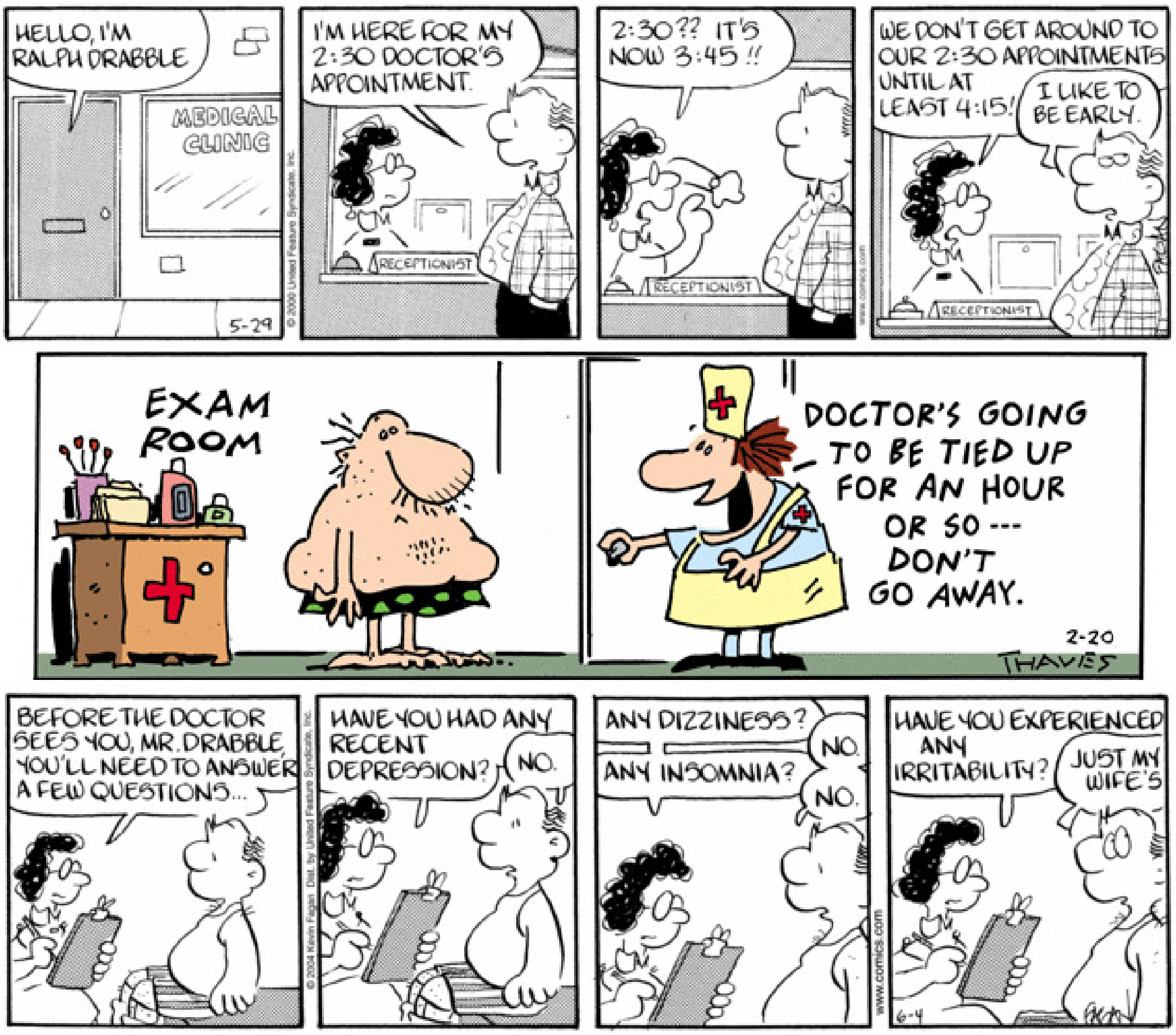
Redesign of the Pre-operative process

A quantitative modeling and optimization study
on process improvements in Isala klinieken, Zwolle



Jeroen Schoenmakers
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Isala klinieken

A study on possible process improvements in the pre-operative process in Isala klinieken, Zwolle

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Summary

Like many other hospitals, Isala klinieken organizes pre-operative screening for surgical patients in an outpatient clinic (PAC). Isala klinieken operates at three locations: two hospitals, “Sophia” and “Weezenlanden”, and one field facility in Kampen. At each location a preoperative screening clinic is present. The screening process involves a visit to the secretary, doctor’s assistant, anesthesiologist, and pre-anesthesia nurse. The pre-anesthesia evaluation clinic receives inflows from almost all specialty departments and is perceived as a potential bottleneck in the pre-operative process, influencing the overall hospital efficiency. Most patients get a screening appointment at the specialty department, and are screened on another day. Increasing waiting times, long access times, non-screened patients, and increasing workload, demands for an improvement in the design and control of the pre-operative process.

In the current design, patients are planned based on their specialty type. All patients are scheduled on 10-minute appointment slots. The appointment schedule slots are divided over more than 20 different slot types. This makes the appointment schedule inflexible to variations in screening demand. To get insight in the actual duration of the screening processes of the PAC we have performed a time registration project. From the data, we show that there is no relation between specialty type and the duration of the anesthesiologist screening. Furthermore, the appointment slot length of 10 minutes is not long enough for a part of the patient mix. We propose to plan patients based on ASA classification [ASA, 2002] (See also Appendix C), since this parameter is correlated to the screening duration. We propose an appointment schedule consisting of 10 and 15-minute slots. The increased workload, long access time, and non-screened patients are also contributed to the shortage of capacity: the number of weekly available appointment slots is smaller than the average number of weekly performed surgeries. The hospital management sees an opportunity to screen patients on basis of walk-in at the PAC. We take this into account in our analysis.

By using a multi class open queuing network model (OQN), we further determine the performance, considering length of stay (LOS), utilization rates, and workload, in the current pre-operative process. The model shows an average LOS of 45-90 minutes depending on the patient class. A large part of this LOS is waiting time. A more important result of this analysis is the robustness of the design. We show that the current design is very sensitive to increased demand and changes in anesthesiologist’s working speed. An increase in demand of 10 %, leads to an almost doubled average LOS. A decrease of 10 % in anesthesiologist’s working speed leads to an increase in average LOS of 35 minutes. This is unacceptable.

Through the analysis of the current design, we develop design and control interventions to improve the performance. Again, we use queuing models, but also event-based simulation models to analyze the performance in a dynamic setting, with varying patient demand. We develop three interventions:

1. *Appointment screening based on ASA classification.*
   We divide the appointment schedule in 10 and 15-minute slots. ASA 1+2 patients are planned in 10-minute slots, ASA 3+4 patients are planned in 15-minute slots. This system requires six hours of extra capacity per week.

2. *Screening based on patient walk-ins*
   ASA 1+2 patients are all seen on a walk-in basis. Due to capacity constraints, 70 % of all ASA 3+4 patients are seen on basis of an appointment outside busy hours. The remaining 30 % is seen on a walk-in basis. We assume that an extra screening day is held at location Weezenlanden on Tuesday, since this is a day with high walk-in demand.

3. *The use of a nurse practitioner (NP) in busy hours.*
   In the walk-in design screening demand fluctuates. In some periods the workload increases. A possibility to deal with this temporarily increased demand is the use of a nurse practitioner, who is allowed to screen ASA 1+2 patients.

In the analysis of these interventions, we show that both an appointment system based on ASA classification and a walk-in system perform better than the current design. Length of stay (LOS) decreases with about 40 % in both system designs. System robustness improves considerably in both systems. Especially an appointment system based on ASA classification shows robust results: an increase in demand of almost 20 % leads to an average increase in LOS of 20%. With a decreased anesthesiologist's speed of 25 %, the average LOS is 45 minutes, which is shorter than in the current design. The improved performance in both systems is partly due to the increase in capacity, but a comparison with the current design with increased capacity also gives better performance for both systems.

In a stakeholder analysis we show the impact of an appointment system and a walk-in system on all stakeholders. From this analysis fundamental questions arise, concerning the performance all stakeholders find acceptable and the costs they are willing to make for this performance. The answers to these questions influence the choice for one of both systems.

To implement one of the designed interventions some changes are necessary. An appointment system requires fewer changes, since the current system already works with appointments. The main change is to plan patients on ASA class instead of specialty type. This requires a new appointment schedule. For a walk-in system, we recommend changes based on the main changes described by Murray (2003). The most important issue is to predict the demand for PAC screening and adapt the capacity over time. This can be done by making service level agreements with the outpatient departments about the outpatient consultation hours and the expected number of screenings, six weeks in advance. By making agreements with all outpatient departments the demand can be predicted over time, and PAC capacity can be set accordingly.

We recommend further research and evaluation of tasks performed at the PAC. In our research we assume the tasks performed at the PAC are fixed. However, the effects of task changes and revised patient flows can be considerable.

Samenvatting

Zoals veel andere ziekenhuizen, organiseert de Isala klinieken de preoperatieve screening voor chirurgische patiënten in een polikliniek. Isala klinieken opereert op drie locaties: twee ziekenhuizen, "Sophia" en "Weezenlanden", en een polikliniek in Kampen. Op iedere locatie bevindt zicht een preoperatieve polikliniek. Het screeningsproces bestaat uit een bezoek aan een secretaresse, doktersassistent, anesthesioloog, en een preoperatief verpleegkundige. De polikliniek ontvangt patiënten van bijna alle specialismen en is een potentiële bottleneck in het preoperatieve proces, invloed hebbend op de algehele efficiency van het ziekenhuis. De meeste patiënten maken een afspraak voor screening op de polikliniek van het specialisme, en worden gescreend op een andere dag. Toenemende wachttijd, lange toegangstijd, niet-gescreende patiënten, en toenemende werkdruk, vraagt om een verbetering van het ontwerp en de sturing van het preoperatieve proces.

In het huidige ontwerp worden patiënten gepland op basis van het behandelend specialisme. Alle patiënten worden gepland op afspraak-slots van 10 minuten. De afspraak-slots zijn verdeeld over meer dan 20 verschillende slottypes. Dit maakt het schema inflexibel voor variatie in de vraag naar screenings. Om een goed inzicht te krijgen in de werkelijke duur van het screenings proces op de preoperatieve polikliniek hebben we een tijdsregistratie project uitgevoerd. Vanuit deze data laten we zien dat er geen relatie is tussen het behandelend specialisme en de screeningsduur bij de anesthesioloog. Verder blijkt dat de geplande afspraaklengte van 10 minuten niet lang genoeg voor een deel van de patiënten. Wij stellen voor om patiënten op basis van ASA classificatie te plannen [ASA, 2002] (Zie ook Appendix C), omdat deze parameter wel gecorreleerd is met de screeningsduur. Hiervoor stellen wij een afspraakschema voor met 10 en 15-minuten afspraak-slots. De toegenomen werkdruk, lange toegangstijd, and niet-gescreende patiënten kan ook worden toegedeeld aan het tekort aan capaciteit: het aantal wekelijks beschikbare afspraak-slots is kleiner dan het wekelijks aantal uitgevoerde operaties. Het ziekenhuis management ziet in een inloopsysteem een oplossing voor de preoperatieve polikliniek. Wij nemen dit mee in ons onderzoek.

Door het gebruik van een multi-klasse open wachtrij netwerk model (OQN) onderzoeken wij verder de prestaties van het huidige ontwerp, kijkend naar de totale doorlooptijd op de polikliniek (LOS), en bezettingsgraad en werkdruk van het personeel. Het model laat zien dat de gemiddelde doorlooptijd 45-90 minuten is, afhankelijk van de patiëntklasse. Een groot deel van deze doorlooptijd is wachttijd. Een nog belangrijkere uitkomst is de robuustheid van het ontwerp. We laten zien dat het huidige ontwerp erg gevoelig is voor toegenomen vraag en verandering in the werksnelheid van de anesthesioloog. Een toename van 10 % in vraag, leidt tot een verdubbeling van de gemiddelde doorlooptijd. Een afname van 10 % in de werksnelheid van de anesthesioloog leidt tot een toename van de doorlooptijd van 35 minuten. Dit is onacceptabel.

Door de analyse van het huidige ontwerp, hebben we interventies ontwikkeld om de prestaties te verbeteren. Om de interventies te analyseren gebruiken we wachtrij modellen, maar ook simulatiemodellen om de prestaties in een dynamische omgeving met variërende vraag te meten. We ontwikkelen drie interventies:

1. *Screening op basis van een afspraak gebaseerd op ASA classificatie.*
   We verdelen het afspraak schema in 10 en 15-minuten slots. ASA 1+2 patiënten worden gepland op 10-minuten slots. ASA 3+4 patiënten worden gepland op 15-minuten slots. De system ontwerp vergt zes uur extra capaciteit per week.

2. *Screening op basis van inloop*
   ASA 1+2 patiënten worden gezien op basis van inloop. Door beperkte capaciteit, wordt 70 % van alle ASA 3+4 patiënten gezien op basis van een afspraak. De andere 30 % wordt gezien op basis van inloop. We nemen aan dat een extra consultatie dag wordt gehouden op locatie Weezenlanden op dinsdag, omdat dit een dag is met een hoge mate van inloop.

3. *De inzet van een nurse practitioner (NP) in drukke uren*
   In een system ontwerp met inloop fluctueert de vraag. In sommige periodes neemt de werkdruk toe. En mogelijkheid om om te gaan met deze tijdelijk toegenomen vraag, is de inzet van een nurse practitioner die ASA 1+2 patiënten mag screenen.

In de analyse van deze interventies laten we zien dat zowel een afspraak system gebaseerd op ASA classificatie, als een inloop system beter presteert dan het huidige system ontwerp. De doorlooptijd neemt af met ongeveer 40 % in beide system ontwerpen. Systeem robuustheid neemt aanzienlijk toe in beide systemen. Vooral een afspraak systeem gebaseerd op ASA classificatie laat robuuste resultaten zien: een toename van de vraag van bijna 20 % leidt tot een gemiddelde toename van 20 % van de gemiddelde doorlooptijd. Een afname van de werksnelheid van de anesthesioloog van 25 % leidt tot een gemiddelde doorlooptijd van 45 minuten, die korter is dan in het huidige systeem ontwerp. De verbeterde prestaties in beide systemen kan gedeeltelijk worden toegewezen aan de extra capaciteit, maar een vergelijking met het huidige systeem inclusief extra capaciteit laat zien dat beide systemen nog steeds beter presteren.

In een stakeholders analyse laten we zien wat de invloed is van een afspraak system en een inloop systeem op alle stakeholders. Uit deze analyse komen fundamentele vragen naar voren, betreffende de prestaties acceptabel voor alle stakeholders en de kosten die zij er bereid zijn voor te maken, die de keuze voor een van de twee systemen beïnvloedt.

Om een van beide systemen te implementeren zijn veranderingen noodzakelijk. Een afspraaksysteem vergt minder veranderingen, omdat het huidige system ontwerp al werkt op basis van afspraken. The hoofdzakelijke verandering die moet plaatsvinden is het plannen van patiënten op basis van ASA klasse in plaats van behandelend specialisme. Dit vereist een nieuw afspraakschema. Voor een inloop systeem, raden we een aantal veranderingen aan die gebaseerd zijn op de punten beschreven door Murray (2003). Het belangrijkste punt is om de vraag naar patiënten screenings te kunnen voorspellen om de capaciteit hierop af te kunnen stemmen. Dit kan gedaan worden door het maken van afspraken (service level agreements) met de specialismen voor de komende zes weken, betreffende de poli-uren van de specialismen and de verwachte patiëntenstroom van de polikliniek naar de preoperatieve kliniek. Door deze afspraken met de specialismen kan de vraag naar screenings over de tijd worden voorspeld, en kan de capaciteit in de preoperatieve kliniek daarop worden afgestemd.

Verder onderzoek en evaluatie van uitgevoerde taken op de preoperatieve kliniek wordt aangeraden. In ons onderzoek nemen wij aan dat de taken die uitgevoerd worden op de preoperatieve kliniek vast staan, hoewel de effecten van taakveranderingen and veranderde patiëntstromen aanzienlijk kunnen zijn.

Abbreviations and terminology

ASA Score A six category physical status classification system for assessing a patient before surgery, established in 1963 by the American Society of Anesthesiologists (ASA) [ASA, 2002]. See also Appendix C.

Eridanos Electronic patient record system developed in-house at Isala klinieken.

IVAS Electronic billing system, in which all consultations are registered to handle the financial side of a consultation. Used to find the number of screenings.

LOS The length of stay (LOS) is defined as the total duration a patient is present at the PAC for one screening.

MCC Electronic planning system of the operating theatre at Isala klinieken.

Nurse Practitioner A nurse practitioner is a registered nurse who has completed advanced nursing education and training in the diagnosis and management of common medical conditions [Nurse Practitioner, 2008].

OPD Outpatient department. Department where the specialist sees patients.

PAC Pre-anesthesia evaluation clinic. The PACs of Isala klinieken are the central topic in this research.

Ultragenda (UG) Electronic appointment system, in which the secretaries of the outpatient departments make appointments for patients. Also used to make appointments at the pre-anesthesia evaluation clinic.

List of symbols

Symbol	**Definition**
c_i	The number of available staff at station *i*
e_i	Effective capacity of station *i*
$E(L)$	Total number of patients present in the system
$E(L_i)$	Mean number of patients at station *i*
$E(L_{Q,i})$	Mean number of patients in the queue at station *i*
$E(S_i)$	Mean average consultation time at station *i*
$E(S_{p,i})$	Mean consultation time of patient class *p* at station *i*
$E(V_p)$	Mean length of stay at the PAC for patients of patient class *p*
$E(W_{q,i})$	Mean waiting time at station *i*
η_p	Arrival rate of patient class p
λ_i	Aggregated arrival rate at station *i*
N	Total number of patients
n_p	Number of patients of patient class *p*
$P_{3,4}$	Fraction of the patients at station 3 flowing to station 4
$Q_{p,1}$	Portion of arrival flow into station 1 originating from arrival flow patient class *p*
ρ_i	The utilization rate of station *i*
$\rho_{i,r}$	The utilization rate of station *i* for patient class *p*
$SCV_{A,i}$	Squared coefficient of variation of the arrival rate at station *i*
$SCV_{A,p,1}$	Squared coefficient of variation of the arrival rate of patient class *p* at station 1
$SCV_{D,I}$	Squared coefficient of variation of the departure process at station *i*
$SCV_{S,i}$	Squared coefficient of variation of the consultation time at station *i*
$SCV_{S,p,i}$	SCV of the consultation time of patient class *p* at station *i*
$STD(S_{p,i})$	Standard deviation of the consultation time of patient class *p* at station *i*

Preface

By finishing this thesis, I have completed a project and experience that I have enjoyed very much. Maybe even more important, I have completed my Master Industrial Engineering and Management at the University of Twente. After six years (and a few months) of studying in Enschede, I close another chapter in my life. A chapter full of experiences: both study and non-study related. I found my passion for sailing at D.Z. Euros (the main reason for some delay in my study progress), learned how to organize in the board of Euros, learned a lot about baggage handling during my Bachelor Thesis at Amsterdam Airport Schiphol, and finally got to know why I chose for Industrial Engineering and Management in the first place, during the last two years of Master courses (with a big influence by Erwin Hans! Thanks for that!).

It were the Master courses of the department OMPL that made it clear for me I really wanted to do a graduation project involving logistical planning, modeling, simulation, and programming. With this in mind, I found a very interesting research project, through Erwin Hans, at the Isala klinieken. The content of this research is described in this report. I am proud of the research and the results! I thank all the people without whom I could not have completed this research. The people below I thank in particular.

First of all, I would like to express my gratitude to Erwin Hans and Martijn Mes, who were willing to become my supervisors. They helped me with working systematically, creating clarity in my mind when I needed it, and critically reviewing my work. I look back on a very enjoying collaboration, which has learnt me a lot for my future work.

I would not have been able to perform this research without the help of Bernd van den Akker. He made it possible for me to do my research at Isala klinieken and was willing to be my supervisor on behalf of the hospital. I thank him for giving direction to my research and introducing me to people in the organization. Dennis Buitelaar also played an important role in this. The daily lunches, coffee breaks and interesting discussions about hospital management in general were very amusing. Bernd and Dennis, thanks for that! I also thank my roommate Ingmar for the fun moments we had, in between work, discussing the stock market, figuring out tactics during the virtual Volvo ocean race (insiders know what I am talking about..), and listening to the daily radio shows.

A lot of people in the hospital have helped me in understanding the preoperative process and have helped me gather the necessary data for this research. Dr. Snel, Sjoerdtje Bergmans, and Simone Runhart have helped me on behalf of the pre-anesthesia clinic, providing a lot of information, and helping setup a time registration project. Without their help, a lot of crucial information would have been a lot harder to gather. Niels van Dam has provided a lot of the data I have used. Thank you! I thank Maartje Zonderland from the Leiden University Medical Centre for her input on my queuing models.

I will always look back at my studying life with a smile. Thanks to all my friends at Euros, I have spent a lot of time on the water, competing in European and World championships, and crossing the English Channel several times by sail. This was fantastic and I will certainly stay involved with Euros. Thanks to all my friends from Hoogeveen, for the nights on the town in Enschede, and the unforgettable skiing trips. Of course, this great time would not have been possible without the help of my parents, sister and brother. I thank my parents for giving me the possibility to study in my own way, always helping me when necessary. Last but certainly not least, I thank my girlfriend Lisette for all her help!

Zwolle, December 2008
Jeroen Schoenmakers

Contents

Chapter 1

Introduction

Like many other hospitals, Isala klinieken organizes pre-operative screening of patients scheduled for surgery in an outpatient clinic. This clinic receives patient inflows from almost all specialty departments and is a potential bottleneck in the pre-operative process, influencing overall hospital efficiency. Increasing waiting times for patients and increasing workload for staff demands for an improvement in the design and control of the pre-operative process. Using operations research techniques, like queuing techniques and discrete-event simulation, we analyze the pre-operative process, leading to recommendations for the optimized control and design of this process.

Keywords: Operations research, multi class open queuing network, simulation, pre-operative anesthesia clinic, patient flow

This chapter describes the background of our research, followed by the context in which we perform our experiments. In Section 1.2 we elaborate on the problem, leading to the research objective and research questions.

1.1 Background

This research was initiated by the Operating Room & Intensive Care (OR&IC) department of Isala klinieken Zwolle. The management is confronted with inefficiency in the pre-operative process leading to long access times and high workload for staff. In today's setting of a new social healthcare system, ageing society, long waiting lists and increasing competition between healthcare institutions [Hans, Nieberg, van Oostrum, 2007], efficiency within the hospital becomes more and more important. Our research focuses on the design and control of the pre-operative process at Isala klinieken.

1.1.1 Isala klinieken

In 1998, Isala klinieken Zwolle was formed by the merger of two hospitals: the hospital "Sophia" and the hospital "Weezenlanden". Isala klinieken is the largest non-academic hospital in The Netherlands with 5.900 employees (over 3900 FTE) and 1.000 beds. Each year, Isala klinieken attends to more than 475.000 outpatient visits and 40.000 admissions. The mission of the hospital is to "be an innovative top-class hospital offering high quality care for a favorable price". Aside from primary care, Isala klinieken offers top clinical care and serves as an educational hospital [Isala, 2007a].

1.1.2 The pre-operative process

This research focuses on the pre-operative process. We define the pre-operative process as the process from an outpatient department (OPD) through the pre-operative department up to the operating theatre. Figure 1.1 gives an overview of the focus of the research in relation to the other hospital departments.

After being sent to the hospital by their general practitioner the first appointment patients have is at the OPD. At this department the patient is seen by the specialist who diagnoses the patient and decides whether surgery is necessary. When patients need surgery, they have to visit the pre-operative department. For this visit an appointment is made by the OPD secretary through a central appointment system, named Ultragenda (UG). The pre-operative department consists of a pre-anesthesia evaluation consult and a nurse consult. The pre-anesthesia evaluation consult is intended to obtain a thorough understanding of the physical condition of the patient. To decrease the risk of surgery for the patient as much as possible the anesthesiologist proposes additional measures to improve the physical condition of the patient and discusses the surgical procedure and the anesthesia. The nurse consult is intended to discuss postoperative matters with the patient, such as home care. In the literature, the pre-operative department is often referred to as the 'pre-anesthesia evaluation clinic' (PAC). This term does not entirely apply to our setting, since the pre-operative department also performs the nurse consult which is not part of the pre-anesthesia evaluation. Nevertheless, we use the term 'pre-anesthesia evaluation clinic' referring to the pre-operative department. After the patient is approved for surgery by the pre-operative department the patient is put on a waiting list and scheduled for surgery. In some cases the patient is admitted on the ward before surgery. A pre-operative screening is valid for all surgeries performed on the patient within half a year.

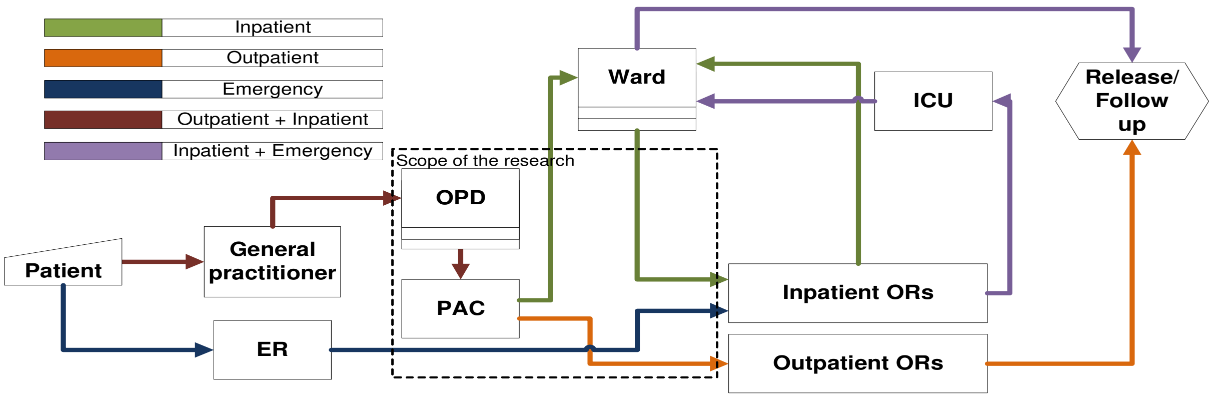

Figure 1.1: Scope of the research within the clinical path

1.2 Problem description

In the past, several optimization efforts have been made in the hospitals of Isala klinieken, focusing on the processes within a certain department. Studies including more than one additional department either upstream or downstream have thus far not been performed in Isala klinieken. Although optimization studies may lead to performance improvements locally, it does not necessarily improve the performance of the clinical path as a whole. The problems in the pre-operative process are caused by the synchronization in the clinical path as a whole.

In February 2007, the Inspection of Healthcare (IGZ) published a report describing the flaws of the pre-operative processes in Dutch Hospitals [IGZ, 2007]. The main conclusions are:

- There is little or no standardization of the procedures involved in the provision of information.
- The transfer of information is inefficient and there is no full cooperation between all care providers.
- Communication with the patient is too limited and is inadequately reported in the medical file.
- The manner in which medical files are completed and the related reporting procedures are extremely varied and incomplete.
- Early planning of the date of surgery on the part of the treatment team reduces the complexity of the process and offers immediate clarity with regard to logistics.

