events in a determined time period, the hypotheses is that the process is Poisson-distributed. The parameter λ is calculated and the distribution hypothesised distribution is tested using a Lilliefors test. This test is similar to the Kolmogorov-Smirnov test, but instead is meant to test if data follows a hypothesised distribution that is calculated using the same data (Campbell & Oprian, 1979). The test statistic is the same between the two tests, the maximum of the difference between the cumulative probability distribution and the cumulative data distribution, but the values for which the hypothesis is rejected differs. The Lilliefors uses a tighter margin for allowed values, the test statistic boundary for rejecting the hypothesis is d=0.125 for 95% accuracy.

The final step is to extrapolate the calculated parameters to include the patients that live far from the hospital and for the total number of expected patients. The zip code of the patient's residence is known in the datafile from all patients that had a screening at the PAC. The concept for living far from the hospital is vague. In this research is assumed that living within 35 kilometres is not considered far. This is not calculated directly but a list of 2-figure zip codes which lay mostly within this radius is used to classify patients. The list and a map are given in Table 11 and Figure 10.

Table 11 List of zip codes for patients near hospital

Zip codes of patients living near hospital	
First two numbers of zip code	
10	20
11	21
12	23
13	24
14	34
15	35
16	36
18	37
19	

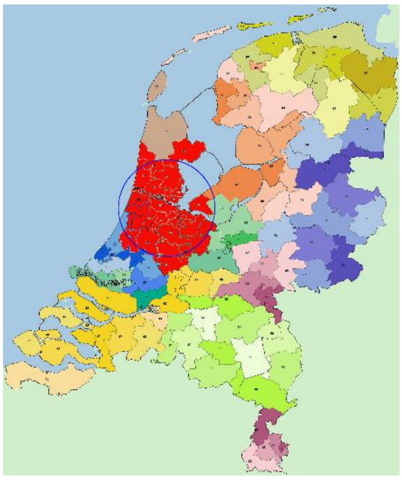

Figure 10 Map with zip code regions (red) for patients living near AMC (blue circle)

Section 4.7 Results

In Table 12 the analysis of specialties is showed. It gives an overview of how many patients to expect from each department that refers patients to the PAC, after indicating the patient for surgery. The share of patients that is scheduled for surgery within four weeks is mentioned as well. A distribution of the time to surgery for each department is displayed in the boxplots in Figure 11. The box represents the first and third quartiles and the median, the lower whisker displays the minimal value and the upper whisker represents the region that is 1.5 times the interquartile region. Outliers with a longer value are not displayed, as they are of interest in this research. The width of the box scales with the number of patients. The plot is cut off at 300 days, as only 18 out all patients had to wait more than 300 days to surgery. Another 242 patients had to wait between 200 and 300 days. A red line marks the 4-week mark, that is considered the upper bound for allowing patients to walk-in.

Table 12 Overview of referred patients to PAC from specialty department

	Specialty	Specialty (NL)	Patients	(surgery within 4 weeks)
GEN	General Surgery	Chirurgie	2000	879
ORS	Orthopaedics	Orthopedie	1263	413
ENT	Otolaryngology (Ear, nose and throat)	KNO	1081	288
GYN	Gynaecology and obstetrics	Gynaecologie	885	391
OPT	Ophthalmology	Oogheelkunde	969	293
GI	Gastroenterology and hepatology	MDL	868	530
PLS	Plastic surgery	Plastisch Ch.	814	128
CTS	Cardiothoracic surgery	Cardio thoracale Ch.	575	326
NEU	Neurosurgery	Neurochirurgie	543	175
URO	Urology	Urologie	505	129
PD-S	Paediatric Surgery	Kinderchirurgie	496	157
ANS	Anaesthesiology	Anesthesiologie	338	184
OMS	Oral and maxillofacial surgery	Mond-kaak-A. Ch.	311	43
PD-U	Paediatric urology	Urologie-kinderen	255	68
CRD	Cardiology	Cardiologie	180	136
RT	Radiotherapy	Radiotherapie	167	39
PD-G	Paediatric gastroenterology	Kindergnsknd-gastro	163	71
PUL	Pulmonology	Longziekten	82	76
PD-L	Paediatric pulmonology	Kindergnsknd-pulm	61	22

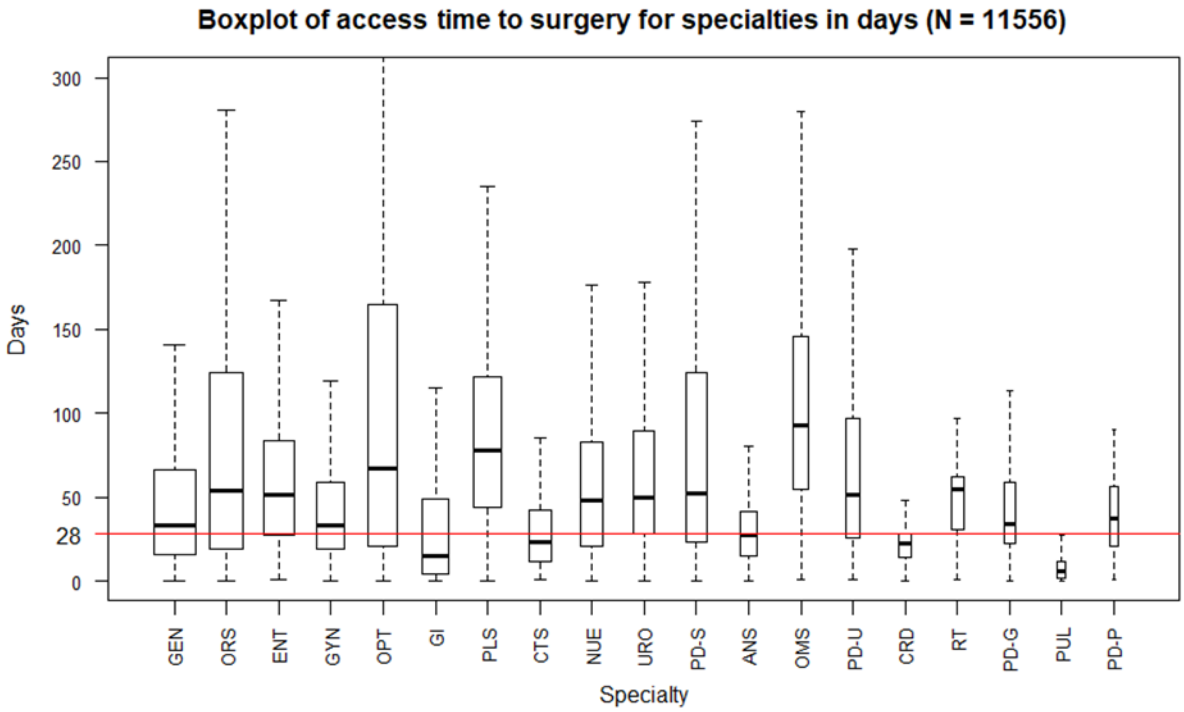

Figure 11 Boxplot of access time to surgery for specialty departments in 2017

Table 13 Overview of access time distribution for different ASA classes (walk-in eligible in bold green)

	<2 weeks			2-4 weeks			4+ weeks			Total	
ASA	**(N)**	**(% of ASA)**	**(% of class)**	**(N)**	**(% of ASA)**	**(% of class)**	**(N)**	**(% of ASA)**	**(% of class)**	**(N)**	**(% of class)**
1	**582**	16,9%	24,3%	469	13,6%	23,8%	2402	69,6%	33,3%	3453	29,8%
2	**1051**	20,4%	43,8%	**879**	17,1%	44,5%	3220	62,5%	44,7%	5150	44,5%
3	**461**	23,8%	19,2%	**417**	21,5%	21,1%	1063	54,8%	14,7%	1941	16,8%
4	**38**	35,8%	1,6%	**22**	20,8%	1,1%	46	43,4%	0,6%	106	0,9%
(blank)	**267**	28,6%	11,1%	**187**	20,0%	9,5%	480	51,4%	6,7%	934	8,1%
Total	2399	20,7%	100,0%	1974	17,0%	100,0%	7211	62,2%	100,0%	11584	100,0%

In Table 13 the distribution of patients over ASA-class and time to surgery is shown. Not all patients have an ASA classification in their record and are counted as blanks. The numbers printed in green are the patients that are eligible for walk-in tot the PAC according to the triage tree. They sum up to a total of 3,904 patients, from which 3,763 are counted in the arrival research. The difference is explained by the patients who have surgery and their screening in 2017, but the surgery request is from 2016. A small group of patients form December is therefore not counted but is expected. As the same issues occurs at the end of 2017, a surgery request but no screening expected in the same year, there should be on average no double counts.

The total table contains 11,584 patients. There is a significant gap with the realised patients, 13,432, but the group can be considered representative. Some minor validation checks are performed, these are discussed in the discussion. Given the assumption that this group is representative, the results are extrapolated to account for the expected walk-in patients who live far from the hospital and the total patients expected.

The results from the analysis of patients living far from the hospital are displayed in Table 14. Based on the first to number of the zip code a classification is made and displayed against the ASA classification. Using this table, the number of additional patients that are eligible for walk-in can be calculated as well with the percentage of patients living far from the hospital for each ASA class. The result is shown in Table 15. This shows that half the patients undergoing invasive surgery are eligible for walk-in screening at the PAC.

Table 14 Distribution of patient's distance to hospital and ASA class

	Patient lives far from AMC		Patient lives near AMC		Total
ASA	(N)	(%)	(N)	(%)	(N)
1	1012	24,2%	3169	75,8%	4181
2	1568	25,3%	4622	74,7%	6190
3	461	16,7%	2295	83,3%	2756
4	30	16,6%	151	83,4%	181
(blank)	33	26,6%	91	73,4%	124
Total	3104	23,1%	10328	76,9%	13432

Table 15 Distribution of walk-in and regular appointment requests

	Walk-in		Appointment		Total	
ASA	(N)	(%)	(N)	(%)	N	(%)
1	1277	37,0%	2176	63,0%	3453	29,8%
2	2746	53,3%	2404	46,7%	5150	44,5%
3	1056	54,4%	885	45,6%	1941	16,8%
4	68	63,8%	38	36,2%	106	0,9%
(blank)	582	62,3%	352	37,7%	934	8,1%
Total	5728	49,4%	5856	50,6%	11584	100,0%

Using the final figures, the walk-in distribution is extrapolated to reflect the expected number of arrivals. The resulting distribution can be found in Table 16 and Figure 12. All but 1 out of 50 derived distributions are not rejected in testing them for the Poisson distribution with an accuracy of 95%. In further processing all distributions are assumed to be Poisson distributed, as by definition there is a small probability of falsely rejecting the distribution. The given average number of arrivals is the expected number of arrivals in the interval [t,t+1), with t the full hour at the start of the interval.

The graph shows clearly the patterns throughout the day. In the early morning few patients are expected. The peak arrivals are in the hours 10 to 13 and 14 to 16. Mondays and Fridays see on average less arrivals than the Tuesday, Wednesday and Thursday, with Friday afternoon being exceptionally calm compared to other afternoons.