These conclusions are in line with important supply chain components identified by Lambert and Cooper (2000). An earlier visit of the IGZ in 2005 and 2006 revealed the same flaws at Isala klinieken. Following this general report and the IGZ visit, a project team was formed to perform an extensive analysis of the pre-operative process in Isala klinieken. One of the conclusions of this analysis was that there is a lack of synchronization of the capacity and planning of the involved departments in the pre-operative process. Waiting lists for surgery are decreasing due to optimization of the surgical processes. As a consequence, the PAC is forced to screen more patients in a shorter time frame. The way the capacity of the pre-operative department in the current design is used is no longer sufficient. A redesign of the pre-operative process is deemed necessary. We formulate the main problem that is relevant for this research:

Deteriorating performance in the pre-operative process leads to extended waiting time and non-screened patients

1.3 Research objective and approach

From the analysis the Isala project team performed in 2007, several recommendations have been made. We take these recommendations into accounts as a starting point for this research. The recommendations made by the project team are:

- To develop connections between information systems such that correct and automatic information transfer between disciplines in the pre-operative process is guaranteed.
- To facilitate the steering function of the main physician in the pre-operative process through agreements and aforementioned connections.
- To develop a clear admission and pre-operative policy towards inpatients and outpatients and define clear moments in the pre-operative process of informing the patient.
- To synchronize the planning and capacity of the PAC with the planning and capacity of the operating rooms.
- To redesign the pre-operative process and the control of this process in such a way that the following steps are performed in one patient visit for at least 80% of all surgical patients:
  - The OPD consult
  - The pre-anesthesia evaluation consult
  - The nurse consult
  - The date of the patients' surgery

  In practice this means the pre-anesthesia evaluation consult and the nurse consult should be based on open access schedules.

Our research takes a logistical perspective, hence we focus on the last two recommendations.

As such, we have the following research objective:

To achieve performance improvements of the pre-operative process by effective and efficient capacity management

To reach this objective we pose the following research questions:

1. *How is the pre-operative process organized, and what is the current performance?*

We define and map the current pre-operative process, identify patient groups and analyze the duration of the process steps. In collaboration with stakeholders in the hospital we define performance measures. By gathering and analyzing data, we can provide insight in the current performance of the pre-operative process. This is discussed in Chapter 3.

2. *What suitable design and control interventions can be developed for the pre-operative process?*

From the literature discussed in Chapter 2, input from the stakeholders in the hospital, and brainstorming we develop interventions that might improve performance of the pre-operative process (Chapter 4). We first concentrate on analyzing and streamlining the capacity demand and planning. Second, we focus on the analysis of a possible open access scheduling setup (Chapter 5).

3. *What quantitative modeling approaches are suitable for the analysis of proposed design and control interventions?*

To be able to analyze several design and control interventions we use mathematical modeling techniques. Based on the interventions developed, several modeling techniques may be necessary (Chapter 4).

4. *What is the performance of the various developed interventions?*

We evaluate the interventions developed through suitable modeling approaches. We describe the model and the assumptions made while modeling and the input in Paragraph 4.2 and Paragraph 4.3. Furthermore the output of the model is described and the model is validated (Chapter 5). From the computational results we can evaluate the interventions, draw conclusions, and give recommendations.

5. *How can we implement the developed interventions?*

We advise the hospital how to implement the developed interventions and realize actual performance improvements (Chapter 6).

Now that we have formulated our research questions, we focus on the literature relevant for this research (Chapter 2), and the analysis of the current preoperative process (Chapter 3).

Chapter 2

Literature review

This chapter reviews the literature studied. Paragraph 2.1 introduces a framework in which we can position the capacity and planning issues. Paragraph 2.2 reviews articles in which healthcare models over several departments are developed. Furthermore, we take a closer look at the concept of pre-operative screening and applications described in the literature (§2.3), and scheduling concepts, such as open access (§2.4). The application of simulation techniques is discussed in several articles over all paragraphs. The mentioned literature and described concepts form a basis for our research.

2.1 Framework for hospital planning and control

Research in hospital environments is diverse and complex. To determine the position of this research we introduce the hospital planning and control framework (Figure 2.1) proposed by Hans, van Houdenhoven, and Wullink (2006). Horizontally four categories of managerial areas are defined: medical planning, resource capacity planning, material coordination, and financial planning. Medical planning deals with the coordination and planning of medical activities and is done by healthcare professionals. Resource capacity planning focuses on the planning and control of resources such as staff, ward beds, etcetera. Material coordination is the coordination of hospital materials. Financial planning deals with the coordination of financial aspects of the hospital processes. This research focuses on resource capacity planning. Decisions made in the medical planning area form restrictions for this research.

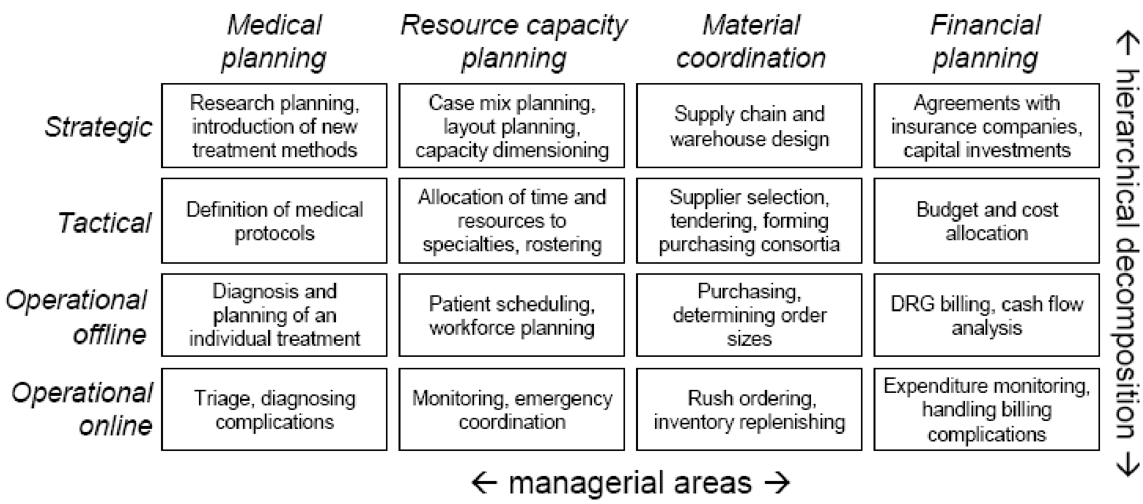

Figure 2.1: Framework for hospital planning and control [Hans, van Houdenhoven & Wullink, 2006]

Next, we introduce the different levels of planning and control, and position the different levels of resource allocation in the pre-operative process in this framework. The framework distinguishes three levels of planning and control: strategic, tactical, and operational level. Strategic decisions are made for the long term (1-5 years). These decisions involve the capacity dimensioning and the patient mix. The decisions are made by the board, the care group manager, care team managers, and medical professionals and are known at the beginning of this research (see Chapter 3). At a tactical level we decide how capacity is used and divided over different patient groups. These decisions can be evaluated on a shorter time frame (years or months) and are made by the care team managers and the medical professionals. Operational decisions are made for the short-term (days-weeks). The operational level distinguishes offline and online decisions. Offline decisions concern patient and staff scheduling. Online decisions deals with the daily coordination of processes, in which unanticipated events, such as emergency surgeries occur. These decisions are made by the medical professionals. The articles discussed in this chapter focus on resource capacity planning.

2.2 Hospital patient flow modeling

In 1999, Jun, Jacobsen, and Swisher completed a survey of discrete-event simulation models in health care citing over 100 articles and discussing the various applications in clinical settings. They focus on articles that analyze single of multi-facility healthcare clinics. In their survey, they conclude that there are a limited number of articles that report on using simulation to study complex integrated systems. They suggest this is due to the complexity and resulting data requirements of the simulation model, and the necessary resource requirements. Studies in multi-facility models they mention are [Rising et al., 1973; Aggarwal & Stafford, 1976; Hancock & Walters, 1984; Swisher et al., 1997].

Swisher et al. (1997) examine the construction and implementation of a simulation model that supports the design and development of the Queston Physician network in the United States. This network consists of clinics located throughout the United States. The network manages all non-medical operations for the clinics, such as patient scheduling and billing. The model consists of generic building blocks which represent the clinics. Accordingly, generic patient groups and flows are defined. The model aims to maximize the utilization of resources. Through the use of several scheduling rules, experiments have been performed. The model shows that the clinical environment is very sensitive to small changes in patient mix and scheduling rules. Our model evaluates scheduling rules and changes in patient mix.

In 2007, Fletcher and Worthington performed a survey under several authors and a literature review in which they try to define the characteristics of generic hospital models. Their literature review found many examples of models of individual departments, but a much smaller number of multi-departmental models. From the results of the survey and literature review they define four levels of modeling in descending order of abstraction and transportability: (1) a broad, generic model that is not setting specific and can be transferred across industries, (2) a generic framework that could be developed into a toolkit, (3) a setting-specific generic model that can be used by any provider of the same service, and (4) a setting-specific model that is not transportable to another provider of the same service. We aim to develop a setting-specific generic model over multiple departments.

Moreno et al. (1999) discuss a generic hospital simulation model to show the movements of patients through a whole hospital, with interactions with human resources and interventions from hospital management. Design issues and issues of generalizability are discussed. No specific examples are discussed. Harper (2002) presents a framework for modeling whole hospitals. Important issues identified include: complexity, demand uncertainty, variability, and limited resources. Pitt (1997) describes a generic simulation modeling framework with the West Yorkshire health authority in the United Kingdom. The case study focuses on usage and allocation of beds. The potential benefits of better patient flows and the importance of interdepartmental relationships within a hospital are stressed by Haraden and Resar (2004). Optimization of individual departments often leads to bigger problems for dependant departments. Furthermore, they present the concept of natural variation (patient arrivals, randomness of disease, and competencies of staff) and artificial variation (preferences of staff, (mis)management of processes). The authors state that “the effect of artificial variation on flow far exceeds the effect of variation resulting from random, highly complex disease presentations”. For this reasons, design changes have to be made to eliminate this artificial variation as much as possible.

As becomes clear by the literature reviews of Jun, Jacobsen and Swisher (1999), and Fletcher and Worthington (2007), a lot of examples can be found of models of individual departments. The perceived importance and influence of these individual departments on the hospital as a whole are often discussed. Belien, Deulemeester and Cardoen (2006) state that the operating room can be seen as the engine that drives the hospital. Outpatient clinics can improve patient satisfaction when run efficiently [Huang, 1994]. Unlike most departments of a hospital, which are designed to treat patients with particular disorders, diagnostic departments are utilized by almost all patient categories which enter the hospital. Hence, efficient utilization of these departments is a necessary condition for overall hospital efficiency. O'Kane (1981) emphasizes this for a radiology department. A PAC can be viewed in the same way.

We aim to include the relationships between the OPD, PAC and OR capacity planning and investigate the influence of these relationships on the performance of the pre-operative process as a whole.

2.3 Origin and organization of pre-anesthesia evaluation clinics

In this paragraph we discuss the concept of pre-anesthesia evaluation clinics and look at the literature discussing PAC design and control interventions. We take the ideas outlined in this literature into account when developing interventions for the PAC at Isala klinieken.

The concept of pre-operative screening in an outpatient clinic was first described by Lee in 1949. The author states that the purpose of the clinic is "to examine and treat the patient, so that he/she arrives in the operating theatre as strong and healthy as possible". The main advantage of opening a PAC is the improvement in the surgical preparation of the patient. The anesthesiologist evaluates the patient in an earlier stage and therefore can optimize the patient's condition for surgery if necessary. He can also reassure patients about the surgery and discusses the anesthetic history. Lee also argues that the anesthesiologists would have a further contribution to make to the recovery and rehabilitation of the patient after surgery if they make themselves competent to run such a department efficiently.

Frost (1975) describes the experiences and results of a PAC in the Bronx Municipal Hospital Center which started in 1972. The author states that the reasons for founding a PAC are reducing hospital length of stay for the patient, and reducing hospital costs. Experiences are positive, both pre-operative and total length of stay have been significantly reduced, patients feel better informed about their anesthesia, bed utilization has improved, and less surgery cancellations occur.

It was not until the 1980s that there was a paradigm shift to an outpatient pre-anesthetic screening [Orkin, 1996]. This shift is attributed to changes in health costs reimbursement in the United States and the growing popularity of elective and same-day admission surgery.

The most important reasons to found a PAC, identified by Lew, Pavlin, and Amundsen (2004), are reducing the expectation of death during surgery, increasing the quality and decreasing costs of peri-operative care, and returning the patient to desirable functioning as quick as possible. Pollard (2002) argues that with the founding of a PAC cost decreases are achieved by less testing and consultation. Excessive testing and consultations lead to patient injuries and significant delays. However, the largest gains in cost savings are associated with shorter lengths of stay.

The American Society of Anesthesiologists (ASA) (2002) (See Appendix C) defines pre-anesthetic evaluation as "the process of clinical assessment that precedes the delivery of anesthesia care for surgery and nonsurgical procedures". At a minimum, it includes an interview and examination of the patient, a review of the patient's medical records, pre-operative testing when indicated, and other specialist consults when necessary. The pre-anesthetic evaluation takes place from two to thirty days before surgery [Lew et al., 2004] or even on the day of surgery [ASA, 2002]. Pollard and Olsen (1999) state the OR cancellation rate of outpatients is not significantly influenced by the time of pre-anesthetic evaluation. Elective patients evaluated within two to thirty days before surgery were compared to elective patients who received their anesthesia evaluation within 24 hours before surgery. Both groups had similar OR cancellation rates.

At the annual meeting of the American Society of Anesthesiologists in 2005, Holt et al. (2007) held a survey to get an overview of the overall use and perceived effectiveness of PACs. The survey shows that PACs are common in healthcare institutions (69% of the respondents work at a healthcare institution which has a PAC). They conclude that further research concerning PACs is needed, since the day-of-surgery delays remain relatively common due to patient information transfer failure and lack of consensus on criteria for surgical readiness.

Lew et al. (2004) argue that it would be cost effective to evaluate only patients who truly require it. The health screening questionnaire has been validated as a useful tool for determining the need and timing for PAC evaluation, the level of expertise required in the evaluation and the risks of anesthesia [Badner et al., 1998]. In this way patients can be classified into three categories: requiring no further review or review via telephone; requiring pre-anesthesia evaluation at the clinic; requiring review of questionnaire by an anesthesiologist, pending further action. In some settings, this has allowed up to 90% of the surgical patients to bypass the PAC.

Lew et al. see a trend towards anesthesiologist-directed, nurse-led pre-anesthesia evaluation. This trend is mainly driven by cost effectiveness. Studies by Fischer (1996) and Pollard, Zboray and Masse (1996) show that anesthesiologist-directed, but nurse-led PACs are feasible without compromising patient safety. In these clinics the health screening questionnaire plays a valuable role in enhancing patient safety by identifying patients who require further evaluation and optimization by an anesthesiologist or specialist [Koay & Marks, 1996].

With the growing use of PACs more literature about the implementation and experiences has been written. Fischer (1996) describes the development and implementation of a PAC at the Stanford Medical Center in California, The United States. In this medical centre the surgeon refers the patient to the PAC if he has hesitations about the patient's pre-operative status. Patients with ASA status 1 or 2 are evaluated by a registered nurse practitioner. The anesthesiologist evaluates patients of all ASA classifications. Results demonstrated a decrease in pre-operative consultations. Furthermore, the economic aspects of a PAC are discussed. Pollard, Zboray and Mazze (1996) extensively discuss the economic benefits of a PAC. Conway, Goldberg and Chung (1992) describe the results of the implementation of a PAC in the Toronto Hospital in Toronto, Canada. Again, the choice for referral to the PAC is made by the specialist and not seen as an obligatory examination before surgery. In other cases all patients are referred to the PAC [Klei et al., 2002; Rutten, Post & Smelt., 1995a; Frost, 1975]. Rutten, Post and Smelt (1995a) discuss the implementation of a PAC in hospital de Weezenlanden in Zwolle, The Netherlands. They especially study the effect of a PAC on the volume of laboratory and function tests, and on the pre-operative hospital days. The authors conclude pre-operative screening in a PAC leads to reduced volumes of laboratory test, ECGs and X-rays. Furthermore, it reduces the number of pre-operative hospital days and improves the anesthetic care. In a second article concerning the same hospital Rutten et al. (1995b) investigate patient satisfaction after the implementation of a PAC. Pre-operative screening in a PAC was preferred over the old situation by 56% of all patients who remembered the interview with the anesthesiologist. Klei et al. (2002) evaluate the possible effects of pre-anesthesia evaluation in a PAC at the University Medical Center Utrecht in Utrecht, The Netherlands. The main outcome measures were surgical cases cancelled for medical reasons, rate of same-day admission, and length of hospital stay. They conclude that the introduction of a PAC lead to improvements on all three outcomes, although these improvements were smaller than anticipated. Further benefits of a PAC are expected when the PAC is fully incorporated in existing practice patterns.

The redesign of the pre-operative evaluation process in the Cleveland Clinic Foundation in Cleveland, The United States, is discussed by Parker et al. (2000). With steadily increasing surgical patient volume, performing a traditional anesthetic pre-operative evaluation for every patient was no longer possible. After the redesign, a pre-operative assessment computer program was introduced that performs a first triage. The computer program scales patient from one to four (analogue to the ASA classification) based on answers given by the patient. Patients with the lowest health risk undergo their pre-anesthetic evaluation on the day of surgery. All other patients are evaluated in the PAC. In the PAC only pre-operative evaluation is executed, optimization of patients for surgery is done elsewhere. The redesign resulted in a 34% increase in outpatient surgery, 49% decrease in pre-operative surgical delay resulting in shorter average length of stay, and a cost reduction. These results emphasize the benefits of a triage system.

With this research, we aim to contribute to the existing literature about PAC redesign, through the analyses of several design and control interventions. Most research uses one modeling technique to perform analyses. We use both queuing theory, and event-based simulation models to perform the analyses.

2.4 Patient scheduling and the concept of open access

Patient scheduling within the hospital has been subject of much research. The drive to reduce waiting time and access time for the patient and the efficient use of medical resources has lead to new patient scheduling techniques. Singh (2006) discusses the use of queuing theory in healthcare organizations. “Queuing theory application is an attempt to minimize the costs through minimization of inefficiencies and delays in the system”. These costs include tangible and intangible costs such as capacity costs and waiting costs. A trade-off between capacity and service delays will always be necessary.

Not much research has been performed concerning patient scheduling and appointment issues in PACs. Dexter (1999) and Edward et al. (2007) are two examples of research about patient scheduling in a PAC. Several articles are available that cover these issues in an outpatient context. Since the PAC has similarities with outpatient clinics these articles can be relevant.

In The Netherlands, several projects concerning patient scheduling have been set up by CBO, the Dutch quality institute for healthcare. They investigate possibilities to reduce access times and improve care for outpatient clinics [CBO, 2005]. In 2008 a similar project for diagnostic clinics started, such as radiology, the laboratory and the PAC [CBO, 2008]. Basic principles used in these projects are: (1) demand and supply synchronization taking seasonal influences into account, (2) delegation of tasks by the use of e.g. nurse practitioners, (3) minimizing the amount of consult types, and (4) standardization of care [van der Voort, 2004]. An example of a successful implementation within this project is the general surgery outpatient clinic at Bernhoven hospital in Oss, The Netherlands. Access time reduced from 2 - 8 weeks to one week for new patients. Besides reduced access times, consultation hours offer enough time to deal with emergency patients and prolonged consults without causing full waiting rooms and overtime [Bodegom et al, 2004].

Cayirli and Veral (2003) propose a framework for designing appointment systems. Designing an appointment system can be broken down into a series of decisions regarding: (1) the appointment rule, (2) the use of patient classification, and (3) the adjustments made to reduce disruptive effects of walk-ins, no shows and emergency patients. Choosing an appointment rule implies decisions about the block size (number of patients scheduled per appointment slot), the initial block (number of patients scheduled in the first appointment slot,) and the appointment interval. The PACs at Isala klinieken currently schedules with a (initial) block size of generally one (sometimes two) and an appointment interval of ten minutes. Patient classification can be used to sequence patients at the time of booking and/or to adjust appointment intervals bases on the characteristics of the patient. In practice, patient classification is often used to assign patients to pre-marked slots when they call for an appointment. This is the case at the PACs at Isala klinieken.

Disruptive effects, like no shows and walk-ins, have a big influence on the performance of appointment systems. Ho and Lau (1992) show that the influence of no show on the performance of an appointment system is considerable. Rising, Baron and Averill (1973) discuss a case study in which they deal with these disruptive effects by adapting the appointment schedule for expected walk-ins. By analyzing the daily arrival patterns appointments were scheduled in periods of low walk-in rates. With this appointment schedule they vary the physician capacity over the hours of the day to determine the best physician schedule. Implementing this new appointment schedule leads to efficiency improvements: patients seen increased by 13.4 % with 5.1% fewer physician hours scheduled.

Several studies investigate appointment systems using queuing theory and simulation. These studies often focus on reducing idle time of healthcare professionals at the expense of increasing patient waiting time [Bailey, 1952; Fetter and Thompson, 1966; Visser & Wijngaard, 1979; Brahimi & Worthington, 1991]. Bailey and Welch (1952) propose to use an initial block of two, such that there are two patients present at the beginning of the session, and an appointment interval equal to the average consultation time to balance the professionals' and patients' waiting time.

The concept of 'open access' was first discussed by Murray and Tantau (2000). Open access, also referred to as 'advanced access' or 'same-day scheduling', has one very simple but challenging rule: do today's work today. When all patients can be offered an appointment on the same day as their request, backlog appointments can be reduced and waiting times can be minimized. The implementation of this concept in a primary care department for Kaiser Permanente in northern California, the United States, has revealed a reduction of the access time for patients from 55 days to one day. It also dramatically increased the odds of patients seeing their personal physician. To successfully implement an open access schedule, Murray and Berwick (2003) identify six specific changes medical practices must make: (1) balance demand and supply, (2) work down the backlog, (3) reduce the number of appointments, (4) develop contingency plans, (5) reduce and shape the demand for visits, and (6) increase the effective supply, especially of bottleneck resources.

Mallard et al. (2004) describe a pilot study implementing open access scheduling in one of the clinics of the Jefferson County Department of Health in Alabama in the United States. Problems identified were: high no-show percentage, long access times (1-3 months), and overbooking of physician's schedules. In the pilot study 70 % or more of daily appointments were kept open for same-day scheduling. As a result of the changes waiting time decreased to 15 days, no-show percentages significantly decreased, the number of new patients increased significantly, and the average provider productivity rate increased. According to the authors, the primary challenge for implementing open access scheduling relates to the radical nature of its requirements. Managers and physicians have always been accustomed to a system built around appointments and overbooking, where an indication of the sophistication of the medical practice was reflected by the complexity of the appointment system [Pinto, Parente & Barber, 2002].

Giachetti et al. (2005) presents the preliminary results of an ongoing research project investigating the patient appointment scheduling for a dermatology outpatient clinic in Miami, Florida, the United States. They develop simulation models to assess an open access scheduling approach. The preliminary results show a 50% reduction in throughput time. Ongoing work is performed to determine the best configuration of an open access scheduling policy.

Bundy et al. (2005) present the results of open access scheduling in four North Carolina primary care facilities. Mitchell (2008) discusses the results of open access scheduling in a family practice in Halifax, Canada. Both articles show positive results concerning access time, no-show rate, and patient satisfaction. Concerning these parameters, other articles [Parente, Pinto & Barber, 2005; Steinbauer et al., 2006; Armstrong et al., 2006; Dixon et al., 2005; O'Hare & Corlett, 2004; Kopach et al., 2006] reveal mixed results. Open access is not always a common practice. Cayirli and Veral (2003) conclude from a survey that only five out of eighty studies mention walk-in patients. Our research combines scheduled and walk-in patients. Furthermore, we contribute to this field of research by evaluating the performance of the appointment schedule of the PAC through queuing theory and event-based simulations. We evaluate the possibility of walk-in and the effects of reducing variability in the arrival process.

2.5 Implications for this research

In this chapter we discuss literature relevant for our research. Hans, van Houdenhoven, and Wullink (2006) give us a framework in which we can position the characteristics of the PAC. We do this in Chapter 3. Through the literature describing research on pre-operative screening, we develop a view on how pre-operative screening can be organized. We find ideas, which we use to develop interventions for the pre-operative process at Isala klinieken. The implementation of ASA classification as planning criterion is one of these ideas. Literature about patient scheduling is used to develop possible interventions in the pre-operative process. Also the modeling approaches chosen in these researches form a basis for our modeling approach. The concept of open access [Murray & Tantau, 2000] is a concept that appeals to hospital management. We investigate the possibility of such a system.

Chapter 3

Current pre-operative process

This chapter describes the current pre-operative process. As we defined earlier the pre-operative process is the process of patients seeing a specialist in an outpatient clinic, visiting the PAC, and being planned for surgery.

In Paragraph 3.1 we give an extensive description of the process design, we give the patient mix, routing, and consultation duration. Paragraph 3.2 discusses the control of the process using the framework for hospital planning and control [Hans, van Houdenhoven & Wullink, 2006] discussed in Chapter 2. At a strategic level we discuss the available staff at the PAC. We discuss the tactical decisions about how the capacity of the PAC is used and divided over different patient groups. At an operational level we discuss how the patient is scheduled and how the PAC deals with unexpected events such as emergency patients. Paragraph 3.3 gives an overview of the performance of the current process.

3.1 Process description

Isala klinieken consists of three locations, Sophia hospital (SZ), hospital “de Weezenlanden” (WL) and field facility Kampen (KP). At all three locations a PAC is situated. All three PAC locations are equipped to see every kind of patient and act accordingly. The outpatient clinics are divided over locations SZ and WL and for some specialties at the field facility Kampen. Table 3.1 gives an overview of all relevant outpatient departments and the corresponding production in 2007.

Location	Outpatient Department	Production / # of patients (in 2007)
SZ	General surgery	62.195
	Plastic surgery	25.318
	Gynecology	94.471
	Neurosurgery	9.085
	Jaw surgery	35.653
	Emergency room	Around 45.500
WL	Orthopedics	47.461
	ENT	47.098
	Ophthalmology	70.481
	Urology	45.913
	Jaw surgery	40.924
	Jaw surgery Rittersma	6.213
	Dental surgery	28.938
	Emergency room	Around 13.000
KP	Orthopedics	1.873
	ENT	8.514
	Ophthalmology	12.344
	Gynecology	3.279

Table 3.1: Overview of the relevant outpatient departments (IVAS, 2008).

A patient seen at an outpatient department at one location can be screened at the PAC at another location, depending on the availability of an appointment slot and the preferences of the patient. The location of the patient's surgery (SZ or WL) depends on the specialty performing the surgery. Since the resources of the PAC are divided over three locations flexibility in usage of these resources is limited.

3.1.1 Patient mix

The majority of patients at the PAC are seen on basis of an appointment. Only a small part is seen on basis of walk-in. These walk-in patients are mainly children from ENT who need outpatient surgery. Inpatients and outpatients from the different specialty departments undergo the same pre-operative screening and in the planning are assigned with the same appointment slot length. A distinction made between patients influencing patient routing is if they are consulted by a nurse of the PAC or not (type 1, 2, and 3 in Figure 3.4).

The PAC screens patients of diverse OPDs. Table 3.2 shows the planned patient case mix divided by the specialties we take into account. Specialties, such as thoracic surgery, pediatrics, neurology, and anesthesiology that request few screenings are grouped as one specialty (other). Thoracic surgery does perform a lot of surgeries (almost 1500 in 2007) but almost all their patients are pre-operatively screened by the specialty itself. The percentages are based on the number of pre-operative screenings performed in 2007. These numbers are not necessarily equal to the annual surgeries performed per specialty since a pre-operative screening is valid for half a year in which multiple surgeries may be performed on a patient. On the other hand, sometimes patients undergo multiple screenings for one surgery. All planned patients are seen based on an appointment.

Specialties	# Pre-operative screenings	Part of total screenings	# Surgeries
1. Orthopedics	3323	16.3 %	3866
2. General surgery	3275	16.1 %	3781
3. ENT	2842	13.9 %	3123
4. Ophthalmology	2518*	12.4 %	3806
5. Plastic surgery	1894	9.3 %	2392
6. Gynecology	1706	8.4 %	1905
7. Urology	1338	6.6 %	1471
8. Neurosurgery	1156	5.7 %	1335
9. Jaw surgery	885	4.3 %	987
10. Dental surgery	225	1.1 %	247
11. Other	519	2.5 %	1761
Total	19681	100 %	24674

Table 3.2: Number of pre-operative screenings in 2007 (MCC, 2008)

** Many ophthalmologic surgery patients undergo two surgeries (one on each eye) within a short time period. They are only pre-operatively screened once since a PAC screening is valid for six months. This explains the difference between the number of screenings and surgeries.*

Besides planned patients, the PAC locations of SZ and WL also see a part of all emergency patients that need surgery. A total of approximately 4000 emergency surgeries were performed in 2007 at both locations. Only a small part of these patients have the possibility to visit the PAC. Most emergency patients are screened by an anesthesiologist at the OR or ward. The PAC uses a different definition of emergency. We define emergencies patients as patients who need surgery within three days after the PAC screening is requested. From the data over 2007 the emergency registrations in March and April were excluded since the number of registrations in these months was extremely high. It is very likely that imprecise registration has occurred in this time period.

In 2007 (excluding March and April), 753 emergency patients were screened at the PAC. This is approximately 20 % of all emergency patients. We assume the remaining 80 % of all emergency patients cannot be seen on the PAC because of the severity of their injuries.

Figure 3.1 gives an overview of the average number of emergency screenings at each day of the week for all locations. The 95% confidence interval is also included.

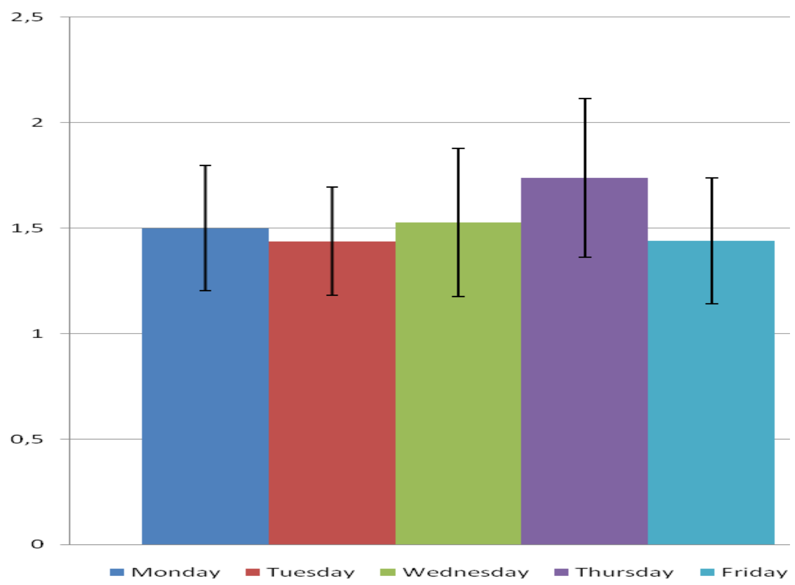

Figure 3.1: Average number of emergencies (MCC 2008, n= 753).

The patient mix can further be characterized by the disturbances caused by these patients. As discussed by Cayirli and Veral (2003), disturbances have a big effect on the performance of an appointment schedule and thus the process. They are caused by emergency patients, patients not showing up for an appointment, patient lateness, emergency patients, walk-in patients, and second consultations.

The IVAS data from 2007 show no show rates of 2.6 % for PAC location WL, 5.2 % for location SZ, and 8.9 % for location Kampen. We assume the number of no shows is evenly divided over all patient types.

From a time registration project, what we set up for this research in July and August 2008, we gather data to get insight in consultation times. From this data, we determine patient lateness: 10.2 % of all patients arrive too late. There is no relation between the patient type and lateness. Figure 3.2 gives an overview of the lateness of patients.

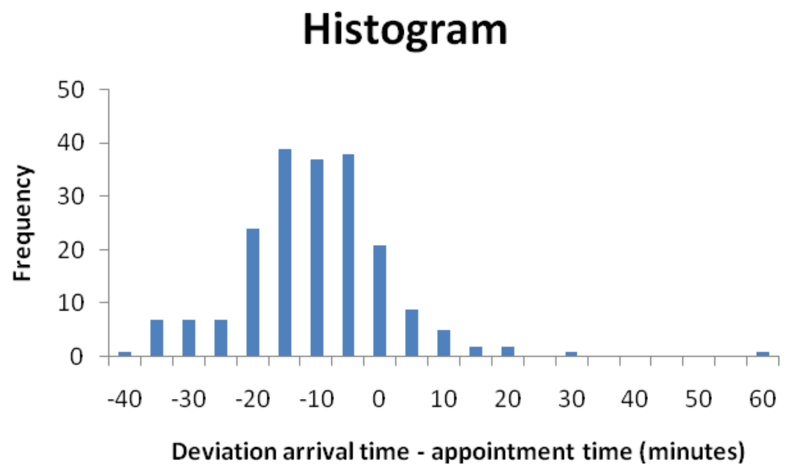

Figure 3.2: Patient arrivals with respect to appointment time (Time registration project, n=203)

Walk-in patients are currently not registered as such and thus it is difficult to determine an exact walk-in rate. As previously mentioned, only children from ENT are screened on basis of walk-in. We estimate that the walk-in rate is less than 5 %.

From PAC and OR data retrieved from MCC and IVAS the second consultation rate is determined. The second consultation rate is defined as the percentage of patients needing a second consultation for one surgery. Overall 2 % off all surgical patients needed a second consultation at the PAC.

3.1.2 Patient routing

When a patient at the outpatient department is diagnosed to undergo surgery, the secretary of the outpatient department has the task to immediately plan an appointment at the PAC. This appointment is made in the appointment system Ultragenda (UG). Children from ENT and the emergency patients that can be seen at the PAC are seen as walk-in patients and therefore do not need an appointment. The secretary indicates if the patient has to undergo a long or short surgery. On basis of this information all available appointment slots at all locations for this patient are given by UG. The patient is planned on the first appointment slot that is suitable for him/her. Finally, the patient takes home a form on which they have to answer questions concerning their medical history and medication usage. This question form is intended to facilitate the PAC screening.

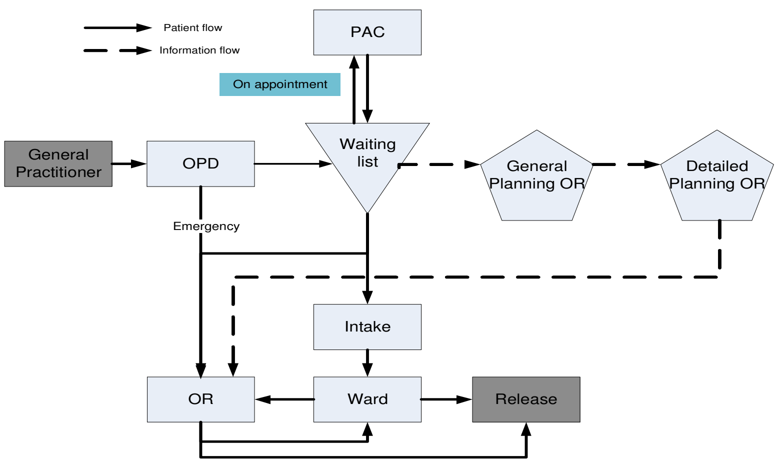

Figure 3.3: Patient routing through the pre-operative process

At the day of the PAC appointment, patients report at the PAC secretary desk and handover the filled-in question form (see Figure 3.4). The secretary enters the information of the question form into the IZIS information system and puts the form together with the patient's file on a pile. The pile represents the patients waiting for screening. The patient is sent to the waiting room to wait for the examination of the doctor's assistant. When the examination of the doctor's assistant is finished, the patient waits in the examination room for the anesthesiologist. Based on the patient file and the anesthetic screening, the anesthesiologist determines if the patient is fit for surgery or if additional examinations are necessary before surgery approval. After anesthetic screening, most patients are seen by a PAC nurse (type 1). Patients referred to the PAC by some specialties are not seen by the nurse since these specialties prefer to do this nurse consult themselves or a nurse consult is not necessary (type 2). Most walk-in patients are not seen by the PAC nurse (type 3).

When a patient needs additional examinations the patient goes to the secretary who contacts the designated department to make an appointment for the patient in UG. After these examinations, in most of the times, the patient does not have return to the PAC. Based on the information gathered by the additional examinations, the anesthesiologist makes the decisions concerning surgery approval. This is communicated by telephone with the patient.

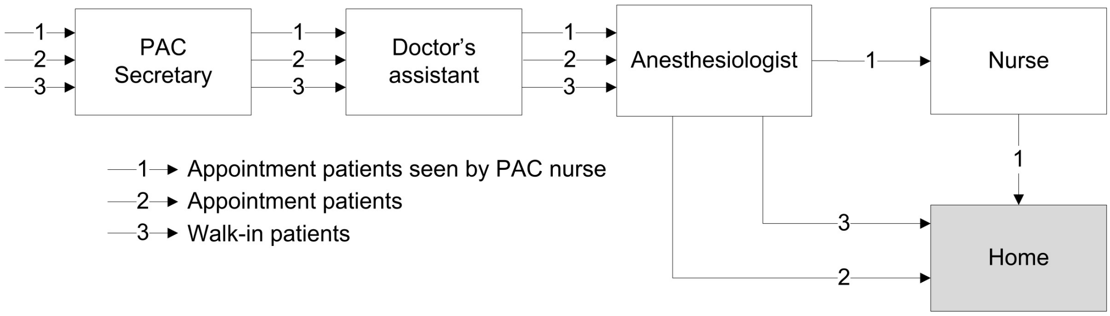

Figure 3.4: Patient routing through the PAC

3.1.3 Process durations

From the previously mentioned time registration project it was possible to get insight in the duration of the PAC processes. Since the process steps within the PAC are the same for all patients (except the nurse consult), process durations are based on all patient types. During the time registration project it was not possible to measure the exact duration of the registration at the secretary desk. By observations it is estimated that the average registration time is equal to 2.5 minutes. Table 3.3 gives an overview of the average durations and the standard deviation in minutes.

Process step	Mean μ	Standard deviation σ
Registration by secretary	2:30	-
Doctor's assistant examination	4:48	2:46
Anesthesiologist screening	7:21	3:55
Nurse consult	13:30	7:43

Table 3.3: Process duration parameters (Time registration project, n=203)

The bottleneck in the process is the anesthesiologist, as all patients need to be seen by him/her. Figure 3.5 gives an overview of the anesthesiologist screening duration distribution. This distribution accounts for anesthesiologist's with "average" working speed. In practice, we see considerable differences (up to an estimated 50%) between anesthesiologist's working speed, and thus in consultation times. We assume that all anesthesiologist have the same distribution shape.

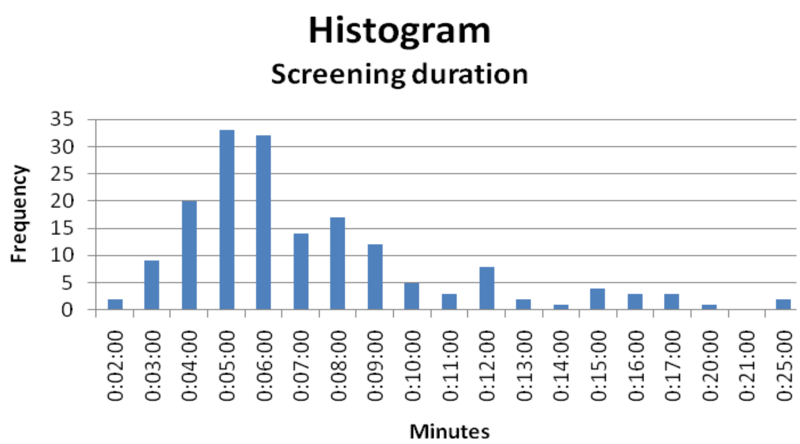

Figure 3.5: Screening duration (Time registration project, n=177):

The nurse consult takes longer on average but is not a necessary consult for all patients. An important conclusion is that the screening duration is independent of the referring specialty. The screening duration did prove to be dependent on the ASA class.

3.2 Process control

In the previous paragraph the current design of the pre-operative process has been discussed. Besides the design we also focus on the control options of the process. We discuss the tasks of the medical staff and the way patients are scheduled in the pre-operative process.

3.2.1 Staff

For this research the employees of the PAC are of particular interest. We do not analyze the occupation of staff at the OPDs. There are four types of employees that work at the PAC. At the moment each location is staffed by one desk secretary, one or two doctor's assistants (depending on the day of the week), one anesthesiologist and one nurse each day. The tasks performed by each employee type are given in Table 3.4. The nurse practitioner is also included. Currently nurse practitioners are not used in the pre-operative process, but it is a possibility for the future.

Employee	Tasks
PAC secretary	Welcomes patients Answer phone calls Answer questions of patients Make appointments for patients for further examination Enter patient data in IZIS
Doctor's assistant	Measure blood pressure of patient Measure body length of patient Measure blood pressure
Anesthesiologist	Medical examination Review medical history of patient Insert patient data in Eridanos Approve patient for surgery Get informed consent from patient
Nurse	Discuss pre surgery fasting with patient Discuss other pre surgery requirements Discuss aftercare
Nurse practitioner	Medical examination of part of patient mix Review medical history of patient Insert patient data in Eridanos Approve patient for surgery

Table 3.4: Tasks per employee at the PAC

Secretary/doctor's assistant

There are eight assistants available for all three PAC locations. At each location, two or three assistants are available during consultation hours. These assistants function as a secretary or doctor's assistant. One of the assistants is always assigned as the desk secretary, while the other one or two perform the tasks of doctor's assistant. The secretary receives patients at the desk of the PAC. She also performs several back office tasks such as the typing of letters but these tasks are less relevant for this research. The doctor's assistant examines the patient on blood pressure, body length and body weight in one of the available examination rooms.

Anesthesiologist

Isala klinieken has 20 anesthesiologists who perform pre-operative screening consults. At each location one anesthesiologist works during consultation hours. The anesthesiologist performs the actual screening of the patients and informs the patient about the risks of anesthesia. By law, the anesthesiologist has to get an informed consent from the patient.

Nurse

At each location one nurse is present during consultation hours to discuss pre and post surgical matters with patients. In total six PAC nurses are available. The nurse discusses practical information with the patient concerning the surgery, e.g. removal of hair, pre-surgery fasting, and aftercare. Not all patients visit this nurse, some specialty departments prefer to perform this consult at the department.

Specialty	**PAC nurse visit? (Figure 3.4)**	**Comments**
General surgery	Yes	
Plastic surgery	Yes	Only planned patients
Orthopedics	Yes	
Ophthalmology	No	
ENT	No	
Neurosurgery	No	
Jaw surgery	Yes	
Dental surgery	Yes	
Urology	Yes	Only outpatients
Gynecology	Yes	

Table 3.5: Patient flows through PAC nurse

Nurse practitioner

The nurse practitioner (NP) can be used to perform tasks the anesthesiologist performs currently. The NP could perform the screening of lower risk patients. She/he is trained specifically for pre-operative training. By law it is stated that the anesthesiologist always has the formal responsibility for the surgery approval and should get an informed consent from the patient. How this could be implemented in practice is not completely clear yet, but it is possible. In several hospitals in The Netherlands, such as the "Maasland" hospital in Sittard and the Eye clinic in Rotterdam, nurse practitioners perform pre-operative screening

3.2.2 Appointment scheduling

The PAC locations SZ and WL are opened on all working days, except WL on Tuesday. Location Kampen is only opened on Friday. The opening hours of SZ and WL are 8:00 - 12:00 and 13:00 - 16:20. In Kampen, opening hours are 8:30 - 12:00 and 13:00 - 15:40. During the lunch break patients that arrive can take place in the waiting room.

WL	8:00-9:00						9:00-10:00						10:00-11:00						11:00-12:00					
Monday	Gyn	GEN	Gyn	Orth	Orth	Eye	Orth	Eye	GEN	Jaw	ENT	Orth	Eye	Preop	Orth	Gyn	GEN	Orth	Preop	GEN	ENT	Jaw	Uro	Preop
Tuesday																								
Wednesday	Orth	Eye	GEN	Gyn	Uro	Jaw	Orth	Eye	PLAS	GEN	Eye	Orth	Eye	Preop	PLAS	Orth	Eye	GEN	Eye	GEN	Preop	Orth	Eye	Dental
Thursday	Orth	PLAS	Orth	Orth	PLAS	Eye	Orth	Eye	Orth	PLAS	Eye	Orth	Eye	Preop	Orth	Orth	Orth	ENT	Uro	Preop	Eye	Neuro	Eye	Preop
Friday	Jaw	Gyn	GEN	Orth	GEN	Orth	Orth	Eye	Gyn	Orth	PLAS	Orth	Eye	Preop	GEN	Orth	Neuro	Eye	Preop	Uro	ENT	ENT	Eye	Preop

	12:00-13:00	13:00-14:00						14:00-15:00						15:00-16:00						16:00-16:20	
Monday		GEN	Orth	GEN	Eye	Dental	GEN	PLAS	PLAS	PLAS	Preop	Orth	Gyn	Neuro	Eye	Uro	GEN	Eye	Eye	Eye	Preop
Tuesday																					
Wednesday	Break	Eye	GEN	Gyn	Jaw	ENT	Orth	Eye	GEN	Orth	Preop	Orth	GEN	ER	Orth	Uro	PLAS	ENT	Eye	Eye	Preop
Thursday		GEN	PLAS	GEN	Eye	Gyn	GEN	PLAS	Neuro	Eye	Preop	Uro	Eye	PLAS	ENT	GEN	Jaw	Eye	Dental	Eye	Eye
Friday		GEN	Preop	GEN	Orth	Preop	GEN	Eye	Preop	GEN	Gyn	Gyn	Preop	PLAS	Preop	Eye	Eye	Eye	Eye	Eye	Eye

Figure 3.6: PAC schedule at location WL

In Figure 3.6, the appointment schedule is shown for location WL. Location SZ and Kampen use a similar appointment schedule (see Appendix B). Appointment slots of 10 minutes are used. Each appointment slot is assigned to a specialty to ensure that capacity is available for patients of each specialty. Extra slots (the white slots) are reserved for patients when 'normal' slots are no longer available for the corresponding specialty within the period before the scheduled surgery. Emergency slots are reserved for emergency patients who are able to visit the PAC. Emergency slots can only be scheduled one day before. The schedule contains a total of 44 slots per day.

The ‘normal’ slots assigned to specialties that require a PAC nurse consult are further divided into slots for “long” and “short” surgeries. A long and complicated surgery implies a more thorough nurse consult. The OPD determines if a surgery is “long” or “short”. By spreading the “long” specialty slots over the schedule, workload for the nurse and waiting time for the patient are controlled. Walk-in patients are screened in between planned patients and can be seen as overbooking.

By using a lot (>10) of different slot types, the PAC wants to make sure there is enough capacity available for all specialties. However, due to the large number of slot types, the schedule has become very inflexible and unable to adequately deal with changes in demand. From a queuing perspective, introducing different slot types means introducing different queues for a single server decreasing flexibility. In theory, the number of appointment slots per week assigned to a specialty equals the average demand for pre-anesthesia screening by this specialty. In practice, this is no longer true: the number of surgeries and thus the demand for pre-operative screenings has increased. By overbooking the appointment schedule at certain days, when “faster” anesthesiologists are on duty, the demand is fulfilled and access time is kept constant.

As previously mentioned, the secretary of the specialists plans patients in the schedule of the PAC. She can only see all the available slots at all PAC locations suitable for the specific patient type. There is no formal planning rule for the secretary. She discusses the options with the patient and eventually plans the patient on a slot.

Since the approval by the anesthesiologist is crucial for the continuation of a surgery, the patient should be planned for surgery after the PAC screening is successfully completed. However, this is often not the case. Surgery dates are sometimes planned by the specialty before the patient is seen by an anesthesiologist at the PAC. The reason that is given to plan before the PAC screenings are: (1) the scheduling problems of the PAC, and (2) the short length of the waiting list for surgery for most specialties.

3.3 Current performance

In collaboration with the stakeholders involved in the pre-operative process, several performance measures have been identified. The performance measures can be divided in measures that quantify the performance of the PAC as a separate department and measures that quantify the performance of the pre-operative process as a whole. Performance measures of the PAC are for example utilization rate, waiting time in the waiting room, and overtime. A performance measure for the pre-operative process as a whole is the access time of the PAC.

3.3.1 Access time PAC

We define the access time of the PAC as the time between the OPD consult at which the specialist determines that surgery is necessary and the time at which the patient is seen at the PAC. The access time of the PAC is measured monthly by the department itself. For each appointment slot type the 3rd available appointment in Ultragenda is monthly registered to monitor the access time. The 3rd available slot is taken because sometimes screenings are cancelled and therefore these slots seem available but are not a realistic indicator for the access time. We have attempted to gather data for the OPD appointment date for the whole patient population under consideration to get a more accurate view of the access time, but this proved to be infeasible since these data were unreliable. Table 3.6 gives an overview of the average access time of the PAC for the most important appointment slot types. This data was monitored manually by the PAC staff. The data shows that the access times fluctuate somewhat over time but are generally stable. The PAC aims to see all patients within two weeks. This is clearly not the case for most slot types.

Specialty	Inpatient avg. access time (in days)	Outpatient avg. access time (in days)
Orthopedics	20	41
General surgery	7	24
ENT	-	41
Ophthalmology	-	6
Plastic surgery	-	12
Gynecology	12	18
Neurosurgery	18	-
Urology	18	-
Jaw surgery	21	-
Dental surgery	23	-

Table 3.6: Average access time for each appointment slot type (Ultragenda, April 2007 – May 2008, n=13)

The percentage patients seen on the same day (walk-in patients) at the OPD and PAC cannot be retrieved from this data. However, from practice it is known that this percentage will be low since a large majority of the patients is seen on basis of an appointment that is scheduled on another day. Only children from ENT may be seen on basis of walk-in. We estimate that this group of patients constitutes less than 5 % of the total PAC patient case mix.

3.3.2 Access time surgery

Almost 50 % of all appointment patients are seen within two weeks before surgery. Patients are seen 26 days before surgery on average. Since almost no extra consultations are necessary after pre-operative screening it should be possible to screen appointment patients closer before surgery such that capacity in the short term remains free and can be used flexibly.

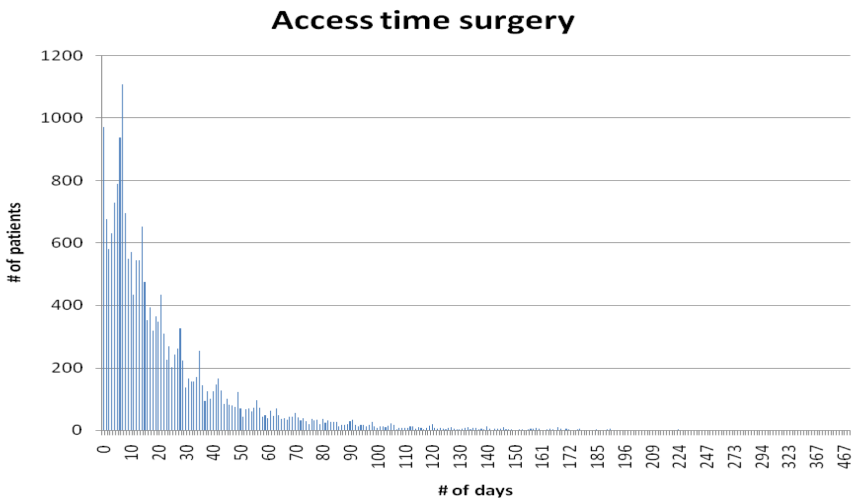

Figure 3.7: Access time surgery (MCC 2007, n=19681)

3.3.3 Utilization

The utilization is an important measure for the use of capacity. A low utilization leads to unnecessary idle time. A high utilization can lead to high staff workload and overtime. We define the utilization of the PAC as the utilization of the anesthesiologist, since data has shown that this staff member is the bottleneck in the screening process.

It is difficult to determine the exact utilization of the PAS since no extensive data is available concerning process durations. As a measure for utilization we have compared the number of screened patients with the number of available appointment slots. We have determined the utilization for all three PAC locations. The following figure gives an overview of the daily utilization over 2007 for PAC location WL. The red line gives the current available appointment slots (=44)

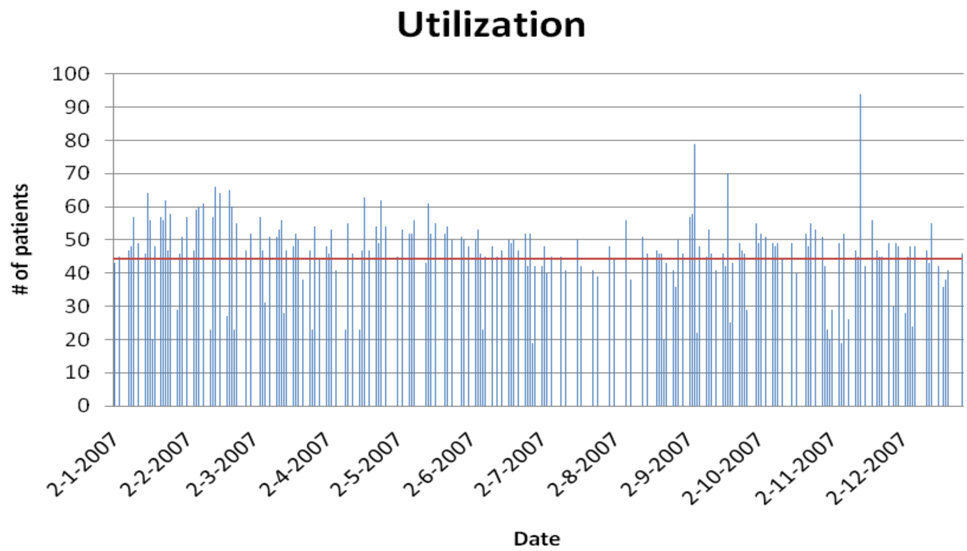

Figure 3.8: Utilization rate at all location WL (Ultragenda, 2007, n=8904)

This calculation includes all patients that have visited the PAC, also the emergency patients. Based on the data behind Figure 3.8 we find an average utilization of 112% at location WL (σ = 19 %), 98 % (σ = 12 %) at location SZ, and 100 % (σ = 13 %) at location Kampen.