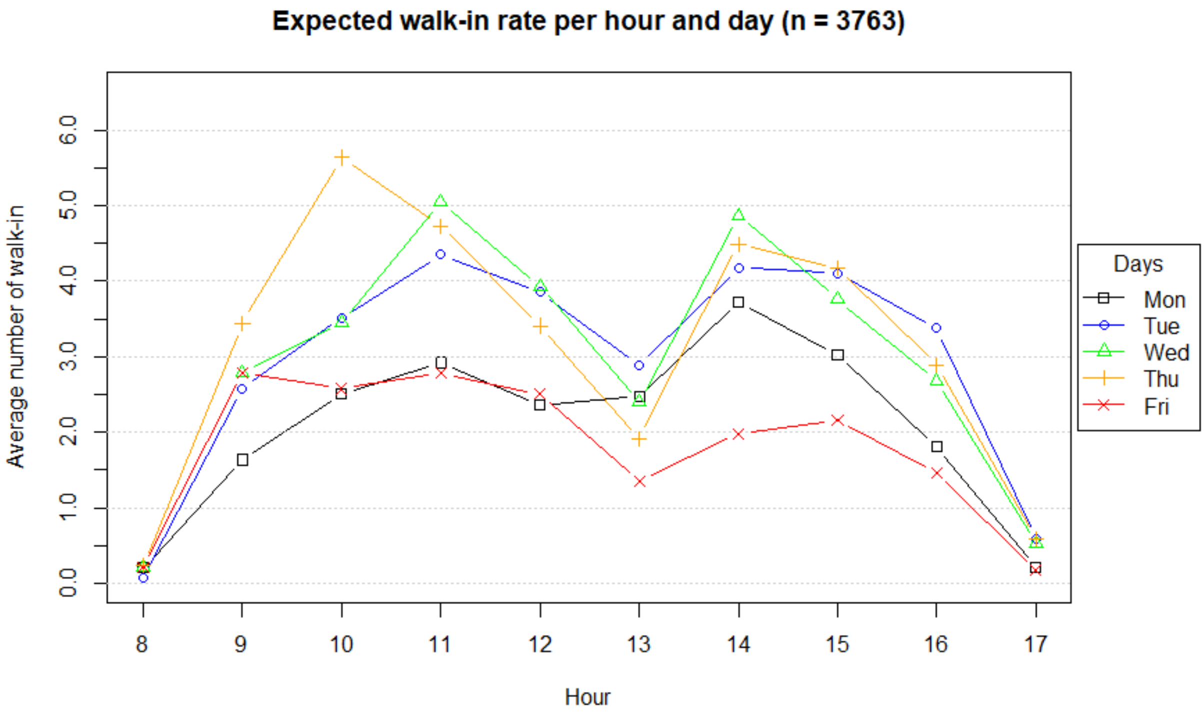

Figure 12 Expected walk-in rate per hour and day

Table 16 Expected walk-in rate per hour and day and appointment requests

Hour	Mon	Tue	Wed	Thu	Fr	Total
8	0.21	0.07	0.21	0.24	0.21	
9	1.63	2.57	2.78	3.44	2.78	
10	2.50	3.51	3.44	5.63	2.57	
11	2.92	4.35	5.04	4.73	2.78	
12	2.37	3.86	3.93	3.41	2.50	
13	2.47	2.89	2.40	1.91	1.36	
14	3.72	4.17	4.87	4.49	1.98	
15	3.03	4.10	3.76	4.17	2.16	
16	1.81	3.37	2.68	2.89	1.46	
17	0.21	0.59	0.52	0.59	0.17	
Total walk-in	**20.87**	**29.50**	**29.64**	**31.51**	**17.98**	**129.50**
Appointment requests	**26.15**	**32.46**	**28.56**	**27.96**	**18.65**	**133.78**
Total	**47.02**	**61.96**	**58.19**	**59.48**	**36.63**	**263.28**

Section 4.8 Conclusion

The research delivered useful results that are critical to designing schedules when incorporating the arrivals of unscheduled patients. It is interesting to note that the found peaks in arrivals correspond to the reported peaks from staff at the clinic.

The research shows the origin of the patient as well. Specialties with many patients who require immediate screening are general surgery and gynaecology. This result is in line with previous research that focusses on finding the specialty departments for setting up pilots for the integral preoperative clinic project.

The data is used as input distribution in the next chapter where a schedule is designed that facilitates the walk-in screening of these expected unscheduled arrivals.

Discussion

This research is based on available data in the hospital management system. As described the goal of this research could not be reached by simply measuring. The found relation between the surgery and the specialty clinic appointment is only hypothetical and derived by combining data from different sources. The research is based on many assumptions. The result is that these results are an educated guess on when unscheduled arrivals should have arrived during 2017. Important for this result to hold is that the referring specialist does send the patient to the preoperative assessment clinic according to the provided triage tree.

In the future, when the projected integral preoperative clinic is implemented, it would be good to explore options to retrieve this information from the hospital data system.

Validation

An attempt to validate the accuracy of the result has been made. The expected arrivals of the subspecialties of general surgery were determined for each part of the day, morning and afternoon, and the referring specialist. This was compared with the consultation hours of the specialists and the self-reported average number of referrals. The results matched closely. This was however not to a detail of an hour, but still gives some confidence to the results of the research.

Chapter 5. Scheduling model

In this chapter the method and results of designing an appointment schedule blueprint will be presented. The method presented by Kortbeek et al. is used. First the method is explained and (computational) challenges are explained and solved. Input parameters are argued and results for a select set of parameters are presented.

Note that throughout this chapter the notation of article is used. A superscript represents an index number and a superscript between parentheses represents a power of the base number.

Section 5.1 Introduction

As stated earlier scheduling is one of the few efficient ways to spread the workload of the clinic. For the preoperative assessment clinic an advanced access model, with both scheduled and unscheduled patients, seems a good solution as it allows patients with a short time to surgery to be seen on the day of arrival and patients who have to wait long for their surgery to be scheduled at a convenient moment. The goal of this research is to create efficient cyclic appointment schedules with a good balance in appointment slots and walk-in slots. The schedule should allow a timely assessment for the patients and the performance of the clinic under the resulting schedule should be within set performance targets. The schedule is cyclic as every week the clinic uses the same schedule.

For designing an appointment schedule the method developed by Kortbeek is used (Kortbeek et al., 2014). This method is meant for outpatient clinics in hospitals with both scheduled and unscheduled arrivals. As the pre-operative assessment clinic has both these patients because not all patients need their physical assessment immediately, this method seems a good starting point. One of the advantages is that it takes into account varying arrival rates during the day, one of the major challenges for the preoperative assessment clinic.

Although the method is designed for outpatient clinics, not all goals are aligned with scheduling for the preoperative assessments. In the general setting, patients are ideally seen as soon as possible. This is not the case for the screening, as argued before. An early screening might be invalid because it expires or the patient condition might change significantly. In those cases, extra work has to be done to revise the release of the patient. The method develops a schedule on the tactical level of medical resource planning, and the actual scheduling of individual patients is an operational decision. Good scheduling rules should prevent the mentioned issues.

One of the drawbacks of this method is that it requires equal number of timeslots and resources every day. However, the number of anaesthetists is constant throughout the week, recall that the opening time on Wednesday is slightly different than other days. On Wednesday the clinic opens at 9:00 am because of a meeting for anaesthetist earlier. This is taken into account by updating the arrival rates for each time slot so the first time slot represents the first time slot after opening, at 9:00 am in this case. The total number of timeslots is the same, but scheduled appointment in the last slots, after closing, are rescheduled at moments in the afternoon when the reserved time for patients is relatively low.

Another drawback is that the model does not directly incorporate breaks. The assumption is that all time slots are consecutive. In order to account for the breaks, the expected number of arrivals before the first timeslot after the break is adjusted to reflect the expected arrivals during the break as well. This leads to a spike in expected arrivals right after the break and these arrivals have to be serviced in the hours after the break. This leads to a minor issue with the presumed patience of walk-in patients. As the patience is defined as the number of slots a patient is willing to wait for a consult, the waiting time during the break is not taken into account with consecutive timeslots. This is not compensated for anywhere, except when assessing the performance measure for waiting time

Finally, it is not necessary to explicitly set a timeslot length, as the underlying assumption is that service of a patient takes a complete timeslot. For convenience a length is set in order to be able to relate the hourly arrival rate to the arrival rate for a given slot and to determine in which slot the arrivals during the break should be represented.

Section 5.2 Research design

The method consists of two models, a day process model that evaluates scheduled and unscheduled arrivals during a given day and access process model that evaluates the access process of scheduled patients, and an algorithm that links these two models to create and improve the cyclic appointment schedule. Using the access evaluation model, the number of appointments to schedule on a day is determined and the day process model determines where during the day these appointments have to be scheduled.

Access process evaluation model

The access process model tries to capture the process of making an appointment. At the moment a client requests an appointment, he enters a queue, the backlog. No clients can be appointed scheduled the same day. At the end of the day the backlog is decreased by at most the capacity for that day. By using an analytic model, statistics from this process performance can be derived.

The access process model is used to determine a backlog distribution from which an access time distribution can be derived. This access time distribution then can be used to derive an expected access time value and a service level for the access time.

The derivation of the access evaluation model starts with a simple Lindley-type equation describing the relation between the backlog, capacity and the appointment requests on day *d* and the backlog at the next day. Given backlog B at day *d*, at most k^d appointments are scheduled and removed from the backlog, and the backlog grows with A^d new appointment requests, which cannot be scheduled on the same day. By determining the transition probabilities and the stationary probabilities (5.2), the given Lindley-type equation can be rewritten to a probability generating function. The full derivation can be found in the published article. From this probability generating function, the stationary backlog probabilities $\pi_j^d, j < k^d$ can be calculated. This calculation is not straightforward and the method for calculation is explained in the next paragraphs. The remaining stationary backlog probabilities are calculated using (5.2).

$$B^{d+1} = \left(B^d - k^d\right)^+ + A^d \tag{5.1}$$

$$\pi_j^{d+1} = a_j^d \sum_{i=0}^{k^d-1} \pi_i^d + \sum_{r=0}^{j} a_{j-r}^d \pi_{k^d+r}^d \tag{5.2}$$

$$P_{B^d}(z) = \frac{\sum_{i=1}^{D}\sum_{r=0}^{k^{d+D-i}}\left(z^{\left(k^{d+D-i}\right)} - z^{(r)}\right)\pi_r^{d+D-i}\left[\prod_{s=d}^{d+D-i-1} z^{(k^s)} \prod_{q=0}^{i-1} P_{A^{d+D-q-1}}(z)\right]}{\prod_{g=1}^{D} z^{(k^g)} - \prod_{h=1}^{D} P_{A^h}(z)} \tag{5.3}$$

$$|z| < 1, z \in \mathbb{C}$$

With the calculated backlog probabilities useful information about the access process can be calculated. First the conditional probability is calculated that the access time for a patient arriving on day *d* exceeds *y* days, given the backlog is b at the start of the day. With these condition probabilities can be multiplied by the probability of a certain backlog and summed to get a probability distribution of the access time of a given day, given formula (5.4). Recall that probability of a certain backlog $\mathbb{P}[B^d = b]$ corresponds to the stationary backlog probability π_b^d. The service level of *y*, defined as the proportion of all scheduled arrivals that can be seen within y days, is calculated using (5.5).

$$\mathbb{P}[W^d > y] = \sum_{b=0}^{\infty} \mathbb{P}[W^d > y | B^d = b] \times \mathbb{P}[B^d = b] \tag{5.4}$$

$$S(y) = \sum_{d=1}^{D} \left(1 - \mathbb{P}[W^d > y]\right) \frac{\mathbb{E}[A^d]}{\sum_{r=1}^{D} \mathbb{E}[A^r]} \tag{5.5}$$

Calculating backlog probabilities

Recall the probability generating function used to describe the stationary backlog probabilities (5.3). The stationary probabilities can be calculated by solving $P_{B^d}(z) = 0$. The probability generating function is bounded by $|z|$<1, and thus the zeros of the numerator are also the zeros of the denominator. Assume the total capacity is *k*, with $k = \sum_1^D k^d$, thus k-1 zeros can be found within the unit disk. Finding these zeros of the probability generating function is simplified to solving the equation $\prod_{r=1}^{D} z^{(k^r)} - \prod_{h=1}^{D} P_{A^h}(z) = 0$. The distribution of appointment request is assumed to be Poisson distributed, following the research from chapter 4. This allows us to rewrite the probability generating function $P_{A^d}(z)$ into $P_{A^d}(z) = e^{\lambda^d (z-1)}$. Substituting and rewriting leads to the more elegant formula (5.4), with λ is the sum of daily expected number of appointment requests.

$$f(z) = z^k - e^{\lambda(z-1)} = 0 \tag{5.6}$$

Solving this formula for z is done by using an adaptation of Cauchy argument principal (5.5). The contour integral around a region returns the number of zeros (*N*) and poles (*P*) within that region. As the analytic function does not have any poles in the unit disk, the contour integral returns only the number of zeros within the contour. This feature is used to iteratively determine a small sub region which isolates the zeros. A contour around a region is evaluated and if the number of zeros is larger than one, the region is split in two non-overlapping regions. This is done until a region either has one or no zeros remaining. In case of no zeros, the region is discarded and in case one zero is remaining, the region is divided three more times and the exact location is determined using Newtons method, in formula (5.8), with the region midpoint as initial value. The steps of this method can be seen visually in Figure 13. The coloured squares show how the method zooms in on the zeros, and eventually the zero is found with (5.8) and displayed as a red cross.

$$N - P = \frac{1}{2\pi i} \oint_C \frac{f'(z)}{f(z)} dz \tag{5.7}$$

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \tag{5.8}$$

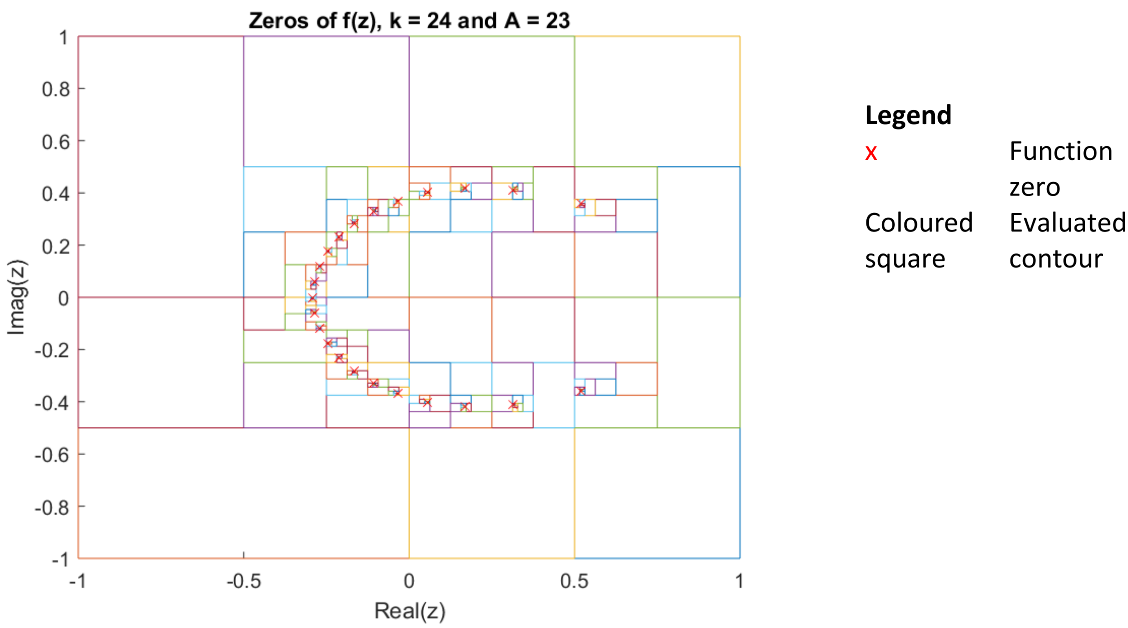

Figure 13 Zeros of arbitrary values for k and λ (A) in the imaginary plane

The k-1 found zeros of the denominator are also the zeros of the numerator of formula (5.3). Recall that a zero to f(x) is the value for x for which f(x) = 0. The numerator consists of a sum of k terms, each term contains a single stationary backlog probability. Using the k-1 known zeros, and a normalizing equation $P_{B^d}(1) = 1$, a total number of k linear equations can be constructed. This makes the system uniquely defined and thus the values of the backlog probabilities can be calculated directly. However, this is near impossible for any moderately large k, as the values for the coefficient matrix are near zero and complex values, resulting in an ill posed system. This is computationally practically impossible because the coefficients can be substantially smaller than the computational accuracy. Given the ill-conditioned nature, a small deviation in input variable results in large changes in a solution value. This can be solved by using a regularisation and or solving a least squares solution of the problem (5.7). The goal of the linear least squares method is to minimize the L_2-norm of the error.

$$\hat{x} = \arg\min_x \|b - Ax\|_2 \tag{5.9}$$

With the stationary backlog probabilities finally calculated for $j < k^d$ the remaining values can iteratively be calculated using formula (5.2). The matrix is updated until no changes in value occur anymore. Calculating the access time distribution with the given formulas is straightforward. The only consideration is that for practical and computational reasons, an upper limit lower than infinity should be chosen.

Day process evaluation

The purpose of the day process evaluation is to determine the distribution of deferred patients for the given day and appointment schedule. The term realised schedule ($\tilde{c}$) is introduced to described the actually used appointment slots for scheduled patients. As the slots are filled bottom up, any realised schedule is a truncated version of the appointment schedule.

Any given state of the system during the day can be described by the tuple (t,s,u), with t the current timeslot, s and u are respectively the number of scheduled and unscheduled patients present at the beginning of the timeslot. These tuples are categorised as either one of eight possible cases. A visual representation is given in Figure 14. For each of these cases transition probabilities are defined given the next state. The state probability can be calculated using formula. With these state probabilities the probability distribution of referred patients arriving during the timeslot φ_t can be calculated as well (formula 5.12). The final probability distribution of referred patients during a day (φ) can be calculated by taking the discrete convolution of the distribution of each time slot.

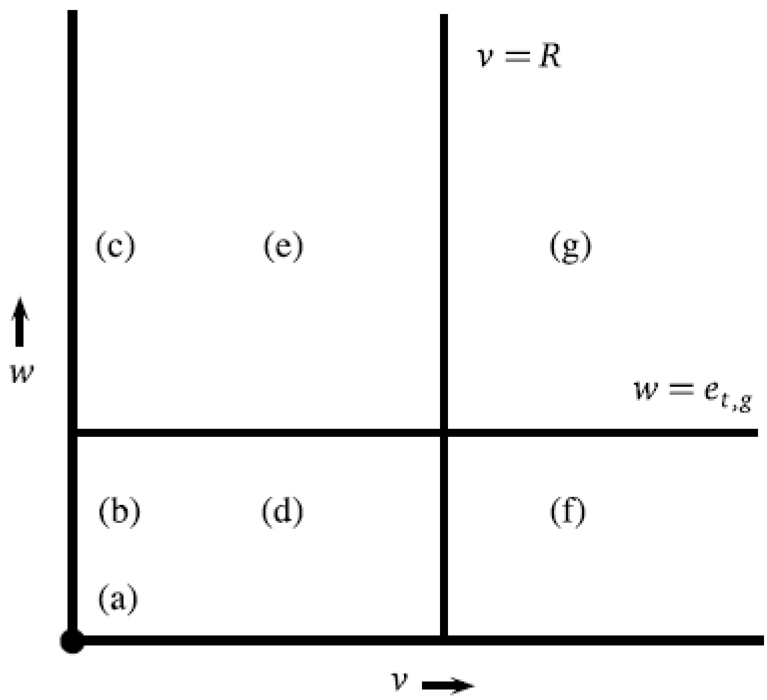

Figure 14 Possible state representation

Case(a) $v = w = 0$; no job served:

$$\mathbb{P}[(s,u)_{t+1} \mid (v,w)_t] = p^s_{t+1}(s)p^u_{t+1}(u).$$

Case(b) $v = 0, 0 < w \le e_{t,g}$; unscheduled job(s) served:

$$\mathbb{P}[(s,u)_{t+1} \mid (v,w)_t] = p^s_{t+1}(s)p^u_{t+1}(u - w + \min\{R, w\})\mathbb{1}_{(u \ge w - \min\{R,w\})}.$$

Case(c) $v = 0, w > e_{t,g}$; unscheduled job(s) served, unscheduled job(s) deferred:

$$\mathbb{P}[(s,u)_{t+1} \mid (v,w)_t] = p^s_{t+1}(s)p^u_{t+1}(u - e_{t,g} + R)\mathbb{1}_{(u \ge e_{t,g} - R)}.$$

Case(d) $0 < v < R, w \le e_{t,g}$; scheduled and unscheduled job(s) served:

$$\mathbb{P}[(s,u)_{t+1} \mid (v,w)_t] = p^s_{t+1}(s)p^u_{t+1}(u - w + \min\{(R - v), w\})\mathbb{1}_{(u \ge w - \min\{(R-v),w\})}.$$

Case(e) $0 < v < R, w > e_{t,g}$; scheduled and unscheduled job(s) served, unscheduled job(s) deferred:

$$\mathbb{P}[(s,u)_{t+1} \mid (v,w)_t] = p^s_{t+1}(s)p^u_{t+1}(u - e_{t,g} + R - v)\mathbb{1}_{(u \ge e_{t,g} - R + v)}.$$

Case(f) $v = R, w \le e_{t,g}$; scheduled job(s) served:

$$\mathbb{P}[(s,u)_{t+1} \mid (v,w)_t] = p^s_{t+1}(s - v + R)p^u_{t+1}(u - w)\mathbb{1}_{(s \ge v - R)}\mathbb{1}_{(u \ge w)}.$$

Case(g) $v = R, w > e_{t,g}$; scheduled job(s) served, unscheduled job(s) deferred:

$$\mathbb{P}[(s,u)_{t+1} \mid (v,w)_t] = p^s_{t+1}(s - v + R)p^u_{t+1}(u - e_{t,g})\mathbb{1}_{(s \ge v - R)}\mathbb{1}_{(u \ge e_{t,g})}.$$

$$Q_{t+1}(s,u) = \sum_{v=0}^{\infty}\sum_{w=0}^{\infty} Q_t(v,q)\mathbb{p}[(s,u)_{t+1} | (v,w)_t] \tag{5.10}$$

$$v_t = v_{t-1} + \sum_{s=0}^{\infty}\sum_{u=e_{1,g}+1}^{\infty} \left(u - e_{t,g}\right) \times Q_t(s,u) \tag{5.11}$$

$$\phi_t(j) = \begin{cases} \sum_{s=0}^{\infty}\sum_{u=0}^{e_{t,g}} Q_t(s,u), & j = 0 \\ \sum_{s=0}^{\infty} Q_t\left(s, e_{t,g} + j\right), & j > 0 \end{cases} \tag{5.12}$$

$$\phi = \phi_1 * \cdots * \phi_T \tag{5.13}$$

Generating day schedules

Now that the two models can be used to determine the access time distribution and daily referral rate, it is possible to construct and evaluate schedules. The method is displayed in **Error! Reference source not found.**. The general idea is that for a given appointment schedule, not all unscheduled arrivals can be seen. These referred patients have to be taken into account when designing the capacity cycle. Every iteration the number of scheduled arrivals is updated with the expected referred patients. The procedure terminates when a balance is reached and the amount of referred patient does not change anymore, within accuracy ϵ. In this part the letter n denotes the iteration counter *n* and subscript *f* denotes the schedule option ($f \in \{1..r\}$).

The procedure starts determining the probability distributions of scheduled and unscheduled arrivals (5.14). This takes into account the φ^d referred patients of the previous iteration. In the first iteration, the number of referred unscheduled patients is set to zero and the number of scheduled and unscheduled arrivals are the same as the initial input parameters. The procedure then constructs capacity cycles, the number of appointments to schedule on each day. Initially the total number of appointments is slightly larger than the number of expected scheduled arrivals over the week. Then an initial capacity cycle is created by assigning an appointment to a day with the most unreserved time, the time not expected to be spent on unscheduled arrivals. When these are all assigned, neighbouring schedules are created by swapping at most r appointments between days. This leads to $l = r \times d(d-1)$ capacity cycles. All these capacity cycles are evaluated using model 1, the access process evaluation. These are ranked on their access time service level. If no schedules do meet the required service level, new capacity with more appointments cycles are constructed. A determined number of best performing cycles is taken and for these cycles day schedules are constructed.

The constructing of day cycles is performed in a similar manner. These are constructed and improved for each day independently. First is determined if the number of appointments to schedule the given day is the same as the previous day. If that is the case, the algorithm uses that schedule as starting schedule, else a new schedule is constructed. All appointments are sequentially assigned to the appointment slot with the least time reserved for already scheduled patients and expected unscheduled patients that arrive at most g slots earlier.

These capacity cycles are evaluated using model 2. As not always all appointment slots are filled, all possible truncated realised schedules must be assessed. The resulting referral rates are multiplied by the probability for that number of filled appointment slots and added together to return an expected referral rate. These probabilities of truncated schedules correspond to the stationary backlog probability from model 1, and the probability of a completely filled schedule is the sum over all stationary backlog probabilities corresponding to an at least as large backlog as number of appointment slots.

This method is repeated a couple of times, denoted by parameter r, and each option is a neighbour solution to the best performing solution that iteration. A neighbour is a solution who has one appointment swapped with a free spot compared to an initial solution. After the set number of comparisons, the best solution is chosen.