Comparing the total number of available slots with the total number of screenings in 2007 (20381 vs. 20368), the capacity is just below demand. By the variability of the demand there are issues in matching capacity and demand over time and thus a lot of over-utilization. Without this over-utilization, and thus planning extra appointments outside the daily available planning slots, the access time would increase.

When measuring utilization with the actual average screening time instead of the planned 10 minute slot we find the following utilization rates:

Location	Average utilization (%)	σ (%)
WL	82.0	13.7
SZ	72.1	8.9
Kampen	87.1	11.6

Table 3.7: Utilization rates taking average screening duration into account

Furthermore the number of screenings increases each year. The utilization rates in 2008 are even higher.

3.3.4 Number of pre-operative screened patients

Currently not all patients are screened at the PAC. A part of these patients is screened by the specialty department itself, but another part of these patients should formally be screened on the PAC, but are not in practice. Why these patients are not sent to the PAC for a screening is unclear. Problems finding a suitable appointment slot at the PAC before the planned surgery date can be a reason. On average 447 surgeries are performed per week, while there are 440 available slots per week. This shows that indeed it is difficult to find a suitable slot for all patients. In practice more than 440 patients can be seen per week. These extra patients are planned in between appointment slots.

Figure 3.9 gives an overview of the relation between the number of screened surgeries and the total number of surgeries (excluding Thorax surgery, since Thorax screens patients themselves). The trend shows that the number of patients not screened remains quite constant at about 5.5 %.

The goal of the management is to screen all patients, excluding Thorax patients, since they are screened by the specialty itself. Given the current utilization and capacity, it will not be possible to screen 100% of these patients.

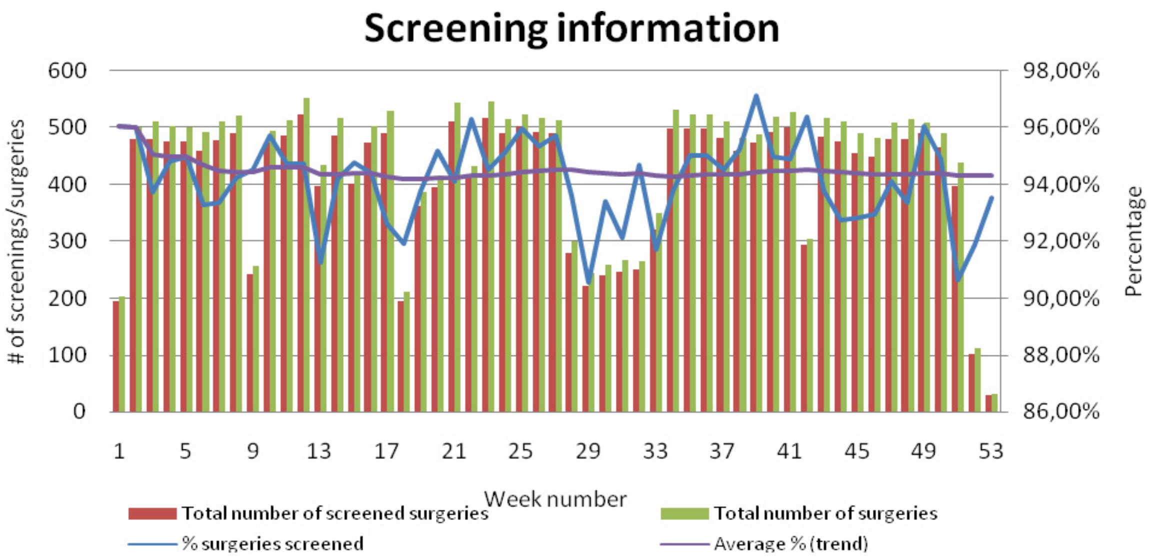

Figure 3.9: Number of screenings vs. number of surgeries (MCC, 200,7 n=23274)

3.3.5 Patient waiting time

As mentioned earlier, the hospital information systems do not provide any information concerning time registration. The consultation times were retrieved from the time registration project we performed. Patient waiting times were also retrieved but are not representative for the current performance of the PAC because the data were gathered in the summer period with less patient screenings. To get better insight in the patient waiting time we have to model the current PAC processes.

3.3.6 Overtime

The PAC does not register the end time of the working day. The time registration project was performed on too few dates to give a representative view of the overtime. From interviews with the secretaries and anesthesiologists of the PAC it became clear that overtime is a serious issue. Besides overtime at the end of the day, a lot of work is performed within the lunch break between 12.00 and 13.00. Keeping the utilization rates in mind it is clear that overtime can be expected.

3.4 Conclusions current performance, problem analysis

This chapter addressed the design and control of the current pre-operative process as well as the performance of the process. We distinguished performance of the pre-operative process as a whole and performance of the PAC as a separate department. From the analysis of the current process and performance we conclude:

- The access time of the PAC is above the aim of the hospital of two weeks for almost all patient types. This conflicts with the short surgery waiting list of some specialties and causes problems for timely pre-operative screening. This access time is kept constant by a large number of planned appointments outside the initial appointment slots.
- All planned patients are screened well before their planned surgery date. By screening patients closer before their surgery date capacity remains free to be used for more urgent patients of the same patient type.
- The utilization of the PAC at all locations is quite high, a part of the time even over 100 % leading to overtime.
- The number of surgeries performed per week (on average 447) is higher than the number of available slots per week (444). This gives difficulties finding a suitable appointment slot for the patient and may be a reason for non-screened patients.
- The number of non-screened patients is about 5%. To attain a screening percentage of 100%, as is the goal of management, the capacity of the PAC has to increase or the PAC has to be organized more efficiently.
- Patient waiting time and actual overtime could not be gathered from the information systems of the hospital. The time registration project was not extensive enough to give conclusive results for these performance measures.

Activity	**Communication through**	**Time**
Patient receives proposal for appointment at OPD Patient undergoes consult at OPD Patient needs surgery A planned surgery date is defined	Secretary Specialist Specialist Planner specialist	Day 1
Patient undergoes pre-operative screening (except if patient indicates an appointment is preferred). If extra consultations necessary at other departments, undergo these consults and then return to PAC for nurse consult	Anesthesiologist / Nurse practitioner	Day 1 Waiting time 1 hour maximum.
Nurse consult	Nurse PAC	Day 1, Waiting time 1 hour maximum
Patient receives surgery date, unless no surgical approval by anesthesiologist. Surgery date is made final	Nurse PAC Planner specialist	Day 1
Check if everything is ready for surgery (materials on the OR, surgical approval)	Planner OR and secretaries OR	24 hours before surgery
Patient arrives for intake (in case of an inpatient surgery)	Employee intake desk	Day 1-28
Introduction on the ward (in case of an inpatient surgery)	Nurse of the ward	Day of intake
Patient meets surgeon	Surgeon	Day of surgery
Patient is operated on planned time		

Table 3.8: Proposed process structure pre-operative process for 80 % of all elective patients [Isala, 2007b]

From the analysis of the appointment schedule and the way appointments are made it became clear that the appointment schedule is a very rigid, inflexible schedule. By defining appointment slots for so many patient types it is difficult to adapt to short term fluctuations in patient supply. By the increasing patient volumes it becomes even more difficult to screen all patients before surgery within the existing appointment schedule. The absence of a formal planning rule for the secretaries of the specialties decreases the control over the schedule.

To improve the performance of the PAC and to increase the patient friendliness of the pre-operative process, the management of the pre-operative department and several anesthesiologists, have proposed a new process structure. This process structure takes into account the recommendations of the hospital management (mentioned in Chapter 1). The aim is to see 80% of all elective patients through a walk-in consult on the same day as the OPD consult. Table 3.8 gives an overview of the proposed process structure. A visual overview is given in Appendix H.

Not all patients can be seen on basis of walk-in. Some patients are more difficult to screen and demand more preparation. These patients have to make an appointment for a PAC screening at the secretary's desk. Which patient classification will be used is not yet clear, but from the literature it is apparent that ASA classification can be useful. In this research we choose to use ASA classification as a patient classification measure. Patient classified into ASA categories one and two can be seen immediately, patient with ASA category three or four are given an appointment by the secretary to visit the PAC at another day. This classification can be made through the pre-anesthesia questionnaire discussed earlier. On basis of this questionnaire the secretary can make a judgment in which patient group the patient belongs. Patients who can be seen immediately go to the nurse consult after they are surgically approved by the anesthesiologist. The PAC nurse also gives the patient their planned surgery date.

To be able to facilitate this process structure, we have to adjust the design and planning of the PAC. We implement open access scheduling. Open access scheduling has a couple of advantages, but also some disadvantages. Table 3.9 summarizes the characteristics of both an appointment system as a walk-in (open access) system.

	Appointment system	**Walk-in system**
Service	Patient has to make an extra hospital visit	Patient can be seen at OPD and PAC during the same visit
Quality and service	Access time can be long	Access time is short
Service	Waiting time is easily controllable	Waiting time varies over time due to varying arrivals
Utilization	Utilization is controllable	Utilization is dependent on varying arrivals
Costs	Planning of appointments is necessary	No costs for the planning, since no planning of appointments

Table 3.9: Appointment system vs. walk-in system

In our analysis we will investigate the performance of both systems at the PAC.

Chapter 4
Solution approach

This chapter discusses possible interventions and the models used to analyze the current and alternative designs. In Paragraph 4.2 we present in detail the queuing model used to analyze the current design. This in depth presentation may not be interesting for all readers. We advise readers who are less interested or familiar in the mathematics of the model to skip Section 4.2.2. Section 4.2.1 suffices to get a general overview of the model. In the following chapters we present results with the corresponding mathematical notation as well as a non-mathematical explanation of notations.

In the previous chapter we have drawn conclusions about the current performance of the PAC. In this chapter we discuss several interventions and two modeling approaches chosen to further analyze the current design and these interventions. We introduce the interventions in Paragraph 4.1. In Paragraph 4.2 we introduce the queuing model, and in Paragraph 4.3 the event-based simulation model. We use queuing theory, because this gives quick results and insight on the influence of input parameters. A disadvantage of queuing theory is that it models a steady state, in which arrivals are constant. The influence of the dynamic and stochastic nature of patient arrivals cannot be seen. For that reason, we introduce an event-based simulation model, as an extension to the queuing model.

4.1 PAC design interventions

Within the PAC design we can make several adjustments that influence patient arrivals and capacity management of the PAC. From the analysis of the current design, we see that the planned screenings and the actual screenings do not match. A first step in the analysis is to plan patients with planning slots that are long enough. As a second step we analyze a walk-in setup, since the hospital is interested in performing pre-operative screening through walk-in. Since capacity issues could possibly occur we analyze the use of extra capacity, as a third step. Following these steps we introduce three interventions in this paragraph. We further analyze these interventions in Chapter 5.

4.1.1 Intervention 1: patient classification

In the current design patients are planned on appointment slots reserved for the referring specialty. To guarantee availability for all specialties this way of planning may be suitable. On the other hand, it makes the appointment schedule more rigid and it becomes more difficult to plan varying patient supply. Furthermore, specialty type of a patient does not give any information about the screening duration. ASA classification proves to be a more suitable classification parameter. It gives information about the screening duration and we have information about the expected ASA patient mix, so that we can divide appointment slots over ASA classes. We will model this intervention and analyze the effects of planning through ASA classification.

4.1.2 Intervention 2: patient walk-ins

As discussed in the previous chapter, the hospital would like to see patient at the PAC on basis of walk-in: patients go to the PAC immediately after their OPD consult. The anesthesiologists have suggested that to see ASA 1 + 2 patients on basis of walk-in and ASA 3+4 patients on basis of an appointment. We analyze the effects of the changing patient arrival rate and investigate the possibilities of combining walk-in with appointment patients.

4.1.3 Intervention 3: use of nurse practitioners

The anesthesiologists have suggested that it might be possible in the future to let lower ASA class patients be screened by a nurse practitioner instead of an anesthesiologist. This could reduce the high workload for the anesthesiologist and improve PAC performance. The nurse practitioner would be specially trained for the screenings. It is even suggested by the anesthesiologists that these nurse practitioners would be able to screen lower ASA class patients qualitatively better than the anesthesiologists, as these patients are less “interesting” patients for the anesthesiologists. A nurse practitioner could staff the PAC in busy consultation hours, e.g. Tuesday morning at location SZ.

4.2 Introduction of a queuing model

One of the models we use to analyze the interventions described is a queuing model. A queuing model is useful to approximate real queuing situations, like a PAC. With the model we can analyze the queuing behavior mathematically in a steady state. A steady state is defined as a state of the system, in which the behavior of the system continues into the future. For the PAC this is not completely true, but with this model we can give performance measures for the expected busy periods at the PAC. Furthermore, we choose for a queuing model, because it gives quick insight into the performance of a design.

This paragraph introduces the queuing model used to further evaluate the performance of the current PAC design. The queuing models for the interventions are very similar to this model.

4.2.1 Model assumptions

To allow a thorough analysis of the PAC processes we make some assumptions. The patient mix described in Chapter 3 is divided into the following four patient classes:

A ASA class 1 and 2 patients not seen by the PAC nurse
B ASA class 3 and 4 patients not seen by the PAC nurse
N ASA class 1 and 2 patients seen by the PAC nurse
M ASA class 3 and 4 patients seen by the PAC nurse

This classification is made because from further analysis it became clear that ASA classification (see appendix C) has an impact of consultation time durations, especially on the screening by the anesthesiologist. All four patient classes have their own arrival and consultation time distributions. No distinction is made between appointment-patients and walk-in-patients. Emergency patients are also included.

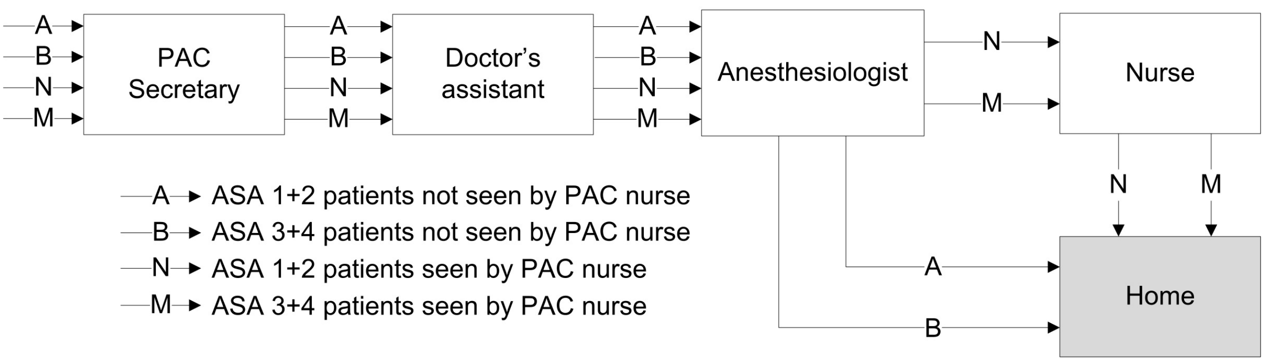

Figure 4.1: Current patient flows for the queuing model

Figure 4.1 shows the patient flows used in the model. This model is the same for all 3 PAC locations. We gather data from the time registration project at PAC locations WL and SZ, at dates when “average speed" anesthesiologists were on duty. Because it is not possible to distinct between individual staff members, we assume that all staff at the different locations has the same consultation time distribution.

Because we only gather data on locations WL and SZ and data is not abundant, we further assume that the arrival process is identical for all locations. This seems plausible as the appointment schedule for all locations is built up the same. Because the consultation time distributions and the arrival processes are assumed to be the same we can represent all PAC locations with the same identical model. The results are applicable to all three locations.

4.2.2 The model

In the previous paragraph we have defined the arriving patient classes treated at the PAC. After patients are screened they leave the PAC. In queuing theory we define such a system as a multi-class Open Queuing Network (OQN). With this model we can get more insight in patient waiting time, patient length of stay (LOS), number of patients in the system, and utilization rate. However, with queuing theory it is only possible to analyze the performance of an OQN with one single patient class. To be able to analyze our multi-class network, we introduce the complete reduction method discussed in the lecture notes of Zijm (2003) and elaborated earlier by Whitt (1983) and Bitran (1996). This method comprises three steps:

1. Reduce the given P class OQN to a single class OQN by aggregating the P classes.
2. Analysis of the single class OQN.
3. Disaggregate to obtain the performance measures per class for the given P class OQN.

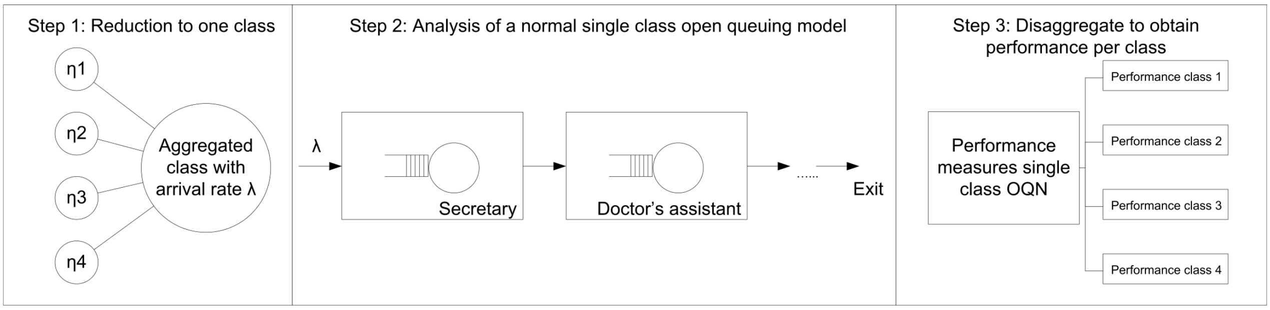

Figure 4.2: The complete reduction method

We define *p* patient classes, *p* = [1..4], and *i* stations, *i* = [1..4] with:

p		I	
1	Class A	1	Secretary
2	Class B	2	Doctor's assistant
3	Class N	3	Anesthesiologist
4	Class M	4	PAC nurse

Table 4.1: Definition of p and i

The number of available staff (number of servers) at station *i* is represented by c_i and the effective time a station is available is represented by e_i.

To be able to complete the calculations with the complete reduction method, the characteristics of the arrival and consultation time distribution have to be known. We represent these characteristics with the following parameters:

η_p	Arrival rate of patient class p
$SCV_{A,p,1}$	Squared coefficient of variation of the arrival rate of patient class p at station 1
$E(S_{p,i})$	Expected consultation time of patient class p at station i
$SCV_{S,p,i}$	SCV of the consultation time of patient class p at station i

We can now perform step 1 of the complete reduction method.

Step 1: Reduction to a single class OQN by aggregation

First we determine the aggregated utilization rate per server and the aggregated arrival rate for each station *i*.

Aggregated utilization rates

The utilization of a station can be defined by the sum of the utilization rates for each patient class *p*. The utilization for patient class *p* depends on the number of arrivals and the expected service time.

$$\rho_1 = \sum_{p=1}^{4} \rho_{1,p} \quad (1)$$

$$\rho_2 = \sum_{p=1}^{4} \rho_{2,p} \quad (2)$$

$$\rho_3 = \sum_{p=1}^{4} \rho_{3,p} \quad (3)$$

$$\rho_4 = \sum_{p=3}^{4} \rho_{4,p} \quad (4)$$

where

$$\rho_{1,p} = \frac{\eta_p E(S_{p,1})}{e_1 c_1} \quad for \quad p=[1..4] \quad (5)$$

$$\rho_{2,p} = \frac{\eta_p E(S_{p,2})}{e_2 c_2} \quad for \quad p=[1..4] \quad (6)$$

$$\rho_{3,p} = \frac{\eta_p E(S_{p,3})}{e_3 c_3} \quad for \quad p=[1..4] \quad (7)$$

$$\rho_{4,p} = \frac{\eta_p E(S_{p,4})}{e_4 c_4} \quad for \quad p=[3..4] \quad (8)$$

In our model each station represents a member of the PAC staff. Since people cannot be utilized more than 100 %, ρ_i and $\rho_{i,r}$ should be < 1. From a theoretical perspective this is also desired. The parameter e_i is added to compensate for small breaks the staff takes. In this way we only take the effective available consultation time into account when calculating the utilization rate.

Aggregated arrival rates

The arrival rates of all patient classes can be added up, to find the arrival rate for the single class network

$$\lambda_i = \sum_{p=1}^{4} \eta_p \quad for \quad i=[1..3] \quad (9)$$

$$\lambda_4 = \sum_{p=3}^{4} \eta_p \tag{10}$$

We have now aggregated the *p* patient classes and can analyze the system as a single class OQN.

Step 2: Analysis of the single class OQN

To analyze a queuing network we need to determine the squared coefficient of variation (SCV) of the arrival processes. In a queuing model we assume stations are in equilibrium. The departure rate of a station equals the arrival rate of the same station. When a patient departs a station he/she goes to another station or leaves the network. The departure process is split into at most M+1 patient flows: M flow to all stations (including itself), and one flow out of the network. By the same reasoning, at most M+1 flows make the arrival process at a station. The SCV of the arrival process therefore depends on the SCV of the departure process at other stations.

The SCV of the arrival process at the secretary desk (station 1) is dependent on the SCV of the arrival rate of all patient classes *p* from the OPDs. We define the SCV of station 1 as

$$SCV_{A,1} = w_1 \sum_{p=1}^{4} Q_{p,1} SCV_{A,p,1} + 1 - w_1 \tag{11}$$

where

$$w_1 = \left[1 + 4(1-\rho_1)^2 (v_1 - 1)\right]^{-1} \tag{12}$$

and

$$v_1 = \left[\sum_{p=1}^{4} Q_{p,1}^2\right]^{-1} \tag{13}$$

and

$$Q_{p,1} = \frac{\eta_p}{\lambda_1} \quad for \quad p = [1..4] \tag{14}$$

The aggregated mean consultation times for the stations 1,2, and 3 are the weighted average of the consultation times of the separate patient classes *p.* In formula this is

$$E(S_i) = \frac{1}{\lambda_i} \sum_{p=1}^{4} \eta_p E(S_{p,i}) \quad for \quad i = [1..3] \tag{15}$$

The SCV of the consultation time for station *i* is dependent on the SCV of the consultation times of patient classes *p* at station *i*. We find the SCV of the consultation time for station 1, 2, and 3 through

$$SCV_{S,i} = \frac{1}{\lambda_i E^2(S_i)} \sum_{p=1}^{4} \eta_p E^2(S_{p,i})(SCV_{S,p,i} + 1) - 1 \quad for \quad i = [1..3] \tag{16}$$

As previously mentioned, the arrival process at a station *i* equals the departure process of the previous stations. For the doctor's assistant and the anesthesiologist all patients arrive from the secretary or doctor's assistant, respectively. Therefore, the arrival process of station 2 is equal to the departure process of station 1, and the arrival of station 3 is equal to the departure of station 2.

The departure process of a station is again dependent on the arrival process, but also dependent on the consultation process of the station. In formula 18 this dependency is shown.

In formula, the SCV of station 2 and 3 are equal to

$$SCV_{A,i} = SCV_{D,i-1} \quad for \quad i = 2,3 \tag{17}$$

where

$$SCV_{D,i-1} = 1 + (1 - \rho_{i-1}{}^2)(SCV_{A,i-1} - 1) + \frac{\rho_{i-1}{}^2}{\sqrt{c_{i-1}}}(SCV_{S,i-1} - 1) \ for\ i = 2,3 \tag{18}$$

Not all patients departing from station 3 (anesthesiologist) go to station 4. Patient class A and N leave the network. Therefore, the SCV of the arrival process at station 4 is influenced by the fraction $P_{3,4}$ of patients visiting the PAC nurse after the anesthesiologist screening. We define the SCV of station 4 as

$$SCV_{A,4} = P_{3,4} SCV_{D,3} + 1 - P_{3,4} \tag{19}$$

where

$$SCV_{D,3} = 1 + (1 - \rho_3{}^2)(SCV_{A,3} - 1) + \frac{\rho_3{}^2}{\sqrt{c_3}}(SCV_{S,3} - 1) \tag{20}$$

and

$$P_{3,4} = \frac{\eta_3 + \eta_4}{\lambda_3} \tag{21}$$

The mean consultation time for station 4 is a weighted average of the consultation times of patient class N and M. In formula

$$E(S_4) = \frac{1}{\lambda_4}\sum_{p=3}^{4} \eta_p E(S_{p,4}) \tag{22}$$

The SCV of the consultation time for station 4 is equal to

$$SCV_{S,4} = \frac{1}{\lambda_4 E^2(S_4)}\sum_{p=3}^{4} \eta_p E^2(S_{p,4})(SCV_{S,p,4} + 1) - 1 \tag{23}$$

We can now analyze the performance of the system

Step 3: Performance measures for each patient class

Using the mean consultation times and the SCVs calculated in step 2, we can analyze the performance of the system. Since all stations can now be seen as separate G/G/1 queues, we can use the formulas for this queue type. Hence, when c_i is no longer equal to one we need to adapt this formula (queues become G/G/c).
The mean waiting time depends on the mean consultation time of the station, but also on the SCV of the consultation time, the SCV of the arrival process and the utilization rate. The mean waiting time at all stations *i* is equal for all patient classes *p* and is defined as

$$E(W_{Q,i}) = \frac{SCV_{A,i} + SCV_{S,i}}{2} \frac{\rho_i}{1 - \rho_i} \frac{E(S_i)}{e_i} \quad for \quad i = [1..4] \tag{24}$$

The length of stay (LOS) for a patient class depends on the route the patients of this class have to follow. Patient classes A (1) and B (2) do not have to visit the PAC nurse. Therefore, their length of stay only depends on the expected waiting time and expected consultation time of station 1, 2, and 3. The mean LOS for patient classes 1 and 2 is given by

$$E(V_p) = \sum_{i=1}^{3} \left[E(W_{Q,i}) + E(S_{p,i}) \right] \quad for \quad p = 1,2 \tag{25}$$

The mean LOS for patient classes 3 and 4, which visit the PAC nurse, is equal to

$$E(V_p) = \sum_{i=1}^{4} \left[E(W_{Q,i}) + E(S_{p,i}) \right] \quad for \quad p = 3,4 \tag{26}$$

We can calculate the number of patients waiting in the queue at a station *i* by looking at the number of patients arriving during the expected waiting time. This dependency is known as Little's law. We can now apply this law to find the mean number of patient in queue for all stations *i*

$$E(L_{Q,i}) = \lambda_i E(W_{Q,i}) \quad for \quad i = [1..4] \qquad (Little's\ law) \tag{27}$$

The mean total number of patients at station *i* is the number of patients in queue plus the number of patients in consultation

$$E(L_i) = E(L_{Q,i}) + \lambda_i E(S_i) \tag{28}$$

Note that the calculation of the number of patients in consultation is again the application of Little's law.

The number of patients in the system is the sum of the number of patients at the stations

$$E(L) = \sum_{i=1}^{4} E(L_i) \tag{29}$$

4.3 Introduction of an event-based simulation model

With a queuing model we evaluate the steady-state performance of a system with a constant arrival rate, a static situation. In practice, the arrival rate varies over time. In the queuing models we have analyzed the state of the system in peak hours, where the arrival rate in highest. To be able to analyze the dynamics of the real-life situation of the PAC, we develop an event-based simulation model.

To validate the results of the models, we introduce an initial simulation model analogue to the queuing model. An overview is given in Figure 4.3. By some minor changes to this initial simulation model we attain a simulation model to analyze the interventions.