This is performed for a number of capacity cycles and after all are assessed the best performing one is selected and a new iteration can start with this schedule as initial one. The method stops if a balance is reached. This happens when the referred patients do not require any more appointment slots to accommodate them in the appointment schedule, and the total referral rate stabilises.

$$\gamma^d(n) = Poisson\left(\lambda^d\right) * \phi^d(n-1) \tag{5.14}$$

$$k(n) \coloneqq \left\lceil \sum_{d=1}^{D} \gamma^d\,(n) \right\rceil \tag{5.15}$$

$$\psi^d(n) = R \times T - k^d(n) - \sum_{t=1}^{T} \chi_t^d \tag{5.16}$$

$$\hat{d} \coloneqq \arg\max_d \psi^d(n) \tag{5.17}$$

$$\theta_t^d\left(n_f\right) = \sum_{\hat{t}=\max\{t-g+1,1\}}^{t} R - c_{\hat{t}}^d\left(n_f\right) - \chi_{\hat{t}}^d \tag{5.18}$$

$$\hat{t} := \arg\max_{t} \theta_t^d(n_f) \tag{5.19}$$

Section 5.3 Computational challenges

The method is implemented in MATLAB because it offers plentiful advantages, and it is available in AMC as well. This allows reusability and further development of the algorithms if the clinic decides to re-evaluate parts of this research. MATLAB has a large library of mathematic and statistic functions so most of the calculations can be implemented using standard routines. The software is optimized for matrix operations and many functions support vectorized input, resulting in efficient computations.

A few challenges arise when implementing the described method. In calculating probabilities, some formulas (5.4, 5.10-5.12) contains summation over infinite elements. These upper boundaries have been transformed to a value such that the corresponding probability is not significant compared to other terms. Probabilities lower than $1*10^{-6}$ are considered not significant. For each case the consistency with dependent equations is checked to prevent errors. Note that higher than necessary bounds result in longer running time of the algorithm.

When calculating the contour integrals in Cauchy's argument principle to determine the function zero locations, there are some issues which should be prevented. The most important is that the contour cannot cross one of the zeros. The integral does not have a function value in that point. The MATLAB routine for evaluating integrals numerically keeps splitting such an interval in infinitesimal pieces, until either a maximum number of intervals is reached, or if the interval length reaches a minimum value. Both cases return a warning message. Normally the routine returns an invalid result, together with the warning. As this is detrimental for the method, this should be circumvented. This is solved by setting the warning messages as errors so they can be recognized with a *try...catch* statement. Now it is possible to recognize when an integral path crosses, or is close to, a zero and adjust the contour to prevent this from happening. As the starting region is defined as the square through (1+i) and (-1-i) and the regions are split through their centres initially, this happens at least once every instance with an even number of appointment slots. The zeros of the analytic function represent the zeros of a polynomial, and from the former it is known that zeros with a complex part are always pairs with their complex conjugate. With an uneven number of zeros, at least one is real valued, and thus has an imaginary part of 0, which coincidentally is exactly on the split when horizontally splitting the initial square.

The MATLAB built-in solver for linear equations and the least square solver are unable to consistently find good solutions to the system of linear equations, especially when the number of variables increases. For finding good approximations to the stationary backlog distribution, the least square solver from Saunders of Stanford University's System Optimization Laboratory (Paige & Saunders, 1982) is used. The solution is accurate enough, as the results get improved in the following steps that iteratively calculates all stationary backlog probabilities, including the $j \geq k^d$that are not calculated with the analytic method.

Last note is that given the problem size, complete enumeration is not viable in determining an optimal schedule. The schedule is determined by the heuristic approach described by Kortbeek et al (2014). This approach uses a local search method to search and evaluate neighbouring solutions randomly.

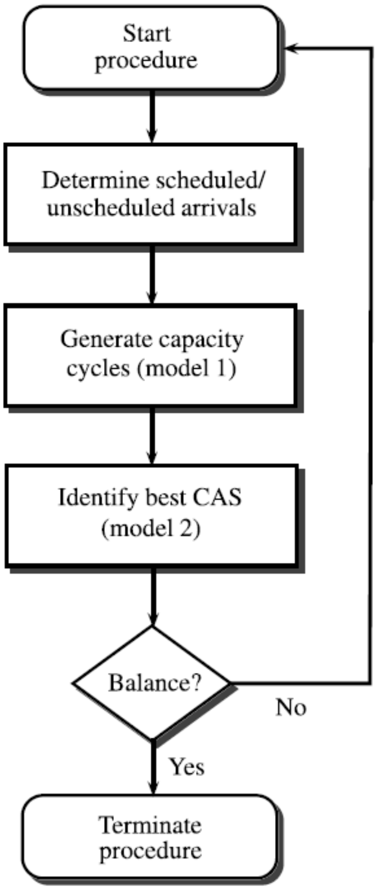

Figure 15 Procedure overview for creating optimal schedules (Kortbeek et al., 2014)

Section 5.4 Input and parameters

The requires some general input which describes the cases this research solves. Next to the case description some parameters have to be set additionally which steers the algorithm behaviour. In the following paragraphs an overview and motivation are given of these parameters, which all are summed up in Table 17 as well.

Table 17 Overview of input parameters

Parameter	Value
Input	
R	{3,4}
T	{21,24,16}
D	5
g	{4,3}
q	0.02
λ	[26.15, 32.46, 28.56, 27.96, 18.65]
S_{norm}	0.95
$y(S_{norm})$	10
Algorithm parameters	
b	3
r	35

m	4
ϵ	$1*10^{-3}$
Max iterations	20

Input parameters

These parameters describe the cases for which an optimal schedule should be determined. Most of these values are discussed in chapter 2 already, so these are shortly motivated here. Parameter R describes the number of anaesthetists. For the schedules with 20-minute appointment slots, 3 anaesthetists are available. For the schedules with 30-minute slots, 4 anaesthetists are available, so enough appointments are available each week to meet the required average demand. Correspondingly the number of timeslots T is set at 21 and 24 for the cases with 3 anaesthetists. In case of extra opening hour, either by staying open longer or by removing the break, there are 24 timeslots. In case of 4 anaesthetist the corresponding number of timeslots is 16.

The maximum patience of a patient g is the number of slots that a walk-in patient is willing to wait for an appointment slot. The patience is determined to be at most 1.5 hour. A patient who is in the hospital already and needs the screening within a few days anyway or lives far from the hospital is willing to wait a bit more probably but 1,5 hours is considered an acceptable time to wait for a free consult spot.

The no-show q rate is determined to be 0.02, from historical data. These are patients that have an appointment and either do not show up for their appointment or the appointment is cancelled the same day. Earlier cancelations are not considered, as these spots can be rescheduled again.

The service level norm for the access time is set 10 (work)days and a norm of 0.95. That means that 95% of all appointment requests can be scheduled within 10 days. This is not directly of importance to most patients, but it guarantees for 95% of referred patients an appointment as well within 10 days. This is especially beneficent for the referred walk-in patients with a surgery in three or four weeks, as it still allows for a decent time between screening and surgery.

The algorithm parameter b represents the maximum number of appointments to swap between days when constructing neighbouring capacity cycles.

Table 18 Overview of input parameters for specific cases

Case	1	2 (extra hour)	3 (no break)	4	5 (no break)
R	3	3	3	4	4
T	21	24	24	16	16
q	4	4	4	3	3
λ and φ	Calculated respective of case and results from chapter 4				

Section 5.5 Results

The results of the method for the different schedules are given in the tables. A visual representation of all schedules is given in Appendix A, in the same style as Figure 16.

Table 19 Results of finding optimal schedules

Day	γ^d	v^d	k^d	CAS^d
Schedule 1				
1	28.29	0.116	34	(3 3 3 2 3 3 1 2 2 3 0 2 0 2 2 0 1 2 0 0 0)
2	36.60	0.184	27	(3 3 3 3 2 3 0 3 1 1 1 1 0 0 1 1 1 0 0 0 0)
3	32.05	0.293	30	(3 2 3 3 0 1 2 2 0 0 0 2 0 1 2 0 0 0 3 3 3)
4	31.69	0.253	25	(3 3 3 2 3 1 0 3 1 1 0 0 0 0 2 2 0 1 0 0 0)
5	20.32	0.043	34	(3 3 3 2 3 2 0 2 2 2 0 2 0 2 3 0 1 2 2 0 0)
Schedule 2				
1	26.38	0.024	32	(3 3 3 1 3 0 3 1 2 0 2 2 0 0 0 2 1 2 0 0 2 2 0 0)
2	33.12	0.068	24	(3 3 3 2 2 2 1 2 0 0 2 0 0 0 0 0 0 2 1 1 0 0 0 0)
3	29.34	0.048	25	(3 2 1 1 1 0 2 1 0 0 0 0 1 1 0 0 1 2 2 0 3 0 3 1)
4	28.59	0.036	19	(3 2 3 2 0 2 2 0 0 0 0 0 0 0 0 2 0 2 0 1 0 0 0 0)
5	18.90	0.078	37	(3 2 3 3 0 3 1 0 3 0 2 1 2 0 1 1 2 1 2 3 0 2 1 1)
Schedule 3				
1	28.23	0.054	34	(3 2 3 2 2 3 0 2 2 2 0 1 2 0 1 2 2 2 1 1 1 0 0 0)
2	36.56	0.142	30	(3 3 3 2 2 2 2 0 2 0 0 3 0 2 0 2 0 2 1 1 0 0 0 0)
3	32.05	0.086	25	(3 3 0 2 0 2 1 1 0 0 0 2 1 2 0 2 1 2 0 0 1 2 0 0)
4	31.57	0.125	25	(3 3 3 1 3 1 0 1 0 0 0 1 2 0 0 2 2 1 1 1 0 0 0 0)
5	20.30	0.022	35	(3 3 2 2 2 0 2 2 0 1 2 2 0 2 0 2 2 2 1 3 1 0 1 0)
Schedule 4				
1	26.90	0.535	33	(4 4 3 3 2 4 0 1 4 0 3 0 3 0 2 0)
2	34.32	1.269	28	(4 4 4 0 3 2 2 0 2 0 0 3 3 1 0 0)
3	29.85	0.560	24	(4 3 0 3 0 1 0 0 0 3 0 3 0 2 4 1)
4	28.87	0.324	20	(4 4 3 0 3 0 1 0 0 0 0 3 1 1 0 0)
5	19.36	0.519	35	(4 3 4 0 3 4 0 2 2 0 2 4 1 3 2 1)
Schedule 5				
1	28.56	0.394	34	(4 4 3 3 2 3 0 3 3 2 0 3 0 2 2 0)
2	37.14	0.721	30	(4 4 3 3 2 2 0 0 4 0 2 3 0 3 0 0)
3	32.40	0.434	27	(4 3 2 0 0 4 0 0 3 2 0 2 0 2 3 2)
4	31.90	0.455	25	(4 4 3 1 2 0 1 0 0 4 0 3 2 1 0 0)
5	20.47	0.192	35	(4 4 2 4 0 3 0 3 3 0 2 4 2 2 2 0)

Table 20 Overview of schedule performance and algorithm running time

Schedule	γ	v	k	$S(10)$	$\gamma \mid S>S_{norm}$	Running time (min)
1	148.95	0.889	150	1.000	4	548.2
2	136.33	0.254	137	1.000	5	659.7
3	148.51	0.429	149	1.000	4	1,539.1
4	139.30	3.207	140	1.000	4	1,882.9
5	150.47	2.196	151	1.000	4	1,192.6

A global theme among all schedules and days is that most appointments are scheduled in the morning. Also Friday afternoon is a moment in which many appointments are scheduled. These moments correspond to times when the arrival rate of unscheduled patients is low. It is attractive to appoint many slots for scheduled patients in these moments, as a set number of appointments has to be scheduled at a given day and at these moments they do not interfere with walk-in patients. In a similar fashion the days with a low walk-in rate have a higher number of scheduled appointment slots.

Interesting to note is that the schedules which use 30-minute appointments have a much higher referral rate than the schedules with 20-minute appointments. The total number of appointments is not much lower, but apparently the higher walk-in rate per slot and the lower number of slots the patient is willing to wait are not compensated fully by the higher number of appointments available.

Schedule 2 has the lowest referral rate, which translates to most patients screened at their optimal time. Because a walk-in patient has to be seen the same day in order to be assessed at the ideal moment, except for the walk-in patients that live far away, a referred patient is a patient that is screened too late. This performance measure is therefore a predictor for the rate of patients screened at their ideal moment.

Schedules with an extra hour at the end of the day have at least 10 less appointment slots reserved. This is reflected in the appointment request as well. These are the expected arrivals in the extra hour that now can be seen on arrival instead of having to be rescheduled. These walk-in patients are not measured in the referral rate but should be taken into account when comparing schedules.

All schedules have an access-time service level of 1.000 for 10 days, which means that there is always a spot free within this time. The access time that corresponds to the first service level above the norm is also constant, 4 or 5 days for all schedules. This means that 95% of patients can get an appointment within a week. This is almost never required given that most patients have to wait longer for their surgery, but it assures that referred walk-in patients can be seen on short notice if necessary.

The running time for the algorithm is long. The problem which takes shortest time to solve still takes almost 10 hours, and the longest problem took more than 31 hours. This is not really considered an issue as the results can be used for some time and the schedule does not have to be updated every week. The reason for this long running time is the sheer number of schedules that have to be analysed. In order to assess a schedule with 30 appointments slots, all 30 truncated variants have to be assessed as well. The implementation keeps track of all assessed schedules and their results, as the day evaluation returns always the same referral rate distribution given that the realised appointment schedule is the same, so these do not have to be recalculated. The difference in running time might partly be explained because there are many different capacity cycles assessed in the problems which took longer. These can less often reuse a result from a previous iteration.

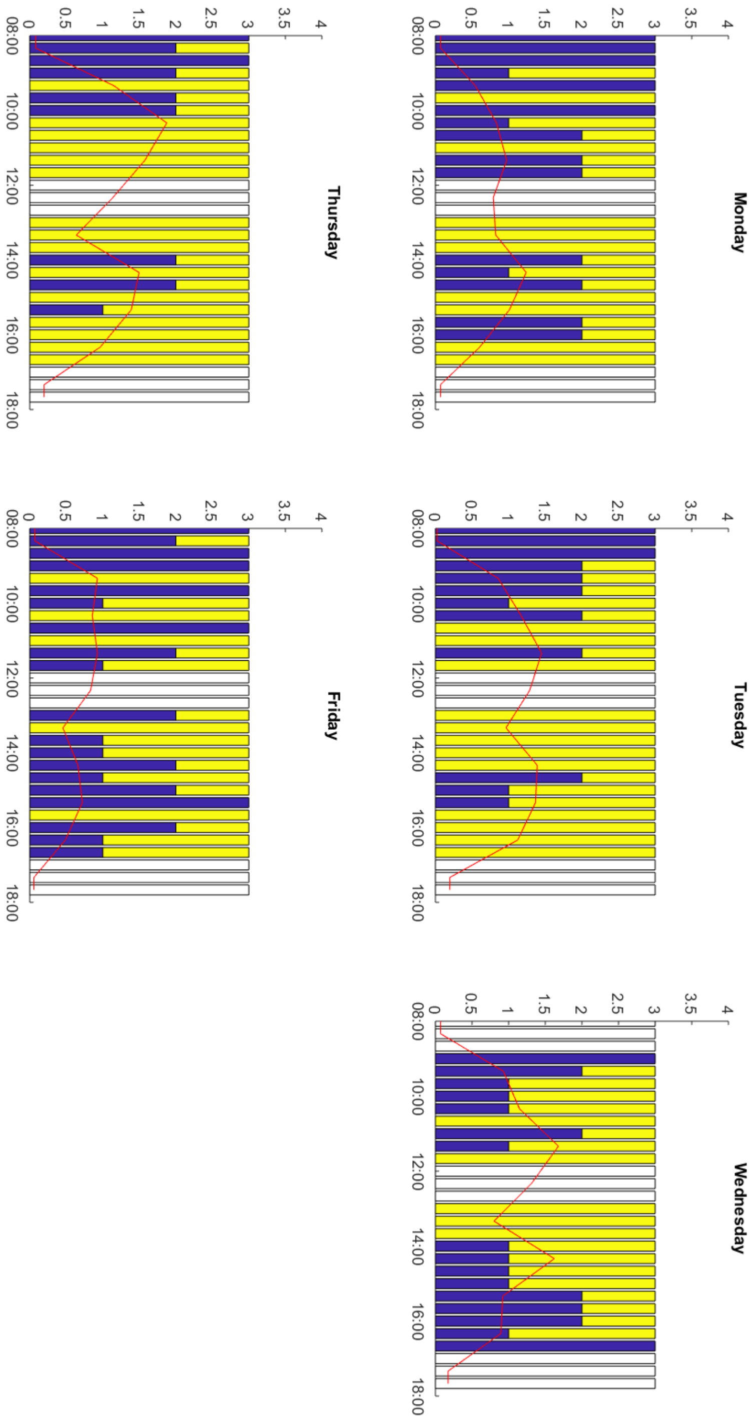

Figure 16 Overview of schedule 2. Appointment slots(blue), walk-in slots(yellow), closed(white) expected arrivals during slot(red). X-axis displays timeslots during day and Y-axis displays number of resources and walk-in rate during time slot

Section 5.6 Conclusion regarding algorithm

Based on the results schedule 2 (Figure 16) seems to have the lowest referral rate and lowest number of scheduled appointments as well. This seems like a good schedule, but at this point it is not possible to say how the schedule perform in practice. In general, all schedules seem to have a decent referral rate. Even schedule 4 with a referral rate of over 3 patients per week, at almost 130 walk-in patients per week this is still a good performance.

Discussion and follow up steps

The used method for creating optimal schedules is a heuristic. That means that there is no guarantee that the found solution is an optimal solution, but merely the best solution that is assessed. Given the huge number of possible schedules it is impossible to calculate every option. However, given the method and the local search method, the final solutions are decent ones and approach an optimal answer.

These values are analytically derived given the assumptions stated in the method. A major assumption is that all services take a single slot to complete. These performance measures only hold when this would be true in practice as well. This is of course not the case. In order to compare these schedules based on performance in practice complementary research is necessary. Therefore, the next chapter reviews a simulation study based on these schedules.

Chapter 6. Simulation study

In this chapter the final research is performed, validating the proposed schedules from the previous chapter by assessing their performance using a simulation study. In this simulation study the schedule blueprints are used during a long period in a model that represents the process of the preoperative assessment clinic. By deriving useful performance measures, it is possible to identify what schedules perform well and might be considered to be implemented.

The previous chapter presented a method to determine optimal schedules and successfully delivered 5 schedules for different settings. In this chapter these schedules will be assessed on their performance in a simulation study. This simulation model represents the processes of the preoperative assessment clinic. This allows for many performance measures to be determined. The performance measures from Chapter 2 will be monitored, and some more relevant measures are extracted. The model is constructed based on the 10 steps for simulation modelling according to Law (2014).

Section 6.1 Research goal

The goal of this research to assess the performance of the presented schedules in a realistic setting with uncertainty and realistic variation seen in processes at the preoperative assessment clinic. This research validates the designed schedules and derives useful statistics which can be used by management make informed decisions regarding which schedule to implement

Section 6.2 Model description

The process modelled in the simulation study closely follows the process at the preoperative anaesthetic clinic. An overview of process steps in the simulation is given. First there is a distinction made between two patient types. Regular patients who are scheduled from a backlog list and walk-in patients who show up during the day and request a screening the same day. At the beginning of the day the number of scheduled regular patients is known, and the arrivals of walk-in patients are randomly scheduled during the day, depending on the walk-in rate derived in Chapter 4.

Scheduled patients arrive 15 minutes before their appointment time. All patient first arrives at the front desk. At that moment all relevant service times and time to surgery are drawn from their respective distribution. These distributions are derived in Chapter 2. Scheduled patients are sent from the desk to the waiting room from here. Walk-in patients are allowed to enter if there is a free appointment slot available that day, either an unused regular appointment slot or a unused walk-in slot. If the arrival is within 10 minutes the start of a slot, these can be appointed to walk-in patients as well. If no appointment slot is available that day walk-in patients are put on the work list as well. The only exception is if the walk-in patients has surgery the next day, then the patient is scheduled after closing time and assessed as last patient during that day.

The number of walk-in patients during a period is not directly determined from the Poisson distribution, but at the start of every hour an interarrival time is calculated. This interarrival time is exponentially distributed with parameter $1/\lambda$. If this arrival is within the current hour, a walk-in patient arrives after the corresponding time. At the patient arrival a new interarrival time is drawn, until the project arrival time is not in the current hour. Then the arrival is discarded and at the start of the new hour the process starts again with a new parameter λ.

When a patient enters the waiting room it is certain that the patient will be assessed that day. Two things happen after a patient enters the waiting room. An idle physician's assistant will lead the patient to a spare room and starts the corresponding consult. Simultaneously the patient is registered in the log which keeps track of all patients that needs to be prepared for assessment. An idle anaesthetist will take on the patient and prepare the consult. When physician's assistant finishes its consult with the patient they leave the room and leaves the patient behind. The patient waits until the anaesthetist is idle and the preparation of the consult is finished. When the anaesthetist is ready they will enter the room in which the patient is waiting and the consult will commence. When the consult finishes the patient leaves the room and clinic and is put in a queue, which only purpose is to gather information at the end of the day. When finished, the anaesthetist can either start a consult with another patient he or she has prepared, start preparing the consult of a new patient or turn idle and wait for new patients to show up.

There are some interactions when the clinic opens or closes and during breaks. The simulation keeps track of opening hours and breaks, if any. The first thing the clinic does at a new day is set the time for the open and close events. These events either locks or unlocks the entrance of the front desk. This happens 15 minutes before the actual closing or opening times. A locked entrance means that patients have to wait and cannot continue to the front desk and the cannot enter the process that starts there. It is the modelling representation of a desk where no server is present. This only affects the walk-in patients that might walk-in during the break. Patients who have entered the clinic always have their consult finished.

Walk-ins who arrive after the clinic closes are send to the worklist. The only exception is when a patient has its surgery the following day. Then it is impossible to schedule a screening. These patients are moved to another drain where they wait till the end of the day to be processed. This minor group of patients are a consequence of the mathematical representation of reality. In a real situation these patients are often emergency patients and do not require a physical assessment in the preoperative clinic, and are therefore not of interest in this research, but a mere anomaly resulting from using probability distributions.

At the end of the day three things happen. First a number of patients based on the distribution for appointment requests are added to the worklist. These represent the patients for whom a surgery request is made. These patients are having a time to surgery longer than 4 weeks. Together with the referred patients that day these complete the worklist. The next step is to schedule these patients at a convenient time and move them to a list where all patients wait until the day of their appointment. The scheduling rules are explained later this chapter. Finally, all patients who are consulted or removed are processed and their relevant statistics are recorded. The patients are deleted afterwards. The statistics from the staff are stored as well and their performance measures are reset for a new day. Then the next day arrives and this process will repeat itself.

Scheduling rules

Essential for good performance is the scheduling of patients. Scheduling allows to balance the work load, and more important, allows for a timely assessment. In the scheduling procedure there will be a differentiation between referred walk-in patients and patients with an appointment request. The former group needs to be scheduled as soon as possible, that is the first appointment slot available. An exception is made in the rare case that no appointment slots are available. Then a walk-in slot the next day will be sacrificed for this patient. The other group of patients are first scheduled in the interval from four weeks to two weeks prior to surgery, starting with 20 workdays and working down to 11 until an appointment spot is available. If nothing can be found within these weeks, the two weeks before this period are checked and scheduled as close as possible to the four-week mark. In the rare case this also is not possible, the two weeks before surgery are checked and scheduled as early as possible.

Initialization

The schedule blueprint is loaded at the beginning of the simulation run. An agenda is created with the entire period of the run length and extra weeks to accommodate patients that need to be scheduled but are not in the time window in which data is gathered. The agenda is filled with empty copies of the blueprint.

One part of the screening process at the pre-operative clinic is not present in this simulation model. After the consult the anaesthetist needs to conclude the file and release the patient for surgery. This is not always possible at the end of the consult due to additional testing. This time is incorporated at the end of the analysis. The amount of idle time is reduced with the expected finishing time for all patients screened.

Data gathering

The parameters that are collected for processing and their purpose are displayed in Table 21**Error! Reference source not found.**. Data is gathered and processed in cycles of one week, as the schedule repeats itself every week. Patient information is gathered every day and processed at the end of the simulation run.

Table 21 Parameters gathered during simulation

Parameter	Purpose
From clinic	
Patients created	Total patients, finishing time
Number of walk-in	General comparison
Number of walk-in after closing time	Referred patients
Patients consulted	General comparison
Patients removed	Patients that cannot be scheduled
Number of schedules with overtime (break)	Occurrence of overtime
Overtime (break)	Total weekly overtime
Total working time physician's assistant	Occupation rate physician's assistant
Total working time anaesthetist	Occupation rate anaesthetist
Time idle anaesthetist	Time available for finishing patient files
From patient	
Walk-in	Optimal scheduling rate, performance goal
Appointment time	Delay between arrival and start
Start time consult	Delay between arrival and start
Waiting time before entering room	Average waiting time and performance goal
Waiting time between consults	Average waiting time and performance goal
Days before surgery	Optimal scheduling rate

The characteristics of the schedules are displayed in Table 22.