We make the following assumptions in our event-based simulation model:

- Patients are divided over the same patient classes as described in Section 4.2.1
- Each task in the PAC process is handled by one staff member (each station has capacity of 1)
- Waiting room capacity is infinite (except waiting room 3, which has a capacity of 1)
- Patients arrive according to their appointment time and lateness factor. We calculate the lateness factor through a Normal distribution (with parameters μ=-660 (negative, since patients arrive too early on average), and σ=789.9).
- Each station is closed 5 minutes/hour or 5 minutes/$^1/_2$ hour (depending on station) to simulate effective working time

The simulation model consists of four main components (in Figure 4.3 we included the referring numbers):

1. The main process flow of the PAC
2. Regulation of arrivals for each patient class
3. Simulating breaks to compensate for effective available time for each staff member
4. Registration of patient data

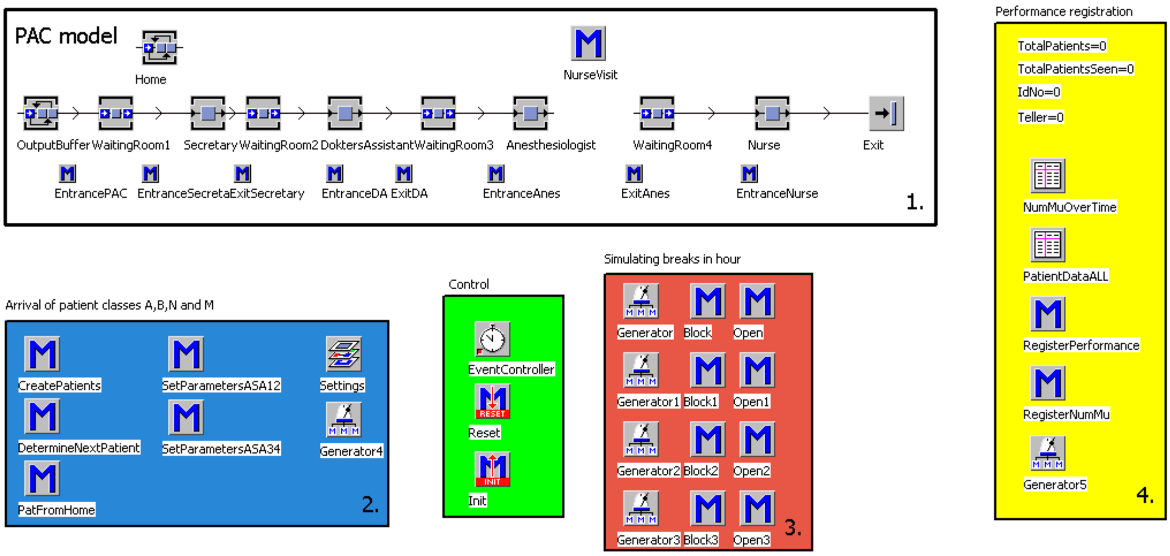

Figure 4.3: Initial simulation model

We will briefly discuss these components.

Main process flow
The main process flow consists of stations representing each staff member. Each station is a single server station, which means we assume one staff member is present at each station. In between server stations buffers have been placed, representing the waiting room. In practice, there is only one waiting room. We represent this waiting room with 4 separate waiting rooms with infinite capacity, with the exception of waiting room 3 (see Figure 4.3). In practice, patients wait in the consultation room where they are seen by the doctor's assistant for the anesthesiologist. They do not go back to the main waiting room in between. We model this by giving waiting room 3 a capacity of one.

Regulation of arrivals
Regulation of arrivals is done through the generation of 2000 patients before the simulation starts. These patients are placed in the "Home" buffer. The patients are given a patient class, corresponding routing, an appointment time, and an arrival time, accounting for lateness. On order of their arrival time patients are moved to the PAC when the simulation time equals that arrival time.

Simulating breaks
In the queuing model we can account for effective consultation time by inserting a parameter e_i. In our simulation model we simulate this by giving the staff one break per hour 5 or 10 minutes (depending on staff type), held randomly within each hour.

Registration of patient data
From each patient exiting the PAC we register several data. We register information such as patient class and the arrival time, but also the time stamps to measure waiting time, consultation time and total length of stay. We further evaluate these data in excel.

After using this model for validation of the queuing model, we can investigate the influence of a dynamic arrival rate. Therefore, we build a simulation model for PAC locations SZ and WL. This model evolves from the initial simulation model used for validation of the queuing model.

4.4 Configuring the models

In this paragraph we give the input settings used in both the queuing and simulation models. The three input categories we need information about, to be able to perform analysis, are: (1) the patient distribution, (2) the arrival process, and (3) the consultation durations. We will assume patient distribution and consultation durations are equal in all models. We will use different arrival processes, since we investigate two situations: (1) working on basis of appointment screenings, hence controlling the arrival process, and (2) working on basis walk-in screenings, hence limited control over the arrival process.

At present patients arriving at the PAC are not monitored. No information is known about the arrival pattern, waiting times, or consultation durations. To be able to perform this research we have setup a small time registration project with the management and staff of the PAC. The results of this time registration project are used to determine input settings of the models.

4.4.1 Patient distribution

ASA classification is currently not used as a criterion to control patient flow. It is however registered in the medical information system Eridanos. Currently the ASA class is determined by the anesthesiologist during the PAC screening, but I may be possible to determine this before the screening as is shown in many hospitals [Lew et al, 2004; Badner et al., 1998].

From the time registration project we evaluated 212 patient screenings (out of 214 registered) to determine the distribution among patient classes A, B, N and M as defined in Paragraph 4.2.1. Table 4.2 gives an overview of the patient distribution.

Patient class p		# patients registered (n_p)	% of total (N)
1	A	104	49.1
2	B	20	9.4
3	N	75	35.4
4	M	13	6.1

Table 4.2: Distribution of patients (Time registration project, n=214)

4.4.2 Patient arrivals

As mentioned earlier we distinguish two arrival processes: appointment arrivals and walk-in arrivals. We discuss these separately in the next section.

Appointment screening
We performed the time registration project at PAC locations WL and SZ and on several days. It was however not possible to register on all weekdays. Since the appointment schedule is very similar for all days at all location we make the assumption that all days have similar patient arrival patterns at all locations.

To determine the patient arrival pattern we use the data obtained during the time registration project. Since the number of arrivals for patient classes B and N were too small to get an accurate arrival rate we have determined an aggregated arrival rate over all patient classes. Figure 4.4 gives an overview of the arrival pattern over the day.

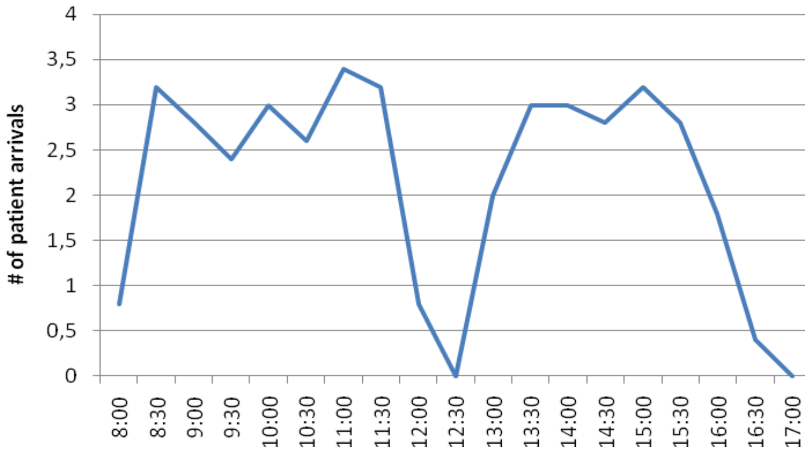

Figure 4.4: Patient arrivals over the day

As the PAC treats individual patients we can assume that patients arrive individually. Furthermore, it is plausible that there is no relation between the arrival of one patient and another. These two observations lead to the assumption that the arrival process is a Poisson process. In queuing models the arrival process is often modeled as a Poisson process. One would assume that patient arrivals on basis of an appointment are not Poisson, since the arrival is correlated to the appointment time. However, from the data we determine that the inter-arrival times of the patients are exponentially distributed. This is a precondition for a Poisson process. We can explain this by the fact that waiting times, in our definition, partly consist of voluntary waiting time. By modeling arrivals through a Poisson process, we include patient lateness in our queuing model. In the event-based simulation model we can simulate the arrival of each patient separately. Therefore, we will include appointment times and patient lateness to determine patient arrivals in this model.

We now model the arrival process with a Poisson process, with an estimated aggregated arrival rate λ equal to 6.2 patients per hour. The number of arrivals during the time registration period was on average less than normal, since the summer period is always less busy. By dividing the total number of patients per year over a total of 42 normal weeks and 10 weeks with reduced capacity of 50 % an average of 6.2 patients per hours was found.

Since a Poisson process remains Poisson under merging and splitting, we can divide the aggregated arrival rate over all patient classes p. We divide the aggregated arrival rate ε by the patient distribution determined in Section 4.4.1:

$$\eta_p = \frac{n_p}{N}\lambda \quad for \quad p = [1..4] \tag{30}$$

with

$$\lambda = \sum_{p=1}^{4} \eta_p \tag{31}$$

Table 4.3 gives the arrival rates.

Patient class	Arrival rate per hour (η_p)
A	3.04
B	0.58
N	2.19
M	0.38

Table 4.3: Patient arrival rates

Walk-in screening
Now that most patients at the PAC are no longer seen through an appointment, it is important to know when the consultation hours of the OPDs take place. Furthermore, it is important which OPD is situated at which location, since walk-in patients visit the PAC at the location of the OPD they visited. In Chapter 3 all OPDs taken into account are given. For all these OPDs, we have acquired the consultation hours and the length of an average planning slot. The division of patients over ASA classes, extracted from the time registration project data, for each specialty is also taken into account. The overall patient distribution used in section 4.4.1 is used for specialties for which there are not enough data entries to get a reliable distribution.

Location Kampen is not modeled separately as this location is currently only opened on Friday and therefore it will not be possible to be seen on basis of walk-in for most patients screened at location Kampen. A total of 19 ASA 1 + 2 (class A and N) and 5 ASA 3 + 4 (class B and M) patients per week from the OPDs located in Kampen have to be screened at the PAC. These patients can be seen on Friday in Kampen. The remaining time on Friday can be used to see appointment patients of the other two PAC locations.

As most walk-in patients arrive between 8:30 and 16:30 (except Friday afternoon) we only take the arrivals in between into account. In the new PAC design ASA 3 + 4 walk-in patients are sent away with an appointment. It is likely that the appointment screenings takes place outside the busy walk-in hours. By looking at the expected weekly amount of ASA 3 + 4 screenings compared to the number of available slots outside busy walk-in hours (9:00 – 16:30, except Friday afternoon), we estimate that 70 % of all ASA 3 + 4 patients can be seen outside busy walk-in hours. We define a as the percentage of ASA 3 + 4 patients (class B and M) arriving at locations SZ and WL that can be seen outside walk-in hours, for example before 9:00, after 16:00, on Friday afternoon, and on Friday at location Kampen.

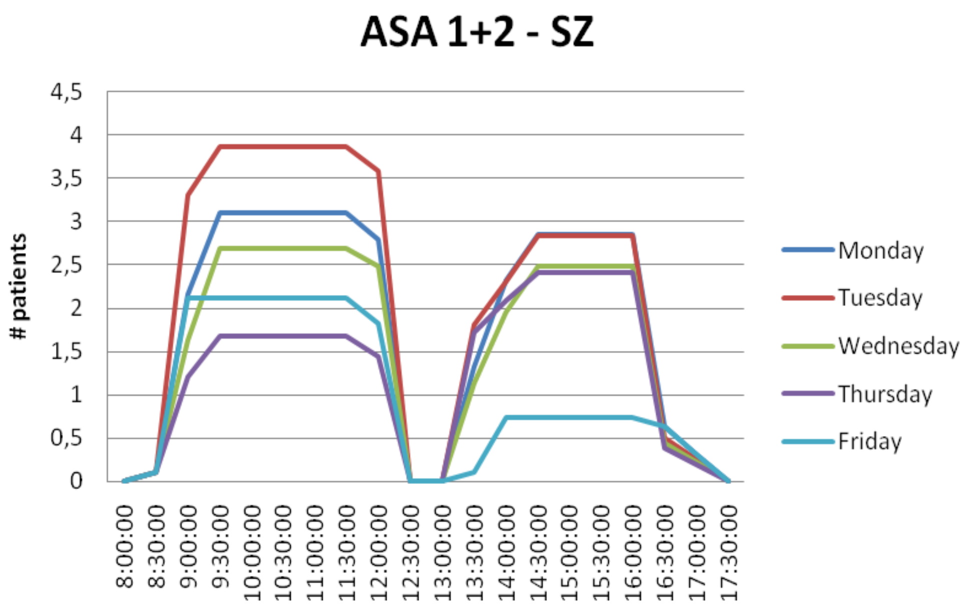

Figure 4.5: ASA 1 + 2 Patient arrivals for location SZ (artificially constructed through calculations)

We assume the patient arrivals follow a Poisson distribution. We define $l = 1$ for SZ, $l = 2$ for WL, and $\eta_{l,p}$ as the arrival rate at location l of patient class p. To estimate the arrival rate we have taken the average morning arrival rate of the three busiest weekdays. We did this to get results for the busiest periods in the week. We found aggregated arrival rates for patient class A and N, and B and M. We define $\lambda_{l,P''}$ as the aggregated arrival rate at location l with P'' defining the included patient classes p. P'' is 1 + 3 or 2 + 4. n_i is defined in Section 4.4.1. Figure 4.5 gives an overview of the arrivals over time of patient classes 1+3 for location SZ. We model the arrival processes as Poisson processes with arrival rate $\lambda_{1,1+3} = 6.4$, $\lambda_{1,2+4} = 1.3$, $\lambda_{2,1+3} = 5.7$, and $\lambda_{2,2+4} = 0.8$. A detailed overview of the arrival rates is given in Appendix F. We have approximated the Poisson arrival rates of the five patient classes' p for both locations l with the following calculations:

$$\eta_{l,p} = \lambda_{l,1+3} \frac{n_p}{n_1 + n_3} \quad for \quad p = 1,3 \quad and \quad l = 1,2 \tag{32}$$

$$\eta_{l,p} = \lambda_{l,2+4} \frac{n_p}{n_2 + n_4}(1-a) \quad for \quad p = 2,4 \quad and \quad l = 1,2 \tag{33}$$

$$\eta_{l,5} = a\lambda_{l,2+4} \quad for \quad l = 1,2 \tag{34}$$

with

$$\eta_{l,1} + \eta_{l,3} = \lambda_{l,1+3} \quad for \quad l = 1,2 \tag{35}$$

$$\eta_{l,2} + \eta_{l,4} = \lambda_{l,2+4} \quad for \quad l = 1,2 \tag{36}$$

These calculations lead to the arrival rates stated in Table 4.4.

Patient class *p*	**Arrival rate** $\eta_{1,p}$	**Arrival rate** $\eta_{2,p}$
1	3.72	3.31
2	0.24	0.15
3	2.68	2.39
4	0.15	0.09
5	0.91	0.56

Table 4.4: Arrival rates per patient class for location l

4.4.3 Consultation durations

The consultation times of all process steps (i.e. stations) in the PAC were measured in the time registration project. From this data we determine the distributions necessary for the queuing model.

Secretary
During the time registration project, it proved to be impossible to measure the time a secretary needed to help a patient at the desk. From discussion with the secretary and monitoring of the process, an estimate was made for the secretary consultation time. For many patients this process takes less than a minute. For a small group it takes longer. We estimate that this consultation time is exponentially distributed with mean ($E(S_{p,1})$) 2:30 minutes. Since the process is equivalent for all patient classes p this distribution is valid for all patient classes. As mentioned in Chapter 3 the secretary has more tasks besides welcoming and registering patients. The effective capacity of the secretary e_1 is estimated at 5/6.

Doctor's assistant and anesthesiologist
From the data of the time registration project we could determine the distribution of the consultation times of the doctor's assistant and anesthesiologist for each patient class. These screenings does not depend on the necessity of a nurse consult. Therefore we merge the datasets of patient class A and N, and B and M. This was also necessary because of the few measured patients in patient class N and M.

We now get the following datasets:

A-N / DA	Dataset of doctor's assistant consultation time of patient classes A and N
B-M / DA	Dataset of doctor's assistant consultation time of patient classes B and M
A-N / A	Dataset of anesthesiologist consultation time of patient classes A and N
B-M / A	Dataset of anesthesiologist consultation time of patient classes B and M

Through the plotted histograms we get the impression that a lognormal distribution fits best for all four datasets. Q-Q plots confirm this impression. Appendix E gives an overview of the histograms and Q-Q plots of all four datasets.

To get formal proof we execute the following steps for the datasets A-N and B-M:

1. Convert the data from minutes into seconds and sort them in ascending order
2. Define H_0 as the hypothesis that the data follows a lognormal distribution
3. Calculate the lognormal values $LN(X_i)$ for all i
4. Calculate the maximum likelihood estimators (MLEs) of the lognormal distribution
5. Perform the Kolmogorov-Smirnov test to calculate the test statistics using the MLEs
6. Reject or accept H_0

These steps are described by Law (2007), pp. 346-352. The K-S test does not reject (insufficient proof to reject) H_0 for both datasets at a 5 % significance level. The doctor's assistant consultation time for both datasets can be described with a lognormal distribution with parameters $\hat{\mu}$ and $\hat{\sigma}$ as given in Table 4.5.

Dataset	Scale parameter ($\hat{\mu}$)	Shape parameter ($\hat{\sigma}$)
A-N / DA	1.38	0.49
B-M / DA	1.72	0.56
A-N / A	1.81	0.43
B-M / A	2.26	0.49

Table 4.5: Parameters of consultation time distributions

The effective capacity e_2 and e_3 of the doctor's assistant and anesthesiologist are estimated at 5/6, and 11/12. These numbers are based on the observation that the doctor's assistant spends about 10 minutes per hour calling people into the examination room, some small administration duties, and drinking coffee. For the anesthesiologist it is estimated that five minutes per hour are spent on other activities, such as drinking coffee.

PAC nurse

The PAC nurse consult is only necessary for patient classes N and M. The distributions of this consultation time are determined in the same way as the determination of the previous consultation times. Again, a lognormal distribution gives the best fit. Table 4.6 gives an overview of the distribution parameters. The effective capacity e_4 is estimated at 11/12 as the PAC nurses has to do some administration and make arrangements for each patient seen.

Patient class	Scale parameter ($\hat{\mu}$)	Shape parameter ($\hat{\sigma}$)
N	2.40	0.52
M	2.76	0.49

Table 4.6: Parameters of PAC nurse consultation time distribution

The lognormal distribution provides a good fit for the consultation times of the doctor's assistant, anesthesiologist, and PAC nurse. We use these lognormal distributions in our model. We calculate the $E(S_{p,i})$ and $STD(S_{p,i})$ (standard deviation), and find results as given in Table 4.7.

At this point we have all input data necessary to perform the analysis of the current design and the proposed interventions. We show the results of the analysis in Chapter 5.

Employee	Patient class	Expected consultation time $E(S_{p,i})$	Standard deviation $STD\ (S_{p,i})$	Squared coefficient of variation $SCV_{S,p,i}$
Doctor's assistant	A and N	4:30	2:20	0.52
Doctor's assistant	B and M	6:32	3:58	0.61
Anesthesiologist	A and N	6:41	3:01	0.45
Anesthesiologist	B and M	10:51	5:41	0.52
PAC nurse	N	12:37	7:06	0.56
PAC nurse	M	17:55	9:24	0.52

Table 4.7: Consultation times for each patient class

Chapter 5
Analysis of current design and interventions

In this chapter we discuss the results of the analyses we performed through the models described in Chapter 4. We present the results for each intervention in separate paragraphs.

5.1 Results current design

This paragraph discusses the results of the queuing model for the current design. In the current design there is one secretary, one doctor's assistant, one anesthesiologist, and one PAC nurse available during consultation hours at all locations, so $c_1 = c_2 = c_3 = c_4 = 1$. The effective capacities, as described in Section 4.2.2, are $e_1 = e_2 = 5/6$, and $e_3 = e_4 = 11/12$.

The only data we have available from practice are the data from the time registration project. As discussed earlier, these data are not completely representative for the performance in busy periods. Therefore, we cannot compare results with these data. To get a feeling for the correctness of the results we ask the expert opinion of the PAC staff. The PAC staff indicates that the performance found through the model and presented below are representative for the current design.

Table 5.1 gives the performance of each station (i.e. process step). Table 5.2 gives the mean length of stay (LOS) for each patient class. The mean total number of patients present at the PAC is 5.47. The utilization rate of the anesthesiologist is 0.827, which leads to a waiting time that is long compared to the total LOS. A high utilization rate for the anesthesiologist is good, since it is the most expensive staff member at the PAC. However, higher utilization leads to longer waiting times. Section 5.1.2 investigates the influence of the anesthesiologist's utilization on the LOS. On average 65 % of the total LOS is occupied by waiting. This includes voluntary waiting time. We conclude that in the current design the anesthesiologist is the bottleneck station, which leads to a LOS that is on average about 3 times longer than the total consultation duration.

Station	**Utilization (ρ_i)**	**Expected waiting time $E(W_{Q,i})$**	**Expected # of patients waiting $E(L_{Q,i})$**	**Expected # of patients waiting + in service $E(L_i)$**
Secretary	0.310	00:01:21	0.14	0.35
Doctor's assistant	0.597	00:06:46	0.70	1.11
Anesthesiologist	0.827	00:26:26	2.73	3.43
PAC nurse	0.627	00:18:04	0.77	1.30

Table 5.1: Performance of the current design

Patient class	**LOS $E(V_p)$**
A	00:48:14
B	00:54:26
N	01:18:55
M	01:30:25

Table 5.2: Length of stay for each patient class in the current design

The results represent a situation with stable arrivals. With this performance the PAC can still be managed. The true problems arise when disturbances occur, such as temporarily increased demand and extended consultation time. As previously mentioned, we see considerable variation in consultation duration among all anesthesiologist's. As a consequence, the secretaries plan fewer patients during consultation hours attended by "slower" anesthesiologists. This has to be made up for during other consultation hours, by other anesthesiologists, leading to over-planned consultation hours. We will investigate the effects of increased demand and extended consultation duration in Section 5.1.2.

5.1.1 Validation

Through the initial simulation model described in Paragraph 4.3 we can validate the results found with the queuing model. We model screening on (mostly) appointment, by giving each patient an appointment slot of 10-minutes. During most hours we plan six 10-minute appointments, but during some hours we plan seven 10-minute appointments by planning two appointments at a time. This is also done in practice. On average 6.2 patients per hour are planned, analogue to the arrival rate used in the queuing model (Section 4.4.1).

We simulate the arrivals by giving patients an appointment time. Based on this appointment time and a random draw from the lateness distribution (see Appendix A), we calculate an arrival time. We must note that we register the waiting time including the voluntary waiting time (the time between arrival and appointment), to be able to compare results with the queuing model.

Five simulation runs of 2000 patients are made. We take a warm-up period of 100 patients during each run to reach a stable state. This number is well above the necessary warm-up period, but since simulation of this model does not account for much calculation time a run of 2000 patients is possible.

By comparing parameter values we can check the validity of the queuing model. Figure 5.1 and Table 5.4: Comparison of utilization rates. Table 5.4 give an overview of the comparing values for some important parameters, such as length-of-stay and utilization rates.

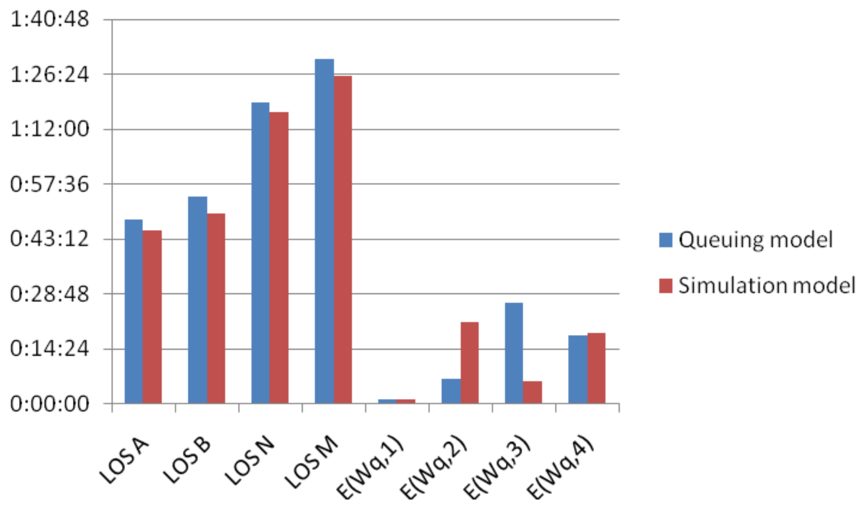

Figure 5.1: Comparison of important parameter values

Comparing the expected waiting times at each station we see that the waiting time for the secretary and PAC nurse are similar. The waiting times at the doctor's assistant and anesthesiologist are however different. This can be explained by the fact that in the simulation model the waiting capacity between the doctor's assistant and anesthesiologist is set to one. This is more realistic, since there are two consulation rooms available at each PAC location. The anesthesiologist sees patients in both consultation rooms. When the patient is seen by the doctor's assistant he/she waits in the consultation room for the anesthesiologist. The modeled waiting room 3 (see Figure 4.3) plus the ansthesiologist station have a capacity of two. In the simulation model the waiting time seen in the queuing model at the anesthesiologist station is shifted to the doctor's assistant station and vice versa.

Comparing the length of stay for each patient class similar results are seen, but all are somewhat lower in the simulation model. A reason could be the way in which the effective working time is modeled. In the queuing model we use the parameter e_i to model effective working time. In the simulation model we give each station breaks of 5 minutes randomly in time each 30 minutes or hour, depending on the station.

To test that both models do not differ significantly, we perform independent one-sample t-tests over the parameters shown in Figure 5.1. Independent, because the results we are comparing are from two different models with are independent. One sample, because we have one sample (the simulation models data) which we compare with a mean extracted from the queuing model.

We formulate the hypothesis H_0 as: no significant difference between the mean of the simulation model and the mean of the queuing model, $\overline{X} = \mu_0$. To test whether this is true, we calculate the *t* statistic with the following formula:

$$t = ABS\left(\frac{\overline{X} - \mu_0}{\sigma_X \sqrt{n}}\right) \tag{37}$$

where

$\overline{X}$	mean of the sample (simulation model data)
μ_0	mean of the queuing model
σ_X	standard deviation of the sample (simulation model data)
n	the number of runs (simulation model data)

We use n = 5 runs, for the calculation of all t-statistics. Table 5.3 gives the values for the t-statistic of each t-test. The t-statistic is compared with the t-table value with α=0.05 and df=n-1=4. This value is 2.776. If t<2.776 accept H_0.

Parameter	**t-statistic**	**Accept or reject H_0**
LOS A	1.09	Accept
LOS B	1.90	Accept
LOS N	1.09	Accept
LOS M	1.53	Accept
Waiting time secretary	1.39	Accept
Waiting time DA + anesthesiologist*	2.23	Accept
Waiting time PAC nurse	0.79	Accept

Table 5.3: T-test statistic value for each analyzed parameter

**We test the combined waiting time at the doctor's assistant and anesthesiologist, because these stations are modeled slightly different in each model as previously explained.*

All parameters show there is not enough evidence to reject our hypothesis (H_0). Therefore we may assume that the results are not significantly different. Besides these parameters, we look at the utilization rate. The utilization rates given in Table 5.4 are corrected for the effective working time. The utilization rates are similar for the queuing and simulation model, which is another indication to conclude that the results of both model are close to each other.