Table 22 Schedule characteristics

Schedule	Time slots	Length	Anaesthetists	Start	end	Break
1	21	20 min	3	8:00	16:00	12:00 –13:00
2	24	20 min	3	8:00	17:00	12:00 –13:00
3	24	20 min	3	8:00	1 6:00	-
4	16	30 min	4	8:00	17:00	12:00 –13:00

5	16	30 min	4	8:00	16:00	-

The described simulation is a non-terminating simulation, there is no clear end event that terminates the simulation. The simulation does however have a warm-up period (Law, 2014). At the beginning of the simulation the clinic starts empty and thus the first weeks not many scheduled patients are serviced that week. The minimal warm-up length can be derived analytically without a lot of effort. As the number of patients scheduled in a week is dependent on the creation of appointment requests, a stable distribution should settle when every week has equal distribution of request for surgery that week. As the upper boundary for the time for surgery for any patient is 300 days, or 43 weeks, this is also the minimum warm-up length. The data gathering starts after that week. Data is collected for a one-year period, without taking into account holidays.

The required number of simulation runs is determined by initially gathering data from 10 runs and the initial schedule (schedule 1). The sample mean and the mean 95%-confidence interval for all measures is calculated using the results. A relatively large confidence interval compared to the sample mean is undesirable. The confidence intervals are assessed individually as not all measures require the same accuracy. The two measures with the largest confidence interval compared to the sample mean have a standard error of 12% compared to their mean the other measure scores less than 5%. This indicates that 10 simulation runs are sufficient for retrieving reliable results.

An overview of the simulation model is added in Appendix B.

Measure	
Waiting time	80% within 20 minutes 95% within 60 minutes
Waiting time walk-in	95% within 60 minutes

Section 6.3 Results

Table 23 Results of simulation study (1). Weekly frequency of overtime and total weekly overtime (Standard error)

Schedule	Overtime during break (frequency)	Overtime during break (time)	Overtime end of day (frequency)	Overtime end of day (time)
1	6.4 (0.13)	01:22:43 (2:46)	2.4 (0.06)	00:18:58 (0:26)
2	4.6 (0.07)	00:42:32 (1.11)	2.7 (0.05)	00:23:31 (0:39)
3	0.0 (0.00)	00:00:00 (0:00)	3.0 (0.08)	00:24:34 (1:04)
4	4.5 (0.09)	00:43:15 (1:09)	1.2 (0.05)	00:08:28 (0:22)
5	0.0 (0.00)	00:00:00 (0.00)	1.8 (0.06)	00:12:55 (0:30)

Table 24 Results of simulation study (2). Occupancy rates for PA and anaesthetist, with and without finishing files

Schedule	Occupation PA	Occupation Anaesthetist	Occupation Anaesthetist Including finishing patient files
1	0.47 (0.00)	0.72 (0.00)	1.06
2	0.40 (0.00)	0.62 (0.00)	0.92
3	0.40 (0.00)	0.62 (0.00)	0.93
4	0.40 (0.00)	0.47 (0.00)	0.70
5	0.40 (0.00)	0.47 (0.00)	0.70

Table 25 Results of simulation study (3). Referred patients and performance rates

Schedule	Patients referred (full)	Patients referred (closed)	W<20	W<60	Wwalkin <60	Optimal moment	Longer than Optimal	Shorter Than Optimal
1	5.7 (0.35)	18.4 (0.35)	0.842	0.988	0.883	0.826	0.139	0.035
2	1.9 (0.10)	5.0 (0.08)	0.906	0.998	0.929	0.827	0.161	0.012
3	0.7 (0.04)	18.0 (0.09)	0.909	0.998	0.991	0.827	0.146	0.028
4	6.9 (0.35)	4.9 (0.12)	0.892	0.995	0.909	0.830	0.153	0.017
5	4.8 (0.28)	18.4 (0.21)	0.913	0.998	0.991	0.824	0.142	0.034

The results for the simulations are given in Table 23,Table 24 and Table 25 and displayed in Figure 17 Results of simulation (SE = highest standard error)Figure 17. All designed schedules do meet the required targets for waiting times, for both scheduled and unscheduled patients. The schedules that book an extra hour perform better than the initial schedule, possibly because the load can be spread more over the day. Interesting to see is that the schedules with an extra opening hour (2 and 4), have a lower occurrence rate of overtime during the break, indicating that the workload is spread out more over the day. Overtime at the end of the day is lower in general, but the schedules with four resources (4,5) score significantly better. One should note that this only incorporates the consults of patients at the clinic, not the time required to finish patient files.

Two important measures are the referral rate of walk-in patients and the share of patients that has a timely assessment. The referral rates show a large variation between the schedules. The first thing to notice is the correlation with the opening hours. As expected, the schedules with an extended opening time, until 17:00, have a lower referral rate for patients who visit the clinic and arrive at a closed desk. These patients are indicated as walk-in so they are requiring immediate screening. The referral rates for walk-in patients who arrive during the day, the referral rate seems to correlate with the total number of appointment slots. As walk-in appointments are scheduled only on available slots, having more slots seems to create better walk-in opportunities. The results differ significantly.

In the results for the rates of optimal scheduling a similar pattern can be noted. Schedules 2 and 4, which are open until 17:00 have a significantly lower rate of patients seen shorter than optimal. This difference might be explained because about a share of walk-in patients has surgery within 2 weeks. If these patients are referred because the clinic is closed, they are, by definition of the measure, late for screening. The opposite holds for the measure longer than optimal, walk-in patients that live far from hospital are seen almost always the day they are in the hospital, and therefor are counted in this rate. The difference in the rate of optimal scheduled patients is equal for all schedules, indicating that the scheduling policy works well, regardless of the schedule.

The results for occupancy rate show predictable results initially. The rate of the physician's assistant correlates with the opening hours, as there are always 2 PAs presents. They see an equal number of patients in every case. A rate below 50% indicate that one of them is systematically underused. The occupancy rates for the anaesthetist tell a different story. If assumed that the anaesthesiologists do not finish any patient files during the opening hours, the occupation rates vary between acceptable (schedule 1) to underused (Schedule 4 and 5). This reflects the good rate for waiting times, as they are related to the idle time. However, if all finishing patient files is performed during work time without interfering with other activities, schedule 1 offers not enough time to complete all files and anaesthesiologists would work in overtime systematically (p = 1.06). Schedules 2 and 3 use the anaesthesiologists for 91% of the time and Schedules 4 and 5 around 70%.

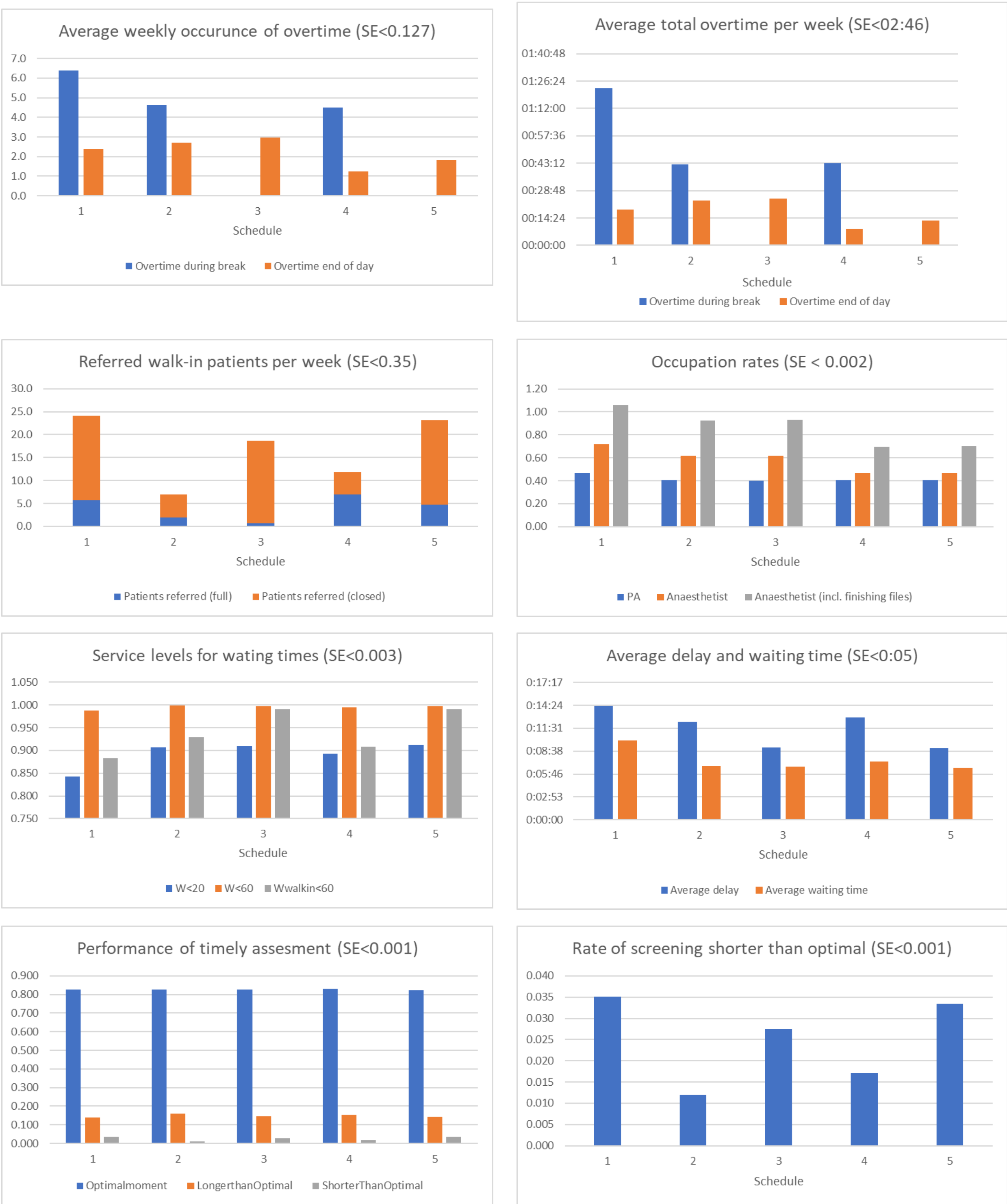

Figure 17 Results of simulation (SE = highest standard error)

Section 6.4 Conclusion

This concludes the research in designing an optimal schedule for the preoperative assessment clinic. The performance is equal in some indicators and differs widely in other measures. Generally, the scheduling rule works well and a significant majority (>95%) is not seen shorter than 2 weeks before surgery. This also implicates that the schedule design method works as expected, as half of all patients are walk-in patients. Many differences in the results reflect the opening times of the clinic, indicating that this might be an important consideration when determining deciding on how the preoperative assessment clinic is redesigned. More on the implications of these results is written in the concluding chapter.

Discussion

An important (inexplicit) assumption in this research is that no distinction is made based on ASA score between patients. The consult times of patients for both caregivers correlate with the ASA score, and thus the consult times between caregivers for a certain patient are correlated as well. By removing this connection, the results are more 'average' and extremes are a bit suppressed. The reason for this is mentioned in chapter 2. There is currently not enough data available to derive accurate distributions for all ASA classes. More on this subject in the general discussion the next chapter.

Many variables that determine performance of the clinic are not considered in this study as they do not reflect performance of the schedule. The punctuality of both patients and caregivers is not accounted for, and neither is the tendency of patients to cancel appointments or reject walk-in appointment slots if they are not willing to wait.

Chapter 7. Conclusion

This chapter first covers the conclusion and a discussion on the results. Next recommendations regarding further improving research and implementations are made and finally the relevance of the thesis is discussed

Section 7.1 Conclusion

The goal of this research was to gain an insight in the arrival of patients at the preoperative assessment clinic and design a schedule blueprint that facilitate the screenings timely. The first part of the research goal was tackled in Chapter 4. Using information from different sources in the hospital information system, it proved it is possible to derive an expected arrival distribution. This data was interpreted using the triage tree to determine when to expect patients who are eligible for walk-in appointments. This information is used to create schedules for the clinic that optimally allocates appointments for walk-in patients. Different schedules are created and evaluated, reflecting design choices the management of the clinic has to make when implanting a new schedule to accommodate timely screening as efficient as possible.