Station	Utilization rate (ρ_i) queuing model	Utilization rate (ρ_i) simulation model
Secretary	0.310	0.298
Doctor's assistant	0.597	0.576
Anesthesiologist	0.827	0.883
PAC Nurse	0.627	0.690

Table 5.4: Comparison of utilization rates

We conclude that the simulation model, as well as the queuing model, gives valid results, so that the results found through the queuing models are meaningful for practice.

5.1.2 Sensitivity analysis

To test the performance of the current design with increasing demand, we gradually increase the aggregated patient arrival rate and consequently evaluate the LOS. From this analysis it becomes clear that the system is now handling almost its maximum number of possible patients. Increasing the aggregated arrival rate λ from 6.2 to 7, leads to a doubled LOS for all patient classes. This is due to the high utilization rate of the anesthesiologist (= 0.827). Increased demand, and thus an increased arrival rate, leads to problems within the current design.

We test the effect of increased consultation time by gradually increasing the consultation time. We assume the distribution shape is the same for all anesthesiologists. Consequently, the standard coefficient of variation (SCV) stays the same for all patient class consultation distributions. Increasing the anesthesiologist consultation duration with 10 %, leads to a utilization rate of 0.91. This is very high and consequently leads to increasing LOS with 35 minutes for all patient classes. This means ASA 3+4 patients, visiting the PAC nurse, are at the PAC for over 2 hours. This is unacceptable for the management of the PAC. As previously mentioned, in practice this problem is dealt with by planning less patients during consultation hours of "slower" anesthesiologists, and more patients during consultation hours of "faster" anesthesiologists.

The current design proves to be vulnerable for increased demand and anesthesiologist's speed. As a consequence some patients are not be screened by the PAC, as we show in Section 3.3.4. We conclude that the performance of the current design is acceptable in a stable situation, but it is vulnerable for disturbances in the process, which lead to increased waiting time and non-screened patients. To measure the vulnerability of interventions we introduce the "robustness" factor of an intervention.

5.2 Intervention 1: planning with ASA classification

Currently patients are planned through their specialty type. As discussed before, this parameter does not give a good indication for the duration of the screening. We now analyze the effect of planning with ASA classification. When appointments are made through ASA classification we can adjust the appointment slot length. Given the consultation distributions, calculated in 4.4.3, we assume ASA 1+2 patients are planned with 10-minute slots and ASA 3+4 patients with 15-minute slots. Using planning slots we analyze two ways of planning:

1. Planning all patient classes within the same hours
2. Planning ASA 1+2 patients and ASA 3+4 patients in separate hours.

We will further address these way of planning as intervention 1A and 1B. With intervention 1A, we analyze the situation in which we plan three 10-minute (for ASA 1+2 patients) and two 15-minutes (for ASA 3+4 patients) slots per hour. We model the three PAC locations as one location, since working with appointments makes locations irrelevant, as we assume patients do not have a preference for a

PAC location. Consultation distributions and staff parameters (effective capacity) used are the same as in the model of the current design.

With intervention 1B, we introduce hours in which only ASA 1+2 patients (six per hour) are screened, and hours in which only ASA 3+4 patients (four per hour) are screened. Grouping patients with the same consultation characteristics decreases variability of the consultation times, and could therefore give better performance. Because we plan fewer patients per hour in both interventions we will need extra capacity to screen all patients: on average six consultation hours extra per week for both interventions. This is a disadvantage. Another disadvantage of these designs is that patients need to make an extra hospital visit for screening. This is why the hospital would like to design a walk-in setup.

We simulate both interventions in the simulation model, since we assume that all patients are seen on basis of appointments. The correct modeling of arrivals on basis of an appointment can easier be done in an event-based simulation model.

5.2.1 Results

Table 5.5 and Table 5.6 give the results of intervention 1A. In the tables, we indicate if the value is lower, equal or higher than the current design. The utilization rate of all staff decreases. As a consequence the LOS for each patient class decreases on average half an hour. However, this is not the main reason for the large decrease in LOS. The main reason is the fact that we now only plan 5 patients per hour and plan enough time for each patient to visit the anesthesiologist. The average number of patients at the PAC is three. One could argue that a part of the improved performance is due to the increased capacity (6 hours/week). This is true. However, comparing the results with the current design with six extra consultation hours, and thus a lower arrival rate per hour (5.6 vs. 6.2), still gives considerable improvements (15-20 minute decreased LOS). With this result, we show that the improvement seen with this intervention is not solely due to extra capacity.

Station	**Utilization** (ρ_i)	**Expected waiting time** $E(W_{Q,i})$
Secretary	0.200 ↓	00:01:04
Doctor's assistant	0.523 ↓	00:02:19
Anesthesiologist	0.789 ↓	00:05:35
PAC nurse	0.513 ↓	00:08:06

Table 5.5: Performance of intervention 1A

Patient class	**LOS** $E(V_p)$
A	00:23:06 ↓↓
B	00:26:21 ↓↓
N	00:44:34 ↓↓
M	00:51:45 ↓↓

Table 5.6: LOS for all patient classes for intervention 1A

This design will probably be less sensitive for the working speed of anesthesiologist, since we plan 10 minutes for ASA 1+2 patients, and 15 minutes for ASA 3+4 patients. These slots are about 30 % longer than the average anesthesiologist consultation duration of ASA 1+2 and ASA 3+4 patients. We will analyze the effect of disturbances on this intervention in Section 5.2.2.

Table 5.7 and Table 5.8 give the performance of intervention 1B. In the tables, we indicate if the value is lower, equal or higher than intervention 1A. The results are similar to the results of intervention 1A. We expected that the results would be better than the results of intervention 1A, since the variability of consultation durations decreases due to the so-called portfolio effect: by grouping appointments with similar variability the total variability is reduced, and therefore the available capacity equally increases. We do not see significant improvements through the portfolio effect. We do expect that intervention 1B is less sensitive to disturbances (increased demand and anesthesiologist's speed) then 1A, due to the portfolio effect. We analyze this in Section 5.2.2.

Consultation hours	Station	Utilization (ρ_i)	Expected waiting time $E(W_{Q,i})$
ASA 1+2 hours	Secretary	0.251 =	00:01:11
	Doctor's assistant	0.452 =	00:02:12
	Anesthesiologist	0.674 ↓	00:04:29
	PAC nurse	0.533 =	00:07:27
ASA 3+4 hours	Secretary	0.167 =	00:00:47
	Doctor's assistant	0.441 =	00:02:28
	Anesthesiologist	0.727 =	00:07:24
	PAC nurse	0.483 =	00:08:06

Table 5.7: Performance of intervention 1B

Patient class	LOS $E(V_p)$
A	00:21:40 =
B	00:30:40 =
N	00:41:33 =
M	00:56:34 =

Table 5.8: LOS for all patient classes for intervention 1B

We show with results of both interventions that by planning with realistic planning slots we can decrease the LOS and the average workload present at the PAC with almost 50 % (for LOS of patient class A and B, and for the workload). This is the reason we introduce ASA classification, since there is a relation between consultation duration and ASA classification.

5.2.2 Sensitivity analysis

Similar to the sensitivity analysis of the current design, we test the "robustness" of interventions by investigating the influence of disturbances on the performance. Since intervention 1A and 1B both require extra capacity, we test the influence of increasing the number of screened patients per hour. We initially increase the number of planned patients with 1 ASA 1+2 patient per hour. Thus, for intervention 1A, we plan 4 ASA 1+2 patients, and 2 ASA 3+4 patients per hour. For intervention 1B, we plan 7 ASA 1+2 patients per hour in ASA 1+2 hours, and 4 ASA 3+4 patients in ASA 3+4 hours. Both setups requires two extra consultation hours per week, compared to the current situation. Table 5.9 gives the LOS for all patient classes.

Patient class	LOS 1A $E(V_p)$	LOS 1B $E(V_p)$
A	00:31:00 ↑	00:25:48 ↑
B	00:34:09 ↑	00:30:40 =
N	00:58:34 ↑↑	00:49:39 ↑
M	01:04:50 ↑↑	00:56:34 =

Table 5.9: LOS with increased planned patients for intervention 1A and 1B

As expected the LOS for each patient class goes up through the increase of the number of planned patients per hour. In intervention 1B the LOS for patient class B and M stays equal, since these patients are screened in separate consultation hours. The results given in Table 5.9 show that intervention 1B is less sensitive to increased demand than intervention 1A.

To test the influence of the working speed of the anesthesiologist we perform several runs with our simulation model with decreasing anesthesiologist's speed. Figure 5.2 gives an overview of the influence on the LOS of patient classes A and N in intervention 1A and 1B. We see that for both patient classes the LOS increases more for intervention 1A compared to intervention 1B. We can therefore conclude that intervention 1B is less sensitive to decreasing anesthesiologist's speed.

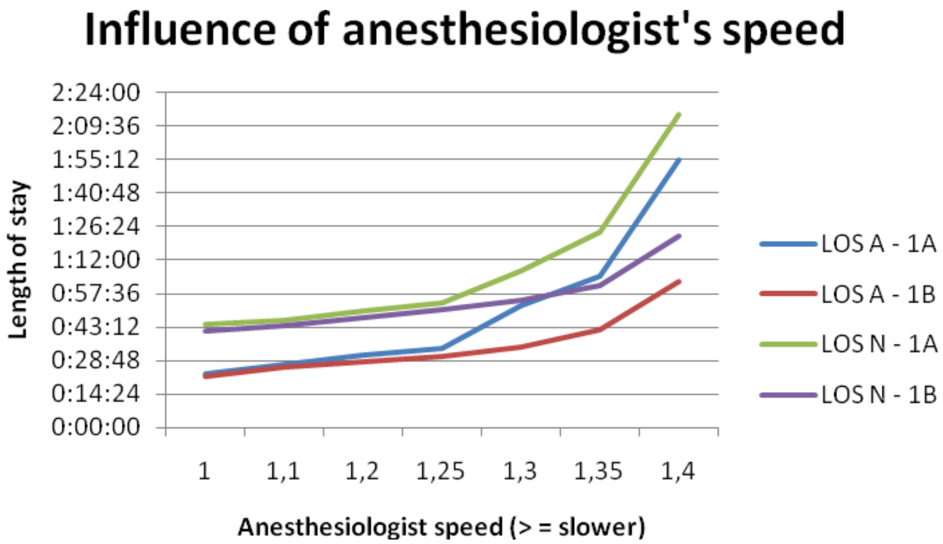

Figure 5.2: Influence of anesthesiologist's speed on LOS

By analyzing the influence of increased demand and anesthesiologist's speed we show that intervention 1B is more "robust" than intervention 1A. We contribute this to the portfolio effect: by grouping patients with similar screening characteristics in intervention 1B the total variability decreases. Comparing both interventions with the current design, we conclude that both are more "robust" than the current design. We contribute this to the use of differentiated planning slots (10-minute and 15-minute slots).

5.3 Intervention 2: patient walk-ins

In the current design patients are all seen on basis of an appointment. In the proposed pre-operative process patients go to the PAC immediately after their OPD consult. Initially we choose to model this intervention in the queuing model to get a quick insight in the performance of a walk-in setup. The assumption that arrivals are Poisson holds for a walk-in setup. Following the results of the queuing model, we analyze the effect of dynamic arrival rates through an event-based simulation model.

In our model, ASA 1 + 2 patients are treated immediately and (most) ASA 3 + 4 patients are sent home with an appointment. The model parameters are now no longer identical for all PAC locations. We therefore introduce an extra set l for the locations. This set is added to the arrival and consultation distribution parameters. Furthermore we introduce an extra patient class S ($p = 5$) for all patients from class B and M that are sent home with an appointment outside the considered consultation hours. Further parameters remain the same as described in Paragraph 4.2. The formulas used in the queuing model were slightly altered to model this intervention. These alterations are shown in Appendix D. We model the arrivals by aggregating the expected number of surgery patients seen at the OPDs of a PAC location (discussed in Section 4.4.2). We assume that patients seen at Kampen are not seen on basis of walk-in (except on Friday), but on appointment at PAC location Kampen on Friday.

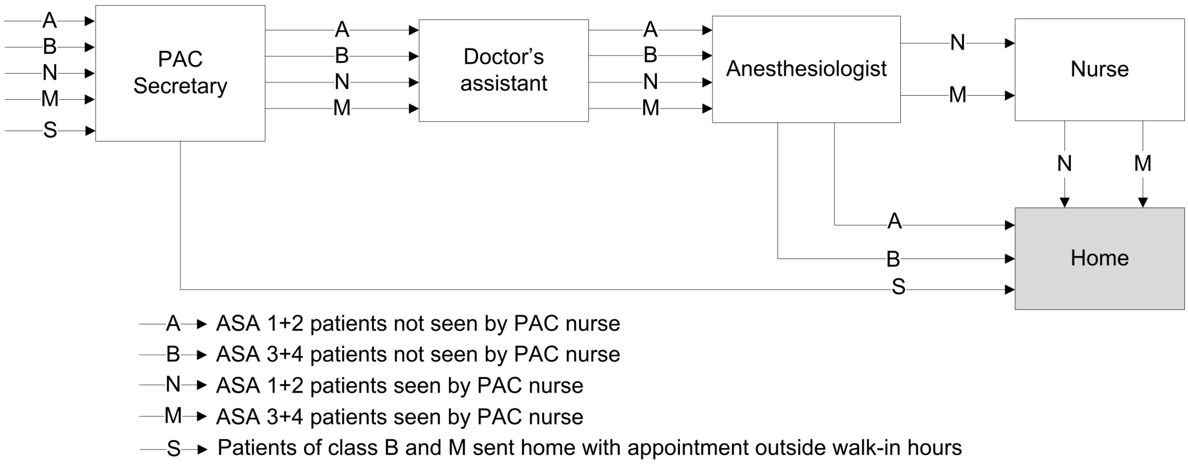

Figure 5.3: Patient flow model for intervention 2

The consultation distributions remain the same for the doctor's assistant, anesthesiologist, and PAC nurse. The number of staff also remains the same. This is equal for both locations. The consultation distribution for the secretary changes to $E(S_{l,p,1})$ = 4:00 minutes, for p = [1..4] and l = 1,2, because she now has to assess the ASA class of the patient by the questionnaire. $E(S_{l,5,1})$ = 5:00 minutes because the secretary has to make an appointment with the patient after the ASA class has been determined.

5.3.1 Results

Queuing model

The performance measures per station are given in Table 5.10. Table 5.11 gives an overview of the LOS for each patient class. This performance is the performance in peak hours. The utilization rate and therefore the waiting time at the secretary increases a lot, because she has to spend more time per patient determining the ASA class. It is advisable to have a backup secretary present to help in busy hours. In practice this would be possible, since several secretaries are present working at the back-office during consultation hours. If two secretaries would be available instead of one, the waiting time at the secretary and therefore the LOS would decrease with on average 6:00 minutes.

Table 5.10 and Table 5.11 give the results. The expected LOS decreases for all patient classes at location WL. At location SZ we see a substantial increase for all patient classes. This is due to the high utilization rate of the anesthesiologist. From these results it is clear that location SZ would be busier when patients would be seen on basis of walk-in. We expected this, since large specialties, such a General surgery and Plastic surgery, have their OPD at location SZ.

Location	Station	Utilization (ρ_i)	Expected waiting time $E(W_{Q,i})$	Expected # of patients waiting $E(L_{Q,i})$	Expected # of patients waiting + in service $E(L_i)$
SZ	Secretary	0.634 ↑	00:08:37	1.11	1.55
	Doctor's assistant	0.627 ↑	00:07:13	0.82	1.25
	Anesthesiologist	0.855 ↑	00:28:05	3.18	3.85
	PAC nurse	0.665 ↑	00:19:55	0.94	1.47
WL	Secretary	0.531 ↑	00:05:35	0.60	0.97
	Doctor's assistant	0.544 ↓	00:05:04	0.50	0.88
	Anesthesiologist	0.740 ↓	00:13:54	1.38	1.97
	PAC nurse	0.579 ↓	00:13:54	0.58	1.04

Table 5.10: Performance at both locations for intervention 2

Patient class	**LOS SZ** $E(V_{1,p})$	**LOS WL** $E(V_{2,p})$
A	00:59:06 ↑	00:39:43 ↓
B	01:05:18 ↑	00:45:55 ↓
N	01:31:38 ↑	01:06:14 ↓
M	01:43:08 ↑	01:17:44 ↓
S	00:12:44 -	00:09:40 -

Table 5.11: LOS for each patient class at both locations for intervention 2

In busy consultation hours extra capacity is necessary at location SZ to decrease the utilization rate of the anesthesiologist and consequently the LOS. For location WL, the LOS and utilization rates are acceptable. At location SZ, extra capacity is necessary to ensure that waiting times are acceptable. We note that these results represent the performance in peak hours. The results of the current design are representative for all consultation hours, since patients are spread over all consultation hours through appointments. For a walk-in setup (intervention 2) this is not the case, arrivals are dynamic and vary over time. This means the results given in this section represent the performance in peak hours. Performance over the whole day may be much better. We investigate the performance over the day with the event-based simulation model, discussed later on.

Since the LOS at location SZ is high in comparison with the current PAC design we investigate the effect of varying the percentage ASA 3+4 patients seen outside regular hours (parameter *a*). As becomes clear from Figure 5.4 increasing *a* from 0.7 to 0.95 can reduce LOS with about 15 minutes for all patient classes. However, this means that extra capacity is necessary outside regular consultation hours to screen these extra ASA 3+4 patients at location SZ. We further investigate this in our simulation model. Decreasing *a* increases the LOS, which is not acceptable, since the LOS is already high. We do not recommend seeing more than 80% inside regular consultation hours, since we only have a certain amount of available time outside consultation hours to plan ASA 3+4 appointments.

After analyzing the effect of increasing the arrival rate, it becomes clear that the system cannot handle large increases in patient arrivals in the busy consultation hours. An increase of the arrival rate with 5 % leads to a 25 % longer LOS on average at SZ, and 10 % longer LOS on average at WL. We estimate an increased arrival rate of 10 % is acceptable at location WL ($\lambda_{2,1+3} = 6.27$, $\lambda_{2,2+4} = 0.88$). Increasing the arrival rate at SZ is not acceptable. We remark that with an increased arrival rate, the number of ASA 3+4 patients screened outside regular consultation hours also increases, which may make it necessary to introduce extra consultation hours.

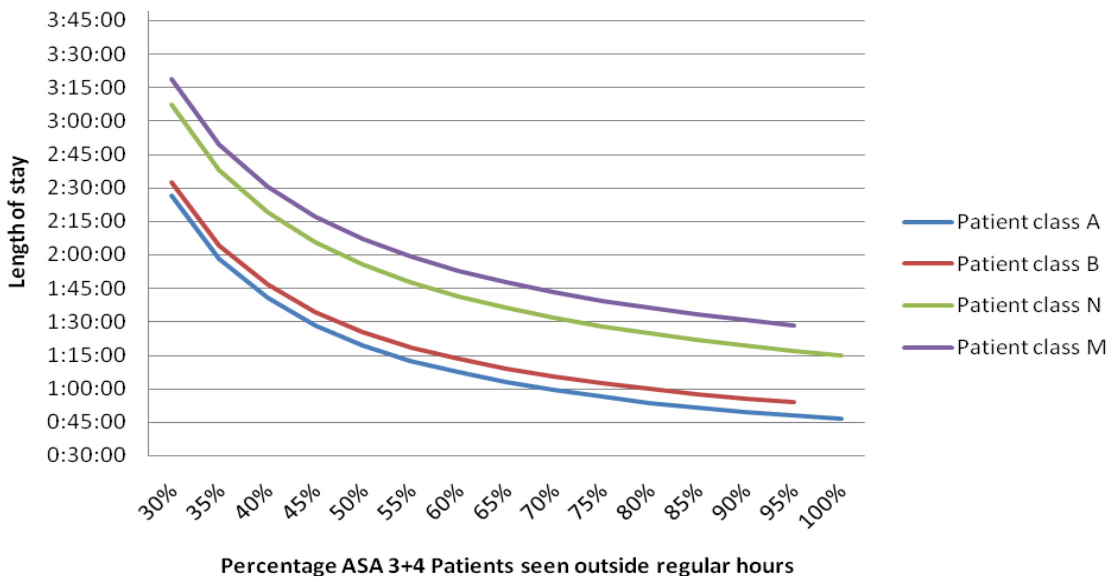

Figure 5.4: Influence of percentage ASA 3+4 patients seen outside regular hours on LOS at location SZ

As with the other interventions, we investigate the influence of prolonged consultation times. Figure 5.5 shows the effect of varying working speed of the anesthesiologist on the waiting time at the anesthesiologist station. A “speed factor” of 1 indicates an average speed. The higher the factor, the longer an anesthesiologist needs to screen a patient of a certain patient class.

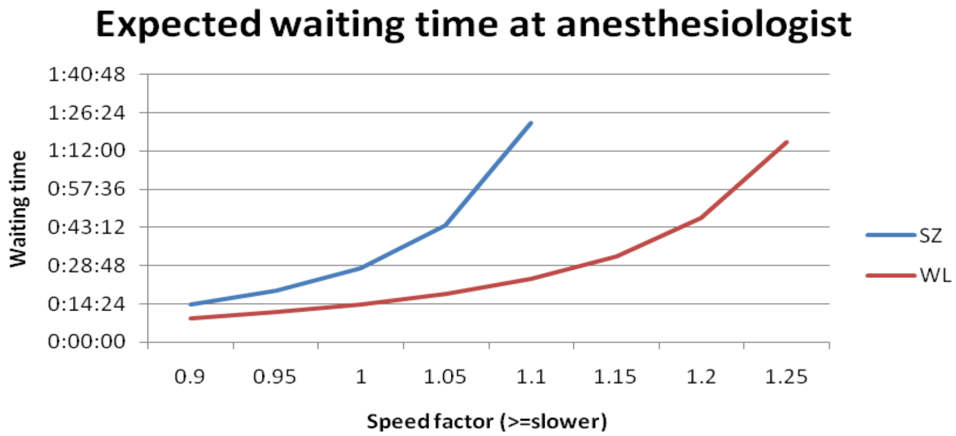

Figure 5.5: Influence of working speed of the anesthesiologist on waiting time

From Figure 5.5 it becomes clear that the speed of the anesthesiologist has a large effect on the waiting time and thus on the total LOS of a patient. Especially at location SZ it is very important that the anesthesiologist works fast enough, or else the number of waiting patients increases quickly. This effect is to be expected since the anesthesiologist’s screening is the bottleneck process of the PAC. Since we analyze the situation of peak arrivals over time, a lower working speed does not have large consequences on the performance over time. Patients who are screened in these busy hours, however, do feel the effect through much longer LOS. It is advisable to create extra capacity during these peak hours. This leads to the investigation of the use of nurse practitioners in Paragraph 5.4.

We conclude that the performance in a walk-in setup during peak hours give mixed results. At location WL, the waiting times are lower than the current design while at location SZ, the waiting times are longer. A walk-in setup with 70 % of ASA 3+4 patients seen outside busy walk-in hours does prove to be more robust for disturbances. Since a walk-in setup gives variation in arrivals we choose to further analyze this intervention in an event-based simulation model.

Event-based simulation model

To analyze the effects of the real-life dynamic situation with a varying arrival rate over time we use the event-based simulation model discussed in Paragraph 4.3. We use a run length of 2000 patients, which corresponds to about twelve weeks of PAC screening. No warm-up period is used, since we are interested in the performance over time, not the performance in a steady-state situation.

As in the queuing model we assume 70 % of all ASA 3+4 patients are seen on basis of an appointment outside the busy walk-in hours. We will further determine which hours are suitable to plan appointment patients.

Figure 5.6 gives an overview of the workload present at PAC locations SZ and WL during the week. Clearly, Monday and Tuesday are the busiest days of the week. The busy Tuesday morning at location SZ is mainly caused by large consultation blocks of the General surgery and Plastic surgery OPDs. The busy Monday and Tuesday at location WL are mainly caused by the large consultation blocks of the Orthopedic OPD. At location SZ it is significantly less busy in the afternoon. During these hours it could be possible to plan appointments with ASA 3 +4 patients. More appointments can be made at the beginning of the day before walk-in patients start arriving around 8:45. Figure 5.6 and Figure 5.7 indicate that on average there is more “space” at location SZ compared to location WL to plan appointment patients.

As a consequence of walk-in the morning peak in workload occurs between 11:00 and 12:00. Following this peak there is still workload between 12:00 and 13:00. This means that it is advisable to delay the current break in the PAC consultation hours (between 12:00 and 13:00) with e.g. one hour. We further investigate this in Section 5.3.2.

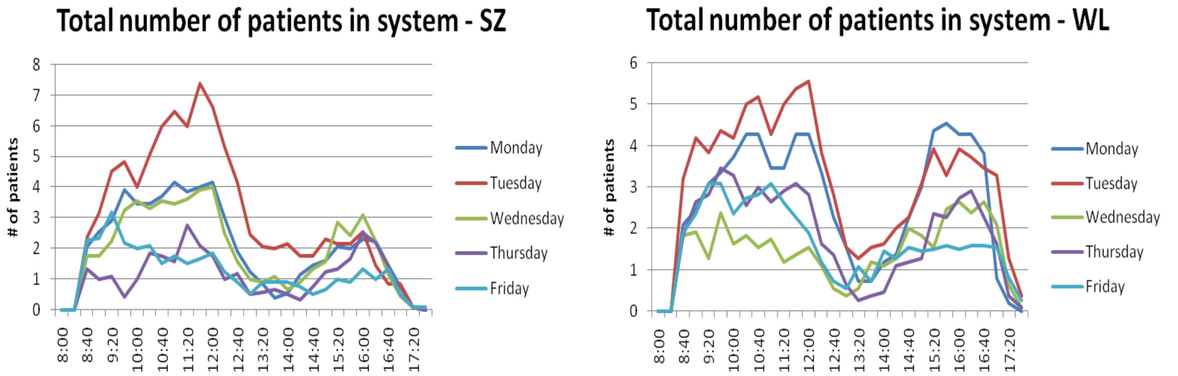

Figure 5.6: The number of patients at both PAC locations over time

As a consequence of the higher workload during a specific part of the week (Monday and Tuesday morning), the utilization rate of the anesthesiologist (bottleneck station) is high (above 85%) during these hours, as can be seen in Figure 5.7. However, these high utilization rates only occur in peaks, which leads to prolonged LOS for some patients (see Figure 5.8), but this is still acceptable. In some cases of high workload, it may be necessary to send away and make an appointment with a part of the walk-in patients.

Figure 5.8 and Table 5.12 indicate that during the high utilization hours LOSs are (almost) all below an hour. This is a very acceptable result for the stakeholders at the hospital. As expected, the values are lower then the results given by the queuing model as we analyzed a steady-state busy hours situation.

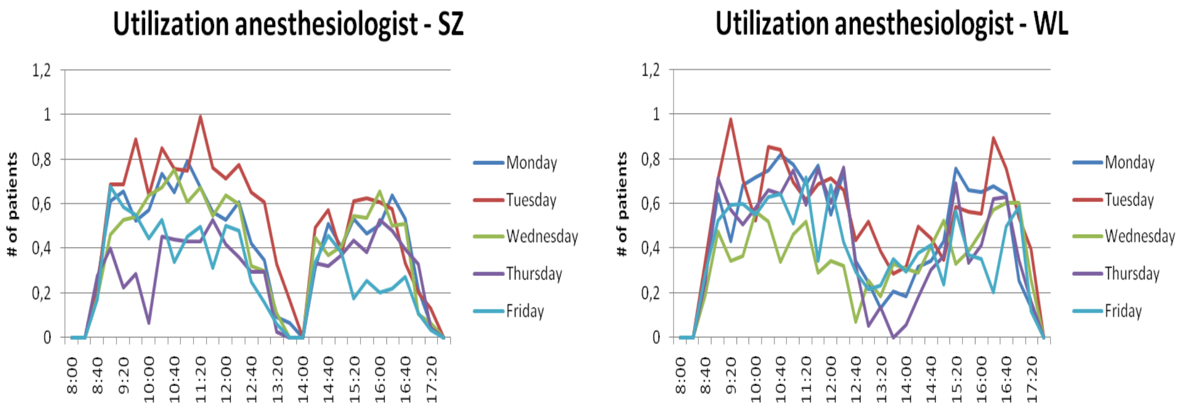

Figure 5.7: Utilization rate of bottleneck station at both PAC locations

We conclude that a walk-in setup of the consulation hours at the PAC is feasible with respect to the utilization rates and the LOS. A disadvantage of walk-in is the variation in the utilization of the capacity (in this case anesthesiologist time). We try to decrease this fluctuation by planning a part of the patients (ASA 3+4 patients) on less busy hours. We will investigate this in the next paragraph.

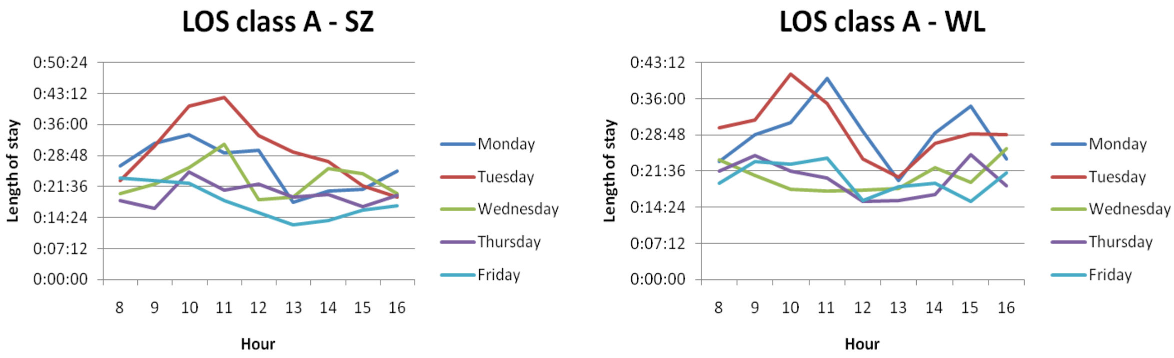

Figure 5.8: LOS at both PAC locations for patient class A

Part of week	**Patient class**			
	A	B	N	M
Monday morning*	00:29:31	00:29:22	00:45:08	00:54:32
Monday afternoon	00:20:32	00:26:59	00:38:55	00:50:27
Tuesday morning*	00:42:16	00:40:28	01:10:40	00:59:39
Tuesday afternoon	00:27:25	00:30:59	00:47:44	01:01:01
Wednesday morning*	00:31:21	00:26:48	00:44:21	01:19:45
Wednesday afternoon	00:25:42	00:16:22	00:41:00	00:28:37
Thursday morning	00:20:37	00:33:57	00:42:15	00:46:13
Thursday afternoon	00:19:34	00:15:54	00:42:28	00:48:13
Friday morning	00:18:21	00:21:44	00:33:32	00:59:19
Friday afternoon	00:13:28	00:19:57	00:39:00	00:54:12

Table 5.12: LOS over the week for all patient classes at PAC location SZ

**These consultation sessions are the busiest sessions at PAC location SZ*

5.3.2 Sensitivity analysis

In the previous paragraph we have analyzed the results of the simulation model. Within this paragraph we analyze the effect of the following practicalities on the performance of the system:

1. Lunch break for PAC staff
2. Planning of ASA 3+4 appointment patients

Figure 5.6 indicates the workload fluctuates over the day. We now investigate the effect of planning appointments in the “low workload” consultation hours. Another disadvantage of the walk-in system is the arrival of patients during all hours of the day. This makes a fixed lunch break difficult. However, it is possible during an hour of few arrivals. Patients arriving within the break will accumulate in the waiting room and create an increased workload at the beginning of the afternoon consultation session.

In Figure 5.9 we represent the workload over time when a lunch break is held between 13:00 and 14:00. This means that all patients arriving in the lunch break have to wait until at least 14:00 to be screened. All patients in the system at 13:00 are screened before the actual lunch break starts. Comparing Figure 5.9 with Figure 5.6, we see that as a consequence of the lunch break, workload increases at the beginning of the afternoon consultation session. Figure 5.10 shows that the LOS also increased, as expected. This increase is on average about 30 minutes.

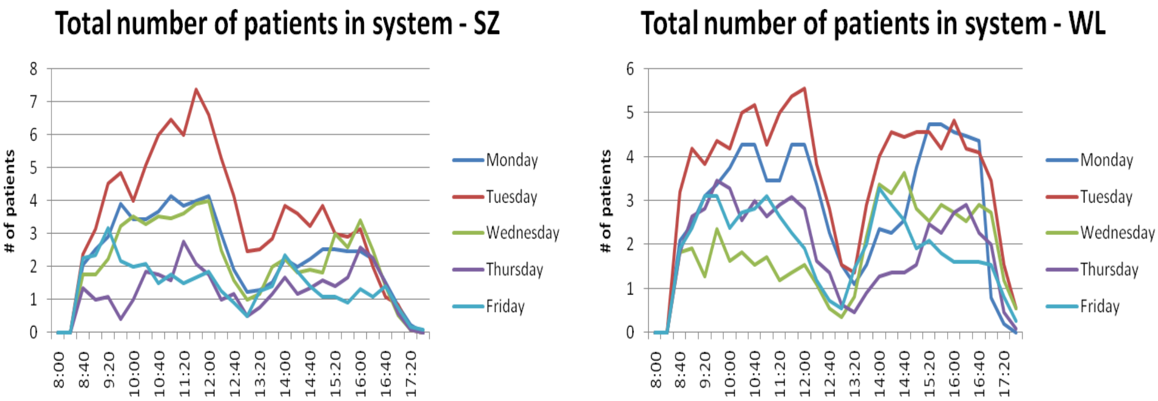

Figure 5.9: Total number of patients at both PAC locations, when lunch break is included

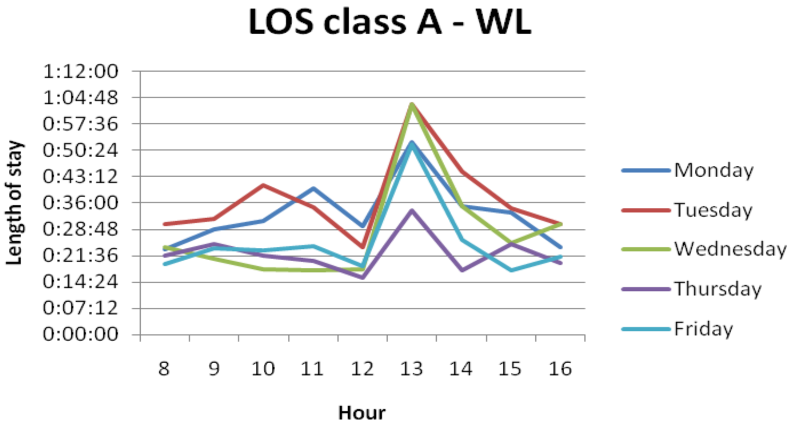

Figure 5.10: LOS at PAC location WL for patient class A

In the models we assume that 70 % of all ASA 3+4 patients are seen on basis of appointments. From the simulation runs we see that this is equal to 35 ASA 3+4 patients at location SZ, and 33 ASA 3+4 patients at location WL. Location KP has enough capacity on Friday to handle patients from the Kampen OPDs and extra capacity to handle a part of these ASA 3+4 appointment patients. We assume 16 15 minute-appointment slots can be created at Location KP to screen ASA 3+4 patients. To create a margin, we plan 56 appointment slots in the schedule of the consultation sessions held at PAC locations SZ and WL. Table 5.13 gives the allocation of these appointments. We distribute these slots evenly over the time frame.

Location	Time period	# of slots per day	Total # of slots
SZ	Each day: 8:00-8:30	2	10
	Each day: 14:30-15:30	3	15
	Wed-Fri: 9:00-12:00	4	12
WL	Each day: 8:00-8:30	2	10
	Thu-Fri: 14:30-16:00	4	8

Table 5.13: Allocation of appointment slots per week at PAC locations SZ and WL

When we simulate the arrival of walk-in patients combined with ASA 3+4 appointment patients as in Table 5.13, we find the results given in Figure 5.11.

By planning appointments at the given time periods we see that the workload is spread more evenly over time. Wednesday morning is the least busy period at PAC location WL. It is possible to plan some extra appointments during this time period. As a consequence of appointments during the afternoon the workload at the end of the day increases and the end time of the afternoon consultation sessions will have to be delayed. Patients arrive up to 17:00, which leads to workload up to 17:30. In practice, a choice can be made to plan an appointment for patients that arrive at the end of the day. These appointments could be planned on Thursday morning at location SZ or Wednesday morning at location WL.

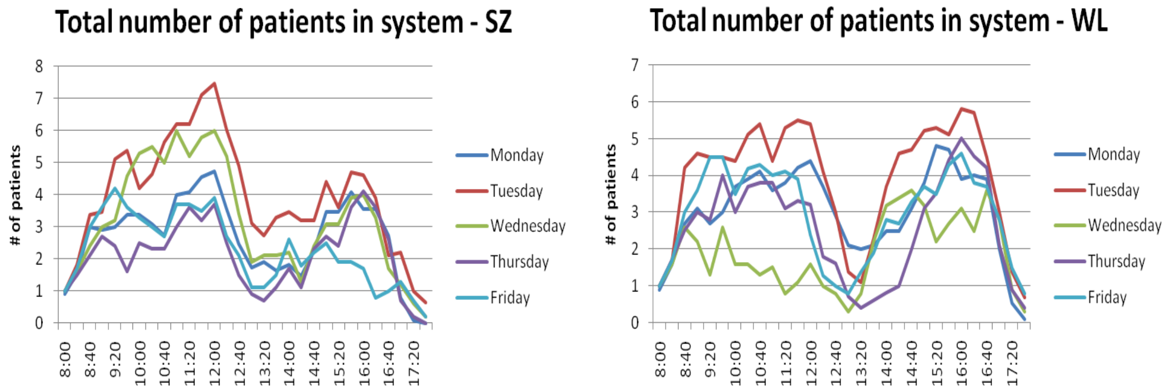

Figure 5.11: Total number of patients at both PAC locations, appointment patients included

Figure 5.12 gives the utilization rate of the anesthesiologist at both locations over the week. On average (excluding lunch break) the utilization rate is 0.7. We see some variation over time, but overall the anesthesiologist can handle the workload, without too much idle time.

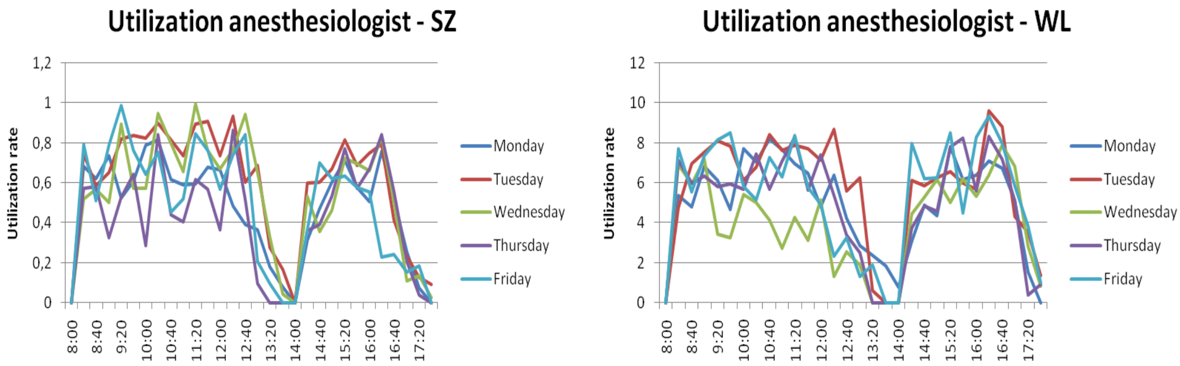

Figure 5.12: Utilization rate of the anesthesiologist at both PAC locations, appointment patients included

Table 5.14 gives the average LOS. What is surprising, is the fact that patient class B has a shorter LOS compared to patient class A (at both locations), and patient class M a shorter LOS compared to patient class N (at location SZ). We contribute this to the fact that the ASA 3+4 patients with an appointment (70 %) are planned on timeslots when workload is low. When we inspect the LOS of appointment patients vs. walk-in patients (of class B and M), appointment patients have a 12 minute shorter LOS on average.

Patient class	**LOS SZ** $E(V_{1,p})$	**LOS WL** $E(V_{2,p})$
A	00:31:46 ↓	00:33:01 ↓
B	00:30:59 ↓	00:31:00 ↓
N	00:55:57 ↓	00:53:01 ↓
M	00:52:38 ↓	00:55:02 ↓

Table 5.14: Expected LOS for each patient class at both PAC locations

We conclude that by planning appointments in the proposed time intervals we balance workload more evenly over time and offer patients an acceptable LOS. During the busy hours it is advisable to have extra capacity, especially at location SZ. We analyze this in intervention 3. An alternative could be to make appointments with patients arriving when workload is already high. These patients can be scheduled on the same day during low workload hours or on another day. We do not investigate at what workload rate this decision should be made. Zonderland (2007) addresses this issue at the PAC of Leiden University Medical Center. They start sending home patients with an appointment when more than four patients are waiting in the waiting room.

5.4 Intervention 3: use of nurse practitioners

As we conclude in the previous paragraphs capacity in peak hours could be a problem if the demand for patient screenings increases. In this intervention nurse practitioners (NP) staff the PAC in busy consultation hours, aside the anesthesiologist, to form extra capacity. We assume a NP only sees ASA 1+2 patients. Figure 5.13 gives an overview of the patient flow for this intervention.

We assume a walk-in setting as described in intervention 2. The patient arrival rates are the same as in intervention 2. Furthermore, we assume that 70 % of all ASA 3+4 patients are seen outside regular walk-in consultation hours.

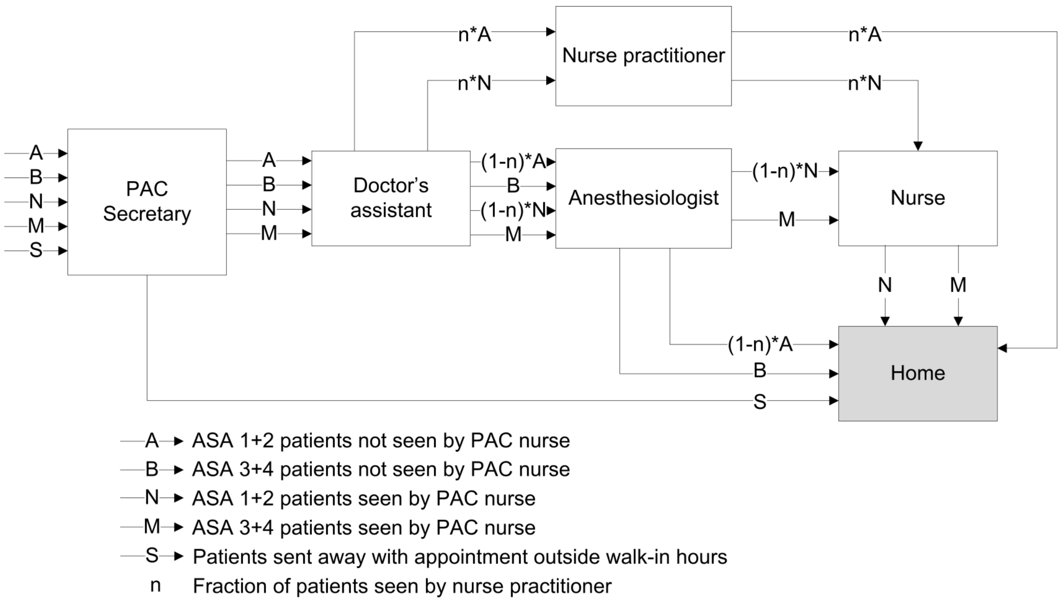

Figure 5.13: Patient flow for intervention 3

Consultation distributions remain the same for all PAC staff. The consultation distribution of the nurse practitioner is derived from the consultation distribution of the anesthesiologist. We assume a lognormal distribution. In discussion with the anesthesiologists we have estimated that the nurse practitioner needs 50 % more time than the anesthesiologist for ASA 1+2 patients. This leads $E(S_{p,i})$ = 10:01, and $STD(S_{p,i})$ = 4:31 for p=1,3. For both locations we choose $c_5 = 1$ and $e_5 = 5/6$.

5.4.1 Results

As an initial solution we assume the fraction of ASA 1+2 patients seen by the nurse practitioner to be 50 % ($n = 0.5$). Table 5.15 and Table 5.16 give an overview of the performance of this intervention. As a consequence of the use of a NP, the utilization rate of the anesthesiologist and the LOS for all patient classes decreases significantly. The LOS for patient class A and N is quite different comparing patients who are treated by the anesthesiologist and patients treated by the NP. In the next section, we further investigate this.

Location	Station	Utilization (ρ_i)	Expected waiting time $E(W_{Q,i})$	Expected # of patients waiting $E(L_{Q,i})$	Expected # of patients waiting + in service $E(L_i)$
SZ	Secretary	0.634	00:08:37	1.11	1.55
	Doctor's assistant	0.627	00:07:13	0.82	1.25
	Anesthesiologist	0.412	00:03:56	0.23	0.63
	PAC nurse	0.630	00:17:34	0.83	1.39
	Nurse practitioner	0.642	00:15:21	0.82	1.26
WL	Secretary	0.531	00:05:35	0.60	0.97
	Doctor's assistant	0.544	00:05:04	0.50	0.88
	Anesthesiologist	0.361	00:03:05	0.16	0.49
	PAC nurse	0.557	00:13:21	0.55	1.04
	Nurse practitioner	0.513	00:09:22	0.45	0.80

Table 5.15: Performance at both locations for intervention 3

Patient class	LOS SZ $E(V_{1,p})$	LOS WL $E(V_{2,p})$
A – Anesthesiologist	00:34:57 ↓	00:28:55 ↓
A – Nurse practitioner	00:49:43 =	00:37:31 ↓
B	00:41:09 ↓	00:35:07 ↓
N – Anesthesiologist	01:05:07 ↓	00:54:52 ↓
N – Nurse practitioner	01:19:53 =	01:03:28 ↓
M	01:16:37 ↓	01:06:22 ↓
S	00:12:44 =	00:09:40 =

Table 5.16: LOS for each patient class at both locations for intervention 3

5.4.2 Sensitivity analysis

What stands out from the results in Table 5.15 and Table 5.16 is the low utilization rate of the anesthesiologist and the difference in LOS for patients of the same class screened by the anesthesiologist versus patients screened by the NP. When we analyze the LOS comparing patients who are screened by the anesthesiologist versus patient who are screened by the NP we see that there is an optimal value of n. When we increase n we see two things, which leads to an optimum value for n (see Figure 5.14):

1. LOS for patients screened by the NP increases
2. LOS for patients screened by the anesthesiologist decreases

Decreasing n gives the opposite results. Knowing this, we can find an optimal value of n by calculating the weighted average LOS for patient classes A and N.

For both locations we find an optimal value of $n = 0.35$. At this level the weighted average LOS for patient classes A and N is optimal and the LOS for patient classes B and M is acceptable compared to the other interventions. Table 5.17 and Table 5.18 give an overview of the performance with optimal n. With the symbols in the tables, we indicate if the results improve, deteriorate, or are equal compared to the results in Table 5.15 and Table 5.16.

Comparing the results with the performance in peak hours of intervention 2, we see that LOS is on average 30 % better for location SZ, and 20 % better for location WL. This indicates that the use of a NP in peak hours leads to a LOS for each patient class that is comparable to the LOS during non-peak hours, when a NP is not used.

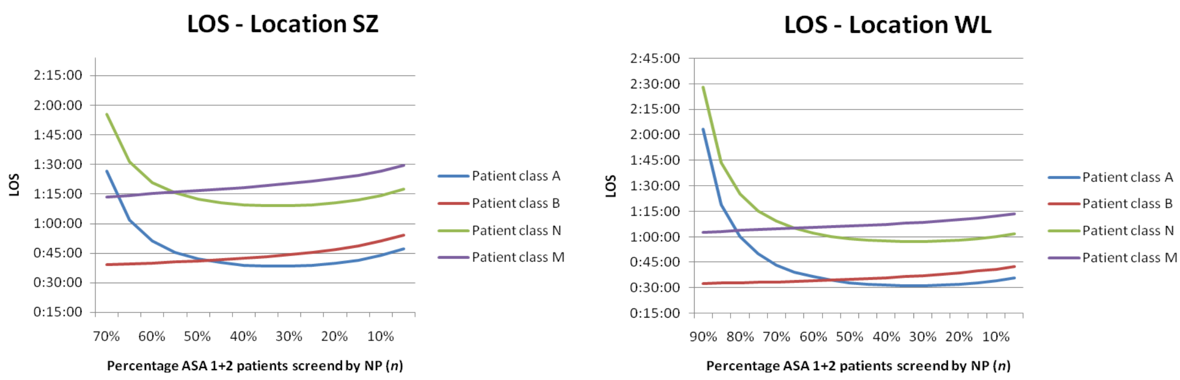

Figure 5.14: LOS in relation to value of n

Location	**Station**	**Utilization** (ρ_i)	**Expected waiting time** $E(W_{Q,i})$	**Expected # of patients waiting** $E(L_{Q,i})$	**Expected # of patients waiting + in service** $E(L_i)$
SZ	Secretary	0.634 =	00:08:37 =	1.11	1.55
	Doctor's assistant	0.627 =	00:07:13 =	0.82	1.25
	Anesthesiologist	0.529 ↑	00:06:07 =	0.46	0.95
	PAC nurse	0.630 =	00:17:56 =	0.85	1.41
	Nurse practitioner	0.449 ↓	00:07:02 ↓	0.26	0.57
WL	Secretary	0.531 =	00:05:35 =	0.60	0.97
	Doctor's assistant	0.544 =	00:05:04 =	0.50	0.88
	Anesthesiologist	0.464 ↑	00:04:39 =	0.31	0.72
	PAC nurse	0.557 =	00:13:23 =	0.55	1.04
	Nurse practitioner	0.359 ↓	00:05:00 ↓	0.17	0.42

Table 5.17: Performance at both locations with optimal n

Patient class	**LOS SZ** $E(V_{1,p})$	**LOS WL** $E(V_{2,p})$
A – Anesthesiologist	00:37:08 =	00:30:28 =
A – Nurse practitioner	00:41:23 ↓	00:33:09 ↓
B	00:43:20 =	00:36:40 =
N – Anesthesiologist	01:07:41 =	00:56:29 =
N – Nurse practitioner	01:11:56 ↓	00:59:09 ↓
M	01:19:11 =	01:07:59 =
S	00:12:44 =	00:09:40 =

Table 5.18: LOS for each patient class at both locations with optimal n

Analyzing the effect of increasing demand within this design, we see that an increase of 6 % is still acceptable for location SZ looking at the LOS and utilization rates compared to the current design. For location WL an increase of 22% is still acceptable. With this design we can screen more patients, but have to hire a NP. Given the current screening demand a NP is not yet necessary. When a NP is used, this is only necessary in busy consultation hours.

5.5 Conclusions

In this paragraph we discuss the results found in the analysis of the current design and the proposed interventions and draw conclusions from these results.

The analysis of the current design showed that the anesthesiologist is, as expected, the bottleneck at the PAC. The high utilization rate of the anesthesiologist indicates that the current system is screening almost its maximum amount of possible patients. The LOS is quite long for all patient classes. The real problem of the current design is its "robustness": the ability to deal with disturbances. We see this through: (1) an increased demand of 10 % leads to 2 times longer waiting times, and (2) a 10% slower than average anesthesiologist's working speed leads to an increase of the LOS for all patient classes with 35 minutes. We contribute these effects mainly to the poor relation between the planned screening time for a patient, and the actual necessary screening time. We conclude that the current design it is not possible to handle increased screening demand.

Intervention 1A and 1B show that ASA classification is a useful classification measure. By planning with 10-minute and 15-minute slots we reduce the LOS for each patient class with 40-50 %. By grouping patients of the same ASA class (intervention 1B) we achieve similar performance. Both interventions are more robust then the current design. Increasing the number of screenings per hour with 1 ASA 1+2 patient increases LOS with 30% on average for intervention 1A, and 20% on average for intervention 1B (compared to 100% increase in current design, going from 6.2 to 7 arrivals/hour). Intervention 1A and 1B are significantly less vulnerable to anesthesiologist's working speed. With a 25 % decrease in speed LOS for patient class A is 30 minutes, and 50 minutes for patient class N, in both interventions. Compare this to the current design, that already performs significantly worse with an anesthesiologist's working speed of 10%. Comparing intervention 1A and 1B, we see that intervention 1B is more robust then intervention 1A. We contribute this to the portfolio effect. A drawback of intervention 1A and 1B is the need for six extra consultation hours per week. Another drawback is the necessity for an extra hospital visit.

Intervention 2 shows that screening on basis of walk-in is possible. If a part of all ASA 3+4 patients is seen on basis of an appointment, all ASA 1+2 patients can be seen on basis of walk-in with similar LOS during peak hours, compared to the current design. We have assumed an extra consultation day is held at location WL on Tuesday, because the walk-in rate is high on Tuesday. With the current capacity (including the Tuesday at location WL), it becomes clear that with a walk-in setup increased screening demand over 10 % cannot be handled. Extra capacity has to be used when demand increases more than 10 %. The working speed of the anesthesiologist is another major factor influencing the LOS. Decreasing speed with 10 % leads to a two times longer expected waiting time at the anesthesiologist station during peak hours. This is another indication for extra capacity in peak consultation hours.

Analyzing the performance over time, we show that by planning a break between 13:00 and 14:00, and planning appointments (ASA 3+4 patients) during time periods of low workload, we can spread patient screenings over time and improve the performance outside the peak hours with 40%: on average a LOS of 30 minutes for all patients of patient classes A and B, and on average a LOS of 50 minutes for all patients of patient classes N and M. We estimate that 70 % of all ASA 3+4 patients can be seen on basis of an appointment. We plan these appointments during periods of low workload:

Location	Time period	# of slots per day	Total # of slots
SZ	Each day: 8:00-8:30	2	10
	Each day: 14:30-15:30	3	15
	Wed-Fri: 9:00-12:00	4	12
WL	Each day: 8:00-8:30	2	10
	Thu-Fri: 14:30-16:00	4	8

Table 5.19: Planning of appointment slots during the week

As we can see in the results of the queuing model, high workload occurs during the peak hours (7 patients in system), leading to much longer LOS. In these periods we recommend extra capacity to keep the LOS on an acceptable level.