Interesting to see is that the appointment schedules that use 20-minute appointment slots, which were considered before new time measurements came in and revealed the hidden time done during the day, do not perform worse than those with 30-minute appointments. No benchmarking is performed on the results. The results do show that the current staffing and opening times are not optimal when reducing the number of patients referred. Another major drawback of current capacity dimensioning is that not all patient related activities can be done in regular time. Overtime is the most prevalent in this schedule and finishing patient files has to be done in own time, raising the occupation rate of anaesthesiologist over 100%. This does not necessarily be an issue, as long as it is acknowledged and enough time is made available to do this another moment, when not scheduled to work at the preoperative assessment clinic. This is however a decision that is for the management to make.

The other schedules all perform better compared to the initial schedule. The extra hour available allows a better spread of the work load at the clinic, increasing all performance measures. This also allows enough time to perform all tasks within scheduled time. The benefits for opening an extra hour longer seem stronger compared to skipping the break, as more walk-in patients can be seen the same day they arrive, significantly reducing the number of patients who have their assessment performed short before surgery.

The case for all 30-minute appointments is not strong given the results of the simulation. Given the way patients are appointed to appointment slots, the referral rate for unscheduled arrivals is higher compared to the schedules with the same hours and 20-minute appointments. The expected overtime is lower and the occupation rate is, logically, lower, because there is one anaesthesiologist scheduled extra. This is however not worth the increase in staff costs, given the low return in key performance indicators. Considered all results the best performing schedule seems to be schedule 2.

Section 7.2 Discussion and recommendations

This section covers the discussion on the method and offers recommendations to improve the research.

This research does not consider the ASA-class of patients in scheduling. This has a few reasons, first of all there was not enough data for all ASA-classes to derive useful statistics from time measurements.

This resulted in the loss of correlation between the consult time for physician's assistants and the consult time for anaesthesiologists in the simulation study.

Another reason is that the real ASA-score is determined during the consult with the anaesthesiologist. The implication is that is difficult to use the ASA class as indicator for online decisions. The ASA class is however an indicator that the triage tree uses. The idea is that this only covers patients with ASA score I, and they are supposedly easily identified by the operator.

The final reason the ASA score is not used is that because the scheduling model assumes timeslots of equal length. This is not explicitly true, because the model uses the arrival probabilities during intervals and assumes service takes one time slot to complete. This does not prevent generating schedules with different appointment lengths, but interpreting results becomes more difficult and a clear understanding of the method is required to accurately implement and interpret results. Having appointment slot of a single length makes scheduling easier as well.

Several studies showed taking into account ASA class for scheduling patients results in better performance. Considered should be the consequences of falsely assign patients to the wrong appointment slot. Especially when using telephone consuls. To successfully apply ASA scores in decision making before the score is actually determined, accurate models have to be available to correctly classify patient's ASA score. Regarding the time measurements, a possible solution to the lack of measurements is using the hospital information system for collecting this data. This could be implemented because most actions that start or end an activity require an action in the hospital information system. These timestamps can be gathered and used to monitor the processes.

The telephone consults are not considered in this research. First of all, the telephone consult is scheduled like a regular appointment, the patient receives a date and time when to expect a call from an anaesthesiologist. Phone consults are recommended for healthy patients if possible because they are supposed to require less time and no traveling is involved for the patient. Some drawbacks are that assessing is more difficult because the person cannot be seen physically and when wrongly assigned to telephone consult, the patient has to be rescheduled to visit the hospital anyway. Anaesthesiologist do report that the time required for the consult does not necessary shorter, considering not all patients answer the phone, more explanation and more information to gather. The decision to schedule telephone appointments is left to management of the clinic. It is however possible to change any appointment in the schedule with a telephone consult, the difference being that the person does not have to visit the hospital.

The later opening times on Friday proved some difficulties in applying the results of the scheduling method, as appointments are scheduled at fictive times the clinic should be closed. These appointments have to be rescheduled to other moments, decreasing performance of the schedule. The method assumes equal number of timeslots per day. An improvement that should not be too complicated to implement is to make the number of timeslots variable as well. Another addition would be the possibility to implement breaks in the schedule.

Section 7.3 How to proceed

This research presented a groundwork from which the preoperative clinic can design their schedule to provide timely screening to patients. Management of the clinic has to decide on a few issues. Some relate to the results of this study, like opening hours and number of appointments. Other relevant things are if telephone consults are desirable, and how many to schedule. Also, the appointment length can be reconsidered, and decided to offer different appointment lengths. Regarding the scheduling method, it should be understood that the number of appointments scheduled on a given day is the requirement for the number, not the length. If, however length of appointments is increased, the available time for walk-ins is decreased, which in turn increases the referral rate and required number of appointment slots.

Important to notice when implementing the schedule is the dependence of other departments correctly referring patients to the clinic. This requires cooperation from the departments and is crucial for the functioning of the schedule. Too many walk-in patients result in more deferred patients. This might be caused by not following the triage tree, but if operators perceive that there is never any free place, they might stop referring altogether. If there are not enough walk-in patients the schedule might provide too few appointment slots. Either way, monitoring the arrival process will prove crucial for good performance and allows to adjust the schedule if necessary.

As appointments are scheduled already for the next period, a transition phase might be necessary for smooth change of schedule. Additional staff as backup might be required to prevent unforeseen peaks in arrivals to clutter the clinic. Some research has to be performed to examine the backlog and possible problems it might cause when implementing new schedules.

Section 7.4 Value for practice

This research provides great value to practice. It delivers insight in the expected patient flows to the preoperative assessment clinic and concrete schedules that can be implemented to facilitate timely assessment of patients. The researches that make up this thesis can be redone separately to adjust schedules or update insights. This will proof valuable if changes occur over time because patient arrivals change, patient population changes or new activities are introduced in the process. Therefor this is a relevant tool to adjust the schedule to reflect these changes and maintain a good performance, as long as these changes are noticed timely.

Section 7.5 Value for science.

Hospitals generate enormous amounts of data from which interesting insights can be derived. This research shows how it is possible to answer specific questions by combining data and using expert knowledge to relate data and generate new insights. This is not new but given the possibilities of this method it is valuable to show that it is possible to answer logistical questions, based on registrations that are done as part of the patient process.

Science is really good at generating new models for solving problems. This research however shows that excising models can be used with some assumptions, and no new models have to be developed. This research hopefully creates some awareness of these models with the audience they are designed for.

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Appendices

Appendix A. Schedules

All schedules are displayed in bar graphs.

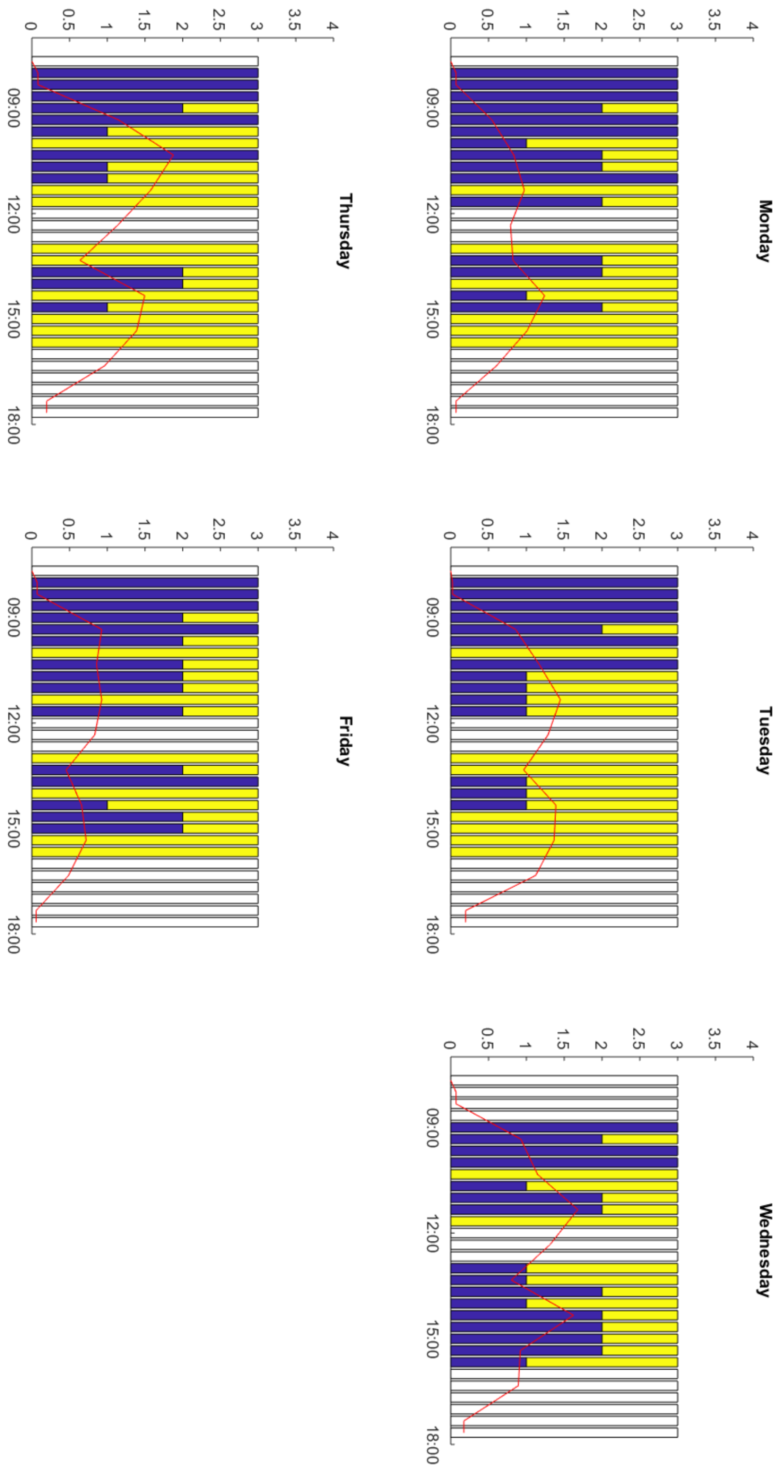
Blue: Scheduled appointment

Yellow: Reserved for walk-in patient

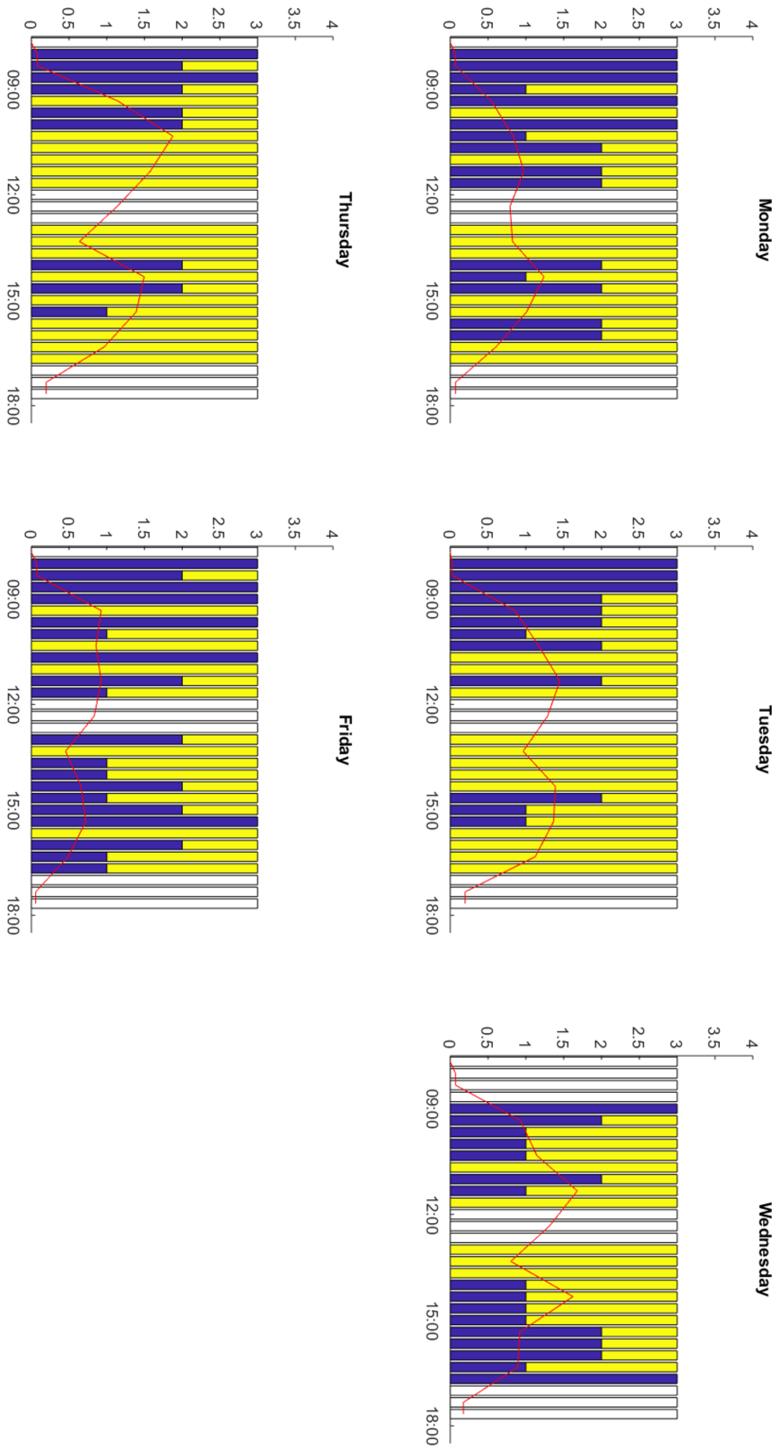
White: Closed (break)

Red: Expected arrival rate during timeslot

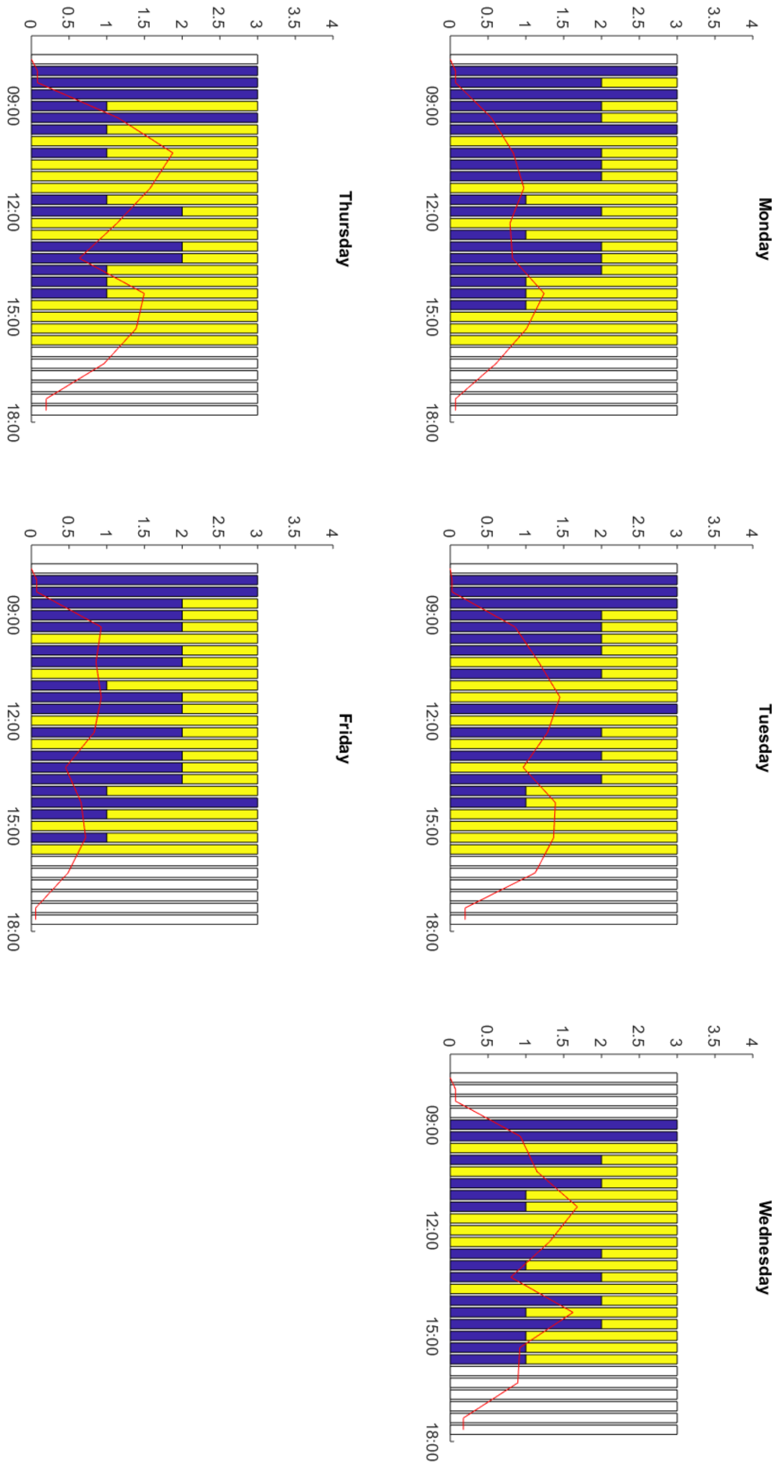
Schedule 1


Monday
Tuesday
Wednesday
Thursday
Friday
09:00
12:00
15:00
18:00
0
0.5
1
1.5
2
2.5
3
3.5
4

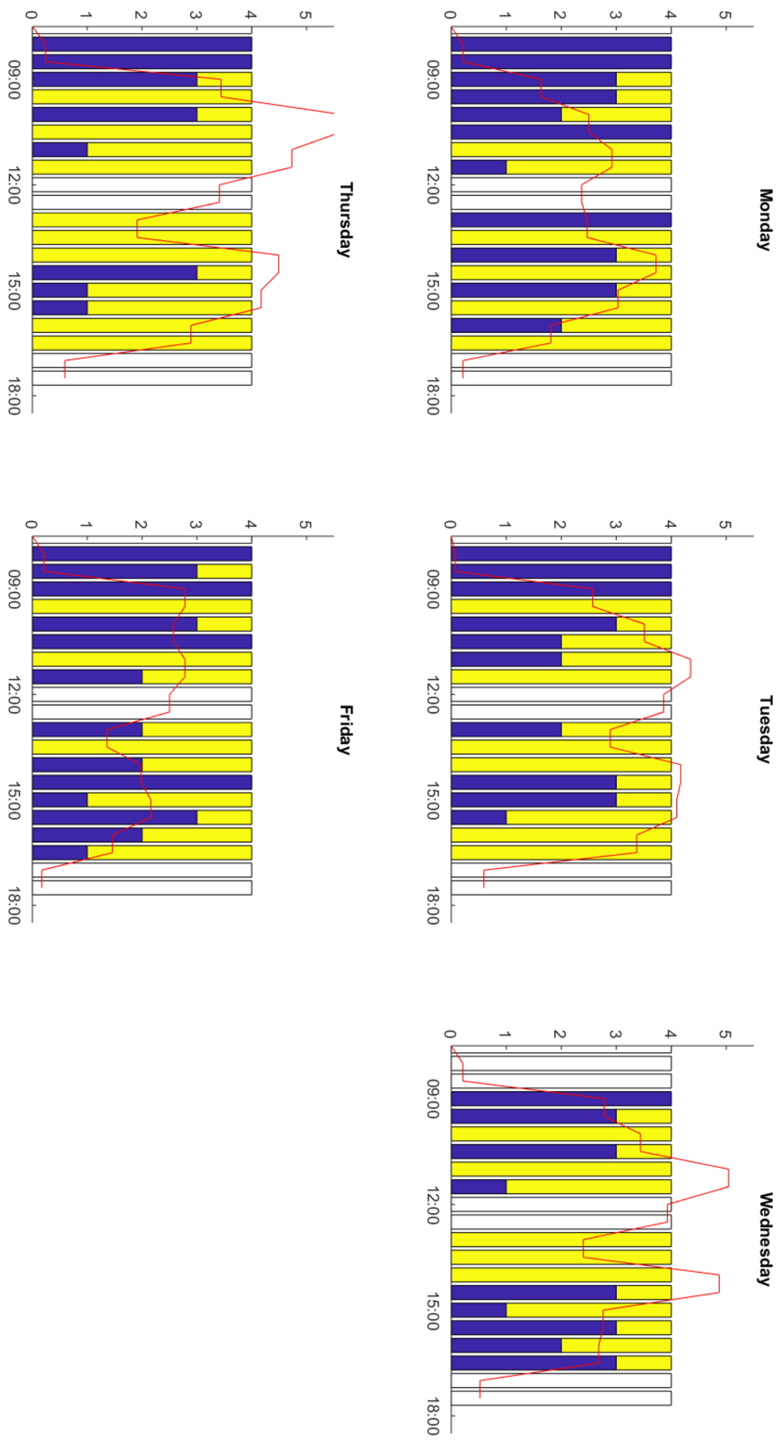
Schedule 2


Monday
Tuesday
Wednesday
Thursday
Friday
09:00
12:00
15:00
18:00

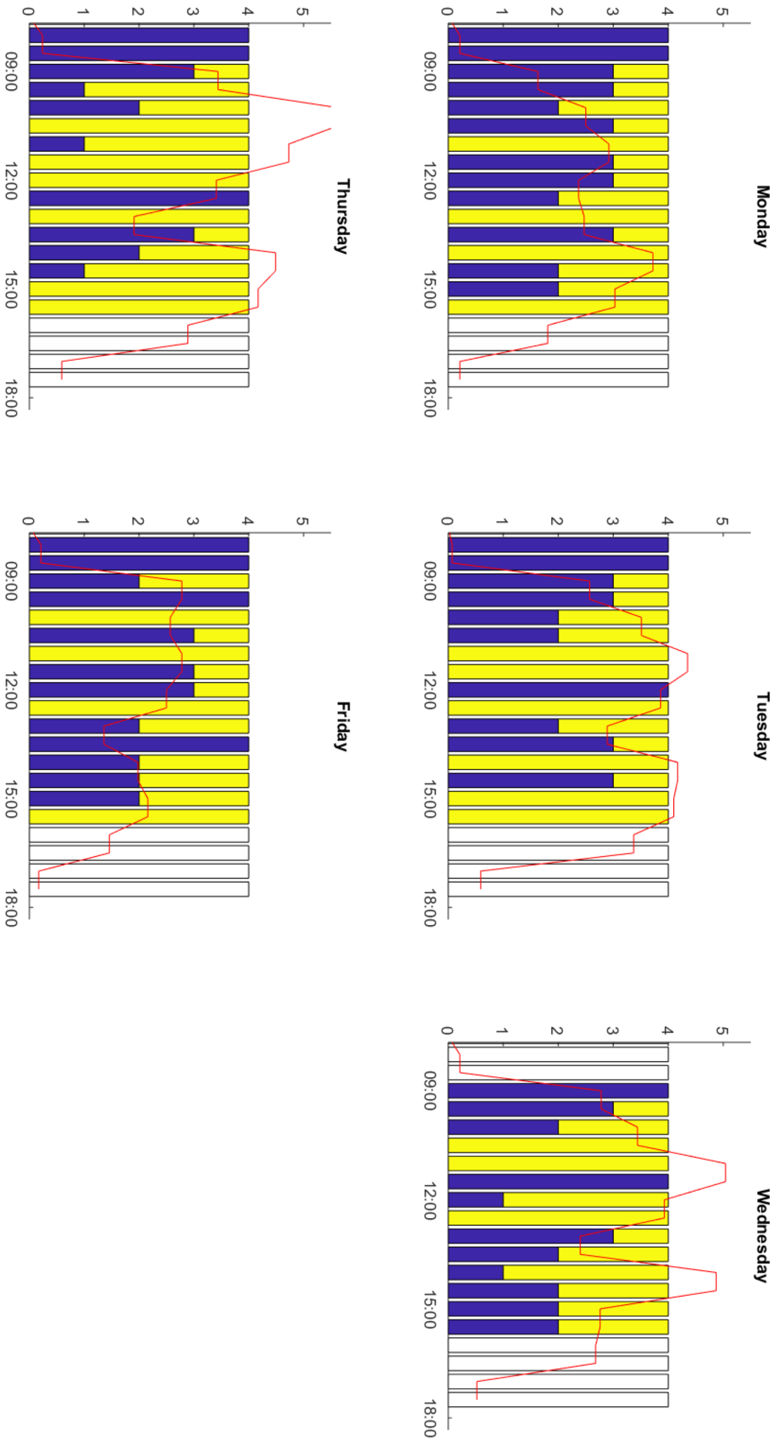
Schedule 3


Monday
Tuesday
Wednesday
Thursday
Friday
09:00
12:00
15:00
18:00

Schedule 4



Schedule 5



Monday
Tuesday
Wednesday
Thursday
Friday
0
1
2
3
4
5
09:00
12:00
15:00
18:00

Appendix B. Simulation model overview