Intervention 3 shows that by creating extra capacity through a nurse practitioner in a walk-in setup, we can guarantee LOSs that are higher than the LOS for patients screened during non-peak walk-in hours (A: 35 min., B: 40 min., N: 60 min., M: 70 min.), but lower than the current LOSs. In the future, when demands increases, a NP could be used during all consultation hours. An increase of demand of at least 20% is possible within this design.

For each intervention we have determined the robustness. Comparing the robustness we see that interventions 1A and 1B perform best. We contribute this to the length of the used planning slots, which corresponds to the actual consultation duration. Intervention 2 (walk-in setup) has problems dealing with disturbances during peak hours, but overall can handle increased demand and anesthesiologist' working speed, since periods with a low walk-in rate make it possible to handle extra patients. Intervention 3 shows that with the use of a NP in peak hours, we can deal with the high workload and offer normal LOS for patients screened during peak hours. The current design proves to be the least robust.

Summarizing, we conclude the following:

- The current design gives acceptable performance, but cannot deal with increased demand and decreased anesthesiologist's working speed. This makes it a vulnerable design, since it is known that anesthesiologist's workings speed varies over all anesthesiologists, and demand may increase in the future.
- ASA classification is an adequate measure to classify patients, since it has a proven relation with the actual screening duration.
- ASA 1+2 patients should be planned in 10-minute slots, and ASA 3+4 patients should be planned in 15-minute slots.
- Planning through ASA classification improves performance with 40-50 % and offers more robustness with respect to increased demand and decreasing anesthesiologist's working speed.
- Anesthesiologist's working speed has a large influence on the total LOS of all patients at the PAC. An appointment setup (intervention 1A and 1B) is less vulnerable to this disturbance compared to a walk-in setup.
- Within a walk-in setup the end time of the consultation session will have to be extended up to 17:00. As an alternative, patients arriving at the end of the day could be seen away with an appointment.
- Within a walk-in setup an extra consultation day will be necessary at location WL on Tuesday.
- Within a walk-in setup the lunch break has to move with an hour to between 13:00 and 14:00, to account for the large amount of walk-ins at the end of the morning session.
- A walk-in setup improves the performance with 40% on average outside peak hours. During the peak hours performance is equal to the current design.
- The use of a nurse practitioner during peak hours reduces the workload of the anesthesiologist and gives extra capacity for increased screening demand in the future. Optimally 35 % of all patient class A and N patients should be screened by the nurse practitioner.

We show that both an appointment system as a walk-in system perform well and prove to be robust. An advantage of an appointment system is that arrivals are easier controllable. A disadvantage is the longer access time, which is often seen in practice in an appointment system (as in the current design). A walk-in system is more difficult to control, since arrivals fluctuate. However, the access time is much shorter. The fundamental choice for one of both systems depends on what the hospital management defines as acceptable performance. Table 5.20 gives an overview of the performance of both systems. We show that the LOS is in both systems comparable. The amount of extra consultation hours needed is also comparable. In a walk-in setup the LOS will fluctuate more as arrival fluctuate. To compensate for this, more patients will have to be sent away with an appointment (which some patient will prefer) or extra capacity (in the form of an NP) is necessary during the busy hours.

The choice for one of the systems depends on some fundamental choices the hospital has to make and what performance, with respect to access time, LOS, and utilization, the management of the PAC finds acceptable. In the next chapter we will show which fundamental questions are important, and how to implement a new PAC design.

Parameter		**Appointment system (Intervention 1B)**	**Walk-in system (Intervention 2)**
Average LOS	A B N M	00:21:40 00:30:40 00:41:33 00:56:34	00:32:23 00:31:00 00:54:29 00:53:50
Average Anesthesiologist utilization		0.70	0.63
Access time		Can be long (21 days)	Short (mostly 1 day)
Extra consultation hours necessary		8 hours/ week	One screening day (Tuesday at WL)
NP necessary during peak hours		No	Yes, or send patients away with appointment
System robustness		Very good	Good
Controllability of arrivals		Very Good	Poor

Table 5.20: Comparison of performance appointment system and walk-in system

Chapter 6

Implementation

In the previous chapters, we have analyzed the pre-operative process, measured its performance and designed interventions to improve the performance of the PAC. This chapter investigates how to implement a new design at the PAC, and what questions have to be answered to be able to implement the chosen design. In Paragraph 6.1, we determine which stakeholders are present in the preoperative process, and what the perceived attitude of these stakeholders is towards effects of a system change (appointment or walk-in system). From this analysis we show that there are still fundamental questions to be answered, and choices to be made.

6.1 Stakeholders analysis

Throughout this research we deal with a lot of people who have an interest in the preoperative process. To be able to perform a stakeholder analysis we choose to divide these people in the following main categories:

1. Patient visiting the PAC before surgery
2. Management of the hospital and PAC
3. Anesthesiologists performing screening
4. PAC staff (secretaries, doctor's assistants, and PAC nurse)
5. The outpatient departments (OPD), sending their patients to the PAC

The patient is the main stakeholder, since the patient is the "product" a hospital works with. The attitude of the patients towards the system performance is important for the hospital. The management of the hospital and the management of the PAC are stakeholders with an economical perspective. They want the preoperative process running efficiently and effectively, but not at all costs. The anesthesiologist is the most important member of the PAC staff, since he/she eventually performs the main task of the PAC: evaluating the patient's readiness for surgery.

We separate the PAC staff in two stakeholders: (1) the anesthesiologists and (2) the rest of the PAC staff. We do this because both groups experience the difference between both systems differently (e.g. different utilization rate). The tasks of the anesthesiologist does not change, will other staff, e.g. the secretary, has to change some of her routines when a walk-in system is introduced. The anesthesiologist wants to optimize the care for each individual patient, without having to work "too fast" because of a full waiting room (and thus high utilization). We include the OPDs, because the chosen design also affects the way they have to work. For example, in a walk-in design, the OPDs no longer have to plan patients on the PAC itself.

For each defined stakeholder, we analyze the effect of a parameter value, in both an appointment system, as a walk-in system. We give the perceived effects on stakeholders based on all experiences and interviews during the period of this research. A detailed analysis in the attitude towards the performance of both system designs is beyond the scope of this research. Table 6.1 gives an overview of the stakeholder analysis.

From a patient's perspective the important factors are the ones that influence them directly. The length of stay and the access time are performance indicators that have a direct impact on the patient. Therefore these indicators are important to the patient. The average LOS (and waiting time) in an appointment system, as proposed in intervention 1, is expected to be shorter compared to a walk-in system (intervention 2). Logically, we can reason that patients (and hospital management) appreciate a shorter LOS, and thus would prefer an appointment system. On the other hand, patients may also appreciate a short access time, which favors a walk-in system. Here, fundamental questions arise: what LOS do patients find acceptable, what access time do patients prefer, and what do they find more important (LOS or access time)? Currently, the hospital management does not have a clear answer on these questions. However, the hospital management can decide on what they find acceptable as an average LOS and access time, and what the budget is to achieve this performance (since extra capacity is necessary in both system designs). These acceptable values play an important role in the choice for one of both systems.

Indicators	**Stakeholders**									
	Patient		Management		Anesthesiologist		PAC staff		OPD	
	A	W	A	W	A	W	A	W	A	W
Length of stay	++	+	++	+	/	/	++	+	/	/
Access time	%	+	%	++	/	/	/	/	%	++
Utilization	/	/	+	+	+	%	+	%	/	/
Extra consultation hours (extra costs)	/	/	-	-	/	/	-	-	/	/
NP in busy hours (extra costs)	/	/	%	-	%	+	%	+	/	/
System robustness	++	+	++	+	++	+	++	+	/	/
Controllability of arrivals	/	/	++	-	+	-	++	-	/	/

Table 6.1: Stakeholder analysis

** Definition of symbols: A=appointment system, W=walk-in system, -=worse, %=equal, +=better, ++=much better (all compared to current design), /=not of interest to stakeholder*

From an anesthesiologist's perspective, the quality of treatment of the individual patient is most important. He/she is therefore less concerned about LOS and access time. For the anesthesiologist, an appointment system would be safer to work in, since workload will be spread out more evenly over time, utilization rate is stable, and arrivals will be easier to control. System robustness is also higher in an appointment system, which means the variation in anesthesiologist's working speed will have less influence on system performance. Psychologically, this is of importance to the anesthesiologist. On the other hand, if a walk-in system is controlled well (meaning capacity over time matches arrivals over time, and patients are sent away or seen by a NP in busy hours), the anesthesiologist will be able to work in the same way as currently. We conclude that if anesthesiologist's can decrease the variability in working speed (e.g. by agreeing on protocols), and the system is controlled well, a walk-in system is viable for anesthesiologists.

The PAC staff, and especially the secretaries and doctor's assistants, have to deal with patients in the waiting room. Therefore, for them it is also important that LOS is acceptable for patients. System robustness, a NP in busy hours (if walk-in system) and controllability of arrivals is important to them, since this also influences the waiting time of patients. With the increase of the number of consultation hours, it may be necessary to hire extra secretaries, doctor's assistants, and PAC nurses, since the current staff may not want to work more hours. Within a walk-in system, the secretary will get the task of planning appointment patients and regulating the workload in the waiting room (by sending patients home with an appointment in busy hours). The secretaries will need instructions how to plan these patients and at what number of patients in the waiting room, patients are sent home with an appointment. Overall an appointment system would be easier for PAC staff, but they do see the possible advantages of a walk-in system for the patient.

The outpatient department is the stakeholder that is least involved. For them it is important that access time is not too long, since they want the patient to be screened before the planned surgery. The surgery is performed by their specialists, and cancelled surgeries due to non-screened patients leads to disturbances in their operating room planning. From this perspective, a walk-in system is preferred by the OPDs.

From this stakeholder analysis we show which parameters are important to stakeholders, and how they value the performance of an appointment system and walk-in system. All stakeholders see the importance of a system redesign. We signal that some important fundamental questions have to be answered and choices have to be made, before the hospital can make a choice between both systems.

Summarizing, the following fundamental questions arise:

1. What is the maximum acceptable length of stay at the PAC for each patient type?
2. What is the maximum acceptable access time at the PAC for each patient type?
3. How can we decrease variation in consultation duration among the anesthesiologists?
4. What is the available budget to create the necessary extra capacity (consultation hours and a NP)?

6.2 Walk-in implementation

Since the decision regarding which system design to implement has not been made yet, we choose to give advice on the implementation of a walk-in design, since this system needs some significant changes to be successful. An appointment system, with appointments based on ASA classification, would be easier to implement, since the current system also works with appointments. The only changes would be the appointment schedule and extra consultation hours.

The implementation of a walk-in system is discussed in several articles [Murray et al, 2003b;Mitchell, 2008;Steinbauer et al, 2006]. All refer to the open access literature of Murray. Murray proposes six specific changes in the implementation process [Murray et al, 2003a]:

1. Balance supply and demand
2. Work down the backlog
3. Reduce the number of appointment types
4. Develop contingency plans
5. Reduce and shape the demand for visits
6. Increase the effective supply, especially of bottleneck resources

We discuss these six changes in the following sections.

Balance supply and demand
To be able to screen more patients on the same day as their OPD visit, the demand of PAC screenings has to be known. We have done this by looking at all OPD consultation schedules and the number of patients they operate. From this, we can predict the arrivals of patients at the PAC. In practice, changes (cancelled consultation sessions, shorter consultation sessions) to the OPD consultation schedules lead to changes in the arrival pattern. To prevent this as much as possible agreements with OPDs have to be made about the consultation sessions of the OPDs. By asking the OPDs when their consultation sessions are planned during the coming weeks (e.g. six weeks), the PAC can adapt their consultation sessions to the expected patient arrivals. Six weeks seems an acceptable time period, since OPDs can plan their staffing schedule six weeks in advance with a high certainty. It is crucial that the OPDs actually perform all these consultation sessions, to ensure that the utilization rates of the PAC staff are not too low. It would be even more efficient if the hospital management could persuade the OPDs to spread their consultation session over time, such that the total patient arrivals at the PAC are spread evenly over time. To ensure the predicted arrivals meet practice, the management of the PAC has to continuously monitor the arrivals at the PAC. Adaptations to the prediction model can be made

if necessary. To be able to predict the arrivals, based on OPD consultation hours as input, we have developed an excel tool for the management of the PAC (See Appendix I).

To ensure the balance of supply and demand, we propose to make service level agreements (SLA) between the PAC and all OPDs, with an evaluation cycle of six weeks. From the OPD side the following should be confirmed: (1) the OPD consultation sessions for the coming period, and (2) the total expected number of patients sent to the PAC by the OPD. Form the PAC side the following performance should be confirmed: (1) the maximum access time of the PAC, and (2) the maximum LOS for patients of this specialty. Be agreeing on these points the PAC can predict the number of patient arrivals over time and can plan capacity (supply), in the form of consultation hours and staff, adapted to this demand.

Work down backlog
To be able to screen patients on basis of walk-in, it is important that enough space is available in the PAC schedule. Currently, the schedule is already booked full quite some time in advance. Before a walk-in system is actually implemented, backlog has to be reduced. This is not an ongoing practice: it requires the temporary tactic of doing more work each day than is generated on that day. By temporarily adding capacity we can reduce the backlog. To determine how much extra capacity is necessary, we have to set a date at which the walk-in system should start. Before that date, secretaries are not allowed to plan any patients after that date. The shorter the time period until the "go live" date, the more capacity has to be created each week to ensure the elimination of backlog. We propose to open the PAC at location WL on Tuesday to create extra capacity to work down backlog.

Reduce the number of appointment types
In the current appointment schedule we see more than 20 types of appointments. This decreases the flexibility. In this research, we have proposed two appointment types: ASA 1+2 patients, and ASA 3+4 patients. Within a walk-in setup we can use this distinction by screening ASA 3+4 patients mostly on appointment, and ASA 1+2 patients mostly on walk-in. Currently, the ASA class of a patient is determined during the PAC screening. In the new design the ASA class of a patient will have to be known beforehand. This could be done by the specialist, or through the pre-anesthetic anamnesis questionnaire (which is currently in use to aid the anesthesiologist's screening). The stakeholders in the preoperative process will have to agree on how to determine ASA class before the PAC screening.

Develop contingency plans
Contingency plans are necessary to keep supply and demand in balance on a daily basis, despite inevitable variations in either. In practice, demand may be higher than predicted, or supply will be lower due to staff sickness. To manage this we have already proposed several options: (1) send home patients with an appointment when the waiting room becomes to full, (2) use nurse practitioners as temporary extra capacity. Through the measures, it is possible to control the higher demand or compensate for loss of normal capacity.

Reduce and shape the demand for visits
This measure is not completely relevant to the PAC, since this measure primarily focuses on covering multiple issues in one patient visit. At the PAC, most patients already visit the PAC only once. From data, we see that about 2% of all patients need a second consultation at the PAC, because extra diagnostic tests are necessary. The hospital could reduce this percentage by evaluating (by the specialist) the need for diagnostic testing, previous to the PAC screening, more thoroughly.

Increase the effective supply, especially of bottleneck resources
At the PAC, the anesthesiologist is the bottleneck. By optimizing the tasks of the anesthesiologist during a screening the consultation duration can decrease, and effective capacity (supply) can be increased. Some tasks now performed by the anesthesiologist, can maybe be performed by the doctor's assistant or PAC nurse. Currently, there are no protocols for the screening consultation by the anesthesiologist. This may be a reason for the large variation in consultation duration among anesthesiolo-

gists. We advise to implement a protocol for screening by the anesthesiologist. This may improve effective supply. The use of a nurse practitioner, screening ASA 1+2 patients, is also a possibility to increase effective supply.

6.3 Conclusions

This chapter discussed the perspectives of all stakeholders involved in the pre-operative process, and discussed the necessary changes for a walk-in system.

From the stakeholders analysis we show that some important questions have to be answered by the stakeholders to be able to make a choice for the system design of the PAC. These main questions are:

1. What is the maximum acceptable length of stay at the PAC for each patient type?
2. What is the maximum acceptable access time at the PAC for each patient type?
3. How can we decrease variation in consultation duration among the anesthesiologists?
4. What is the available budget to create the necessary extra capacity (consultation hours and possibly a NP)?

A consensus has to be reached about the answers of these questions. We show that for all stakeholders both proposed systems (intervention 1 and 2) offer advantages. By answering the questions above a founded choice can be made between both systems.

If the choice is made to implement a walk-in system, we advise on the six main areas of change, described by Murray (2003). To implement a walk-in system we advise the following:

1. Predict and control the number of patient arrivals at the PAC by making service level agreements with the OPDs about the OPD consultation hours, and PAC service concerning access time and LOS. Evaluate every six weeks.
2. Monitor and register patient arrivals and performance of the PAC to be able to analyze performance, and adapt the prediction of patient arrivals if necessary.
3. Work down backlog before the actual "go live" date of the walk-in system by setting a "go live" date and increasing capacity before this date. Start with introducing consultation sessions on Tuesday at location WL.
4. Agree on how the ASA class of a patient is determined before PAC screening, such that it can be used in the planning of a patient. This could be done by the specialist.
5. Control demand and supply in periods of unexpected variation by sending home patients with an appointment if workload becomes too high, and temporary create extra capacity through a nurse practitioner.
6. Try to decrease the number of second consultations by thoroughly evaluating (by the specialist) the necessity for diagnostic testing before PAC screening.
7. Setup protocols for the anesthesiologist's PAC screening to decrease variation in consultation duration and increase effective capacity.
8. Review the tasks of all PAC staff: maybe some tasks performed by the anesthesiologist can be performed by the doctor's assistant or PAC nurse. Tasks performed by the doctor's assistant may be unnecessary, if these tasks are already performed at the OPD.

These changes will benefit the implementation of a walk-in system. By answering the questions posed in this chapter, the hospital management will have a fundament to make a choice for the PAC system design.

Chapter 7
Conclusions and recommendations

The aim of this research was to improve performance of the preoperative process by effective and efficient capacity management. We have measured the performance of the current preoperative process design. From the analysis of the current design, we have developed several interventions in system design and control to improve performance. Through queuing models and event-based simulation models we have demonstrated possible performance improvements of these interventions. We have shown what important questions must be answered before a choice can be made for a system design. Finally, we have discussed how to implement the developed interventions. In this chapter we discuss the conclusions of each of these research steps in this chapter.

7.1 Conclusions

In the current design patients are seen on basis of appointments. Appointment slots (10 minutes) are dedicated to specialty types. As a result, more than 20 slot types are defined. This makes the appointment schedule inflexible. We have shown that there is no relation between the appointment type and the screening duration of a patient. The number of appointment slots available per week is not enough to see all patients that should be seen. As a consequence, on average 5 % of all patients that theoretically should be screened, is actually not screened. The access time is quite long and above the hospital intended maximum of 2 weeks. The access time is kept constant by a large number of planned appointments outside the initial appointment slots (§ 3.3). Our queuing model analysis shows that the length of stay (LOS) is quite long (45-90 minutes), but may be acceptable (§ 5.1). An important outcome of the analysis is the robustness of the system. We show that the current design is vulnerable to an increase in screening demand and variation in the anesthesiologist's working speed. This is mainly due to the high utilization rate of the anesthesiologist (0.84). An increase of 10 % in demand leads to an almost doubled LOS. Extra capacity is necessary to be able to see all required patients.

We have developed three interventions to improve performance: (1) appointment scheduling based on ASA classification, (2) screening in a walk-in design, and (3) extra capacity in the form of a nurse practitioner (NP). These interventions contribute to two system designs: (1) an appointment system (intervention 1), and (2) a walk-in system (intervention 2+3). We analyze these systems through queuing models and event-based simulation.

An appointment system based on ASA classification (with 10 and 15 minute slots), leads to a decrease of LOS of 40-50 %, and is more robust (§ 5.2). This is partly due to the six extra necessary consultation hours. In the analysis we show that 50 % of the improvement is due to ASA classification appointments. This appointment system proves to be more robust than the current design. Increasing the demand with 1 patient per hour (17 % increase) leads to an on average 20 % longer LOS. Anesthesiologist's working speed also has less influence on the performance: decreasing working speed with 25 % leads to an average LOS of 45 minutes. This is shorter that the current system performance.

A walk-in system, in which the largest part (70%) of all ASA 3+4 patients is seen on basis of an appointment outside busy hours, is feasible with the current patient mix (§ 5.3). Improvement of the performance (LOS and waiting time) outside the peak hours is approximately 40 %. We have assumed one extra consultation day is available at location WL on Tuesday, since this is a busy walk-in day. We show that in a walk-in system the lunch break should be held one hour later than currently (thus from 13:00-14:00). Furthermore, we advise to use a NP in the busy hours to reduce workload (and utilization rate) of the anesthesiologist. We have assumed NPs can only screen ASA 1+2 patients.

Optimally 35 % of all ASA 1+2 patients should be seen by a NP when she/he is working (§ 5.3). Sensitivity analysis shows that a walk-in setup is more vulnerable to increased demand and variation in anesthesiologist's working speed, compared to an appointment system as in intervention 1. Predicting demand and matching supply and demand, is very important to ensure a smooth performance of the walk-in setup. In case workload gets too high unexpectedly, the secretaries can regulate workload by sending patients home with an appointment for another consultation session.

We show that both an appointment system as a walk-in system perform well and prove to be robust. An advantage of an appointment system is that arrivals are easier to control. A disadvantage is the longer access time, which is often seen in practice in an appointment system (as in the current design). A walk-in system is more difficult to control, since arrivals fluctuate. However, the access time is much shorter. The fundamental choice for one of both systems depends on what the hospital management defines as acceptable performance. Table 7.1 gives an overview of the performance of both systems.

Parameter		**Appointment system (Intervention 1)**	**Walk-in system (Intervention 2)**
Average LOS	A	00:21:40	00:32:23
	B	00:30:40	00:31:00
	N	00:41:33	00:54:29
	M	00:56:34	00:53:50
Average Anesthesiologist utilization		0.70	0.63
Access time		Can be long (21 days)	Short (mostly 1 day)
Extra consultation hours necessary		8 hours/ week	One screening day (Tuesday at WL)
NP necessary during peak hours		No	Yes, or send patients away with appointment
System robustness		Very good	Good
Controllability of arrivals		Very Good	Poor

Table 7.1: Comparison of performance appointment system and walk-in system

As Table 7.1 shows the performance of both systems is comparable. The question remains what the hospital management finds acceptable for the performance of the preoperative process. From a stakeholders analysis (§ 6.1) we show that some fundamental questions have to be answered to make a decision for one of both systems. These questions are:

1. What is the maximum acceptable length of stay at the PAC for each patient type?
2. What is the maximum acceptable access time at the PAC for each patient type?
3. How can we decrease variation in consultation duration among the anesthesiologists?
4. What is the available budget to create the necessary extra capacity (consultation hours and possibly a NP)?

7.2 Recommendations

If the choice is made for a walk-in system we recommend changes that are necessary to facilitate walk-in screening (§ 6.2). These changes are based on the implementation issues Murray (2003) describes. We recommend the following changes to facilitate walk-in screening:

1. Predict and control the number of patient arrivals at the PAC by making service level agreements with the OPDs about the OPD consultation hours, and PAC service concerning access time and LOS. Evaluate every six weeks. For this purpose, we have developed an excel tool (See Appendix I)

2. Monitor and register patient arrivals and performance of the PAC to be able to analyze performance, and adapt the prediction of patient arrivals if necessary.
3. Work down backlog before the actual “go live” date of the walk-in system by setting a “go live” date and increasing capacity before this date. Start with introducing consultation sessions on Tuesday at location WL.
4. Agree on how the ASA class of a patient is determined before PAC screening, such that it can be used in the planning of a patient. This could be done by the specialist.
5. Control demand and supply in periods of unexpected variation by sending home patients with an appointment if workload becomes too high, and temporary create extra capacity through a nurse practitioner.
6. Try to decrease the number of second consultations by thoroughly evaluating (by the specialist) the necessity for diagnostic testing before PAC screening.
7. Setup protocols for the anesthesiologist’s PAC screening to decrease variation in consultation duration and increase effective capacity.
8. Review the tasks of all PAC staff: maybe some tasks performed by the anesthesiologist can be performed by the doctor’s assistant or PAC nurse. Tasks performed by the doctor’s assistant may be unnecessary, if these tasks are already performed at the OPD.

These recommended changes help to implement a walk-in setup successfully.

Further research should focus on the possibility of integral planning between appointment patients and their planned surgery. We have not given an answer on when patients should be planned, if patients are seen through an appointment. Recent research shows interesting views about the possibility to plan on urgency [Vermeulen et al, 2008]. This might be an interesting angle in research concerning integral planning between the PAC and the OR.

In this research we have assumed the process at the PAC to be fixed. A point of interest is to analyze the influence of task changes, to improve effectiveness and efficiency of processes. An example mentioned in the hospital, are the tasks of the doctor’s assistant. All information she gets from the patient is often known in advance. Maybe the tasks of the doctor’s assistant may not be necessary for all patients. Zonderland (2007) analyses the effect of task changes on the performance at a PAC. Another point of interest: do all patients actually need to be screened by the PAC? In the Maxima hospital in Eindhoven, patients are pre-selected by assistant aided by an automated knowledge system [Dekker et al., 2008]. Only patients with high risk are seen by the anesthesiologist. The screening of only a part of the patient mix is a discussion that is yet to be held in the hospital.

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Appendices

A. Determining lateness distribution

We find the lateness distribution from the data gathered in our time registration period. We register the arrival time and the appointment time of a patient. By comparing these two time “stamps”, we determine how much the patient is early or late. We assume patients arrive with the same lateness at all PAC locations.

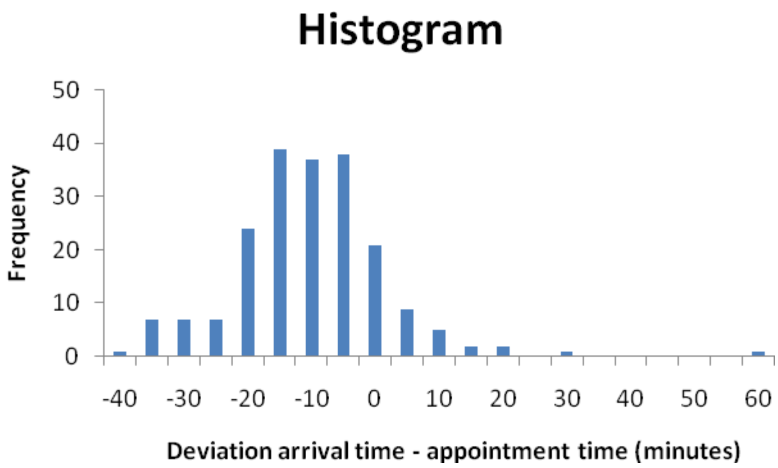

Figure A.1: Lateness of arriving patients at the PAC

We determine the distribution type and distribution parameters through the statistical analysis software package SPSS. Figure A.2 gives the Q-Q plot comparing the data with a Normal distribution. SPSS estimates a normal distribution with μ = -11.0 and σ = 13.115. These values are measured in minutes. For the simulation model we convert these values to seconds, which leads to μ = -11-660 and σ = 786.9.0. We decide to use a Normal(-660,786.9) distribution to calculate the lateness of patients.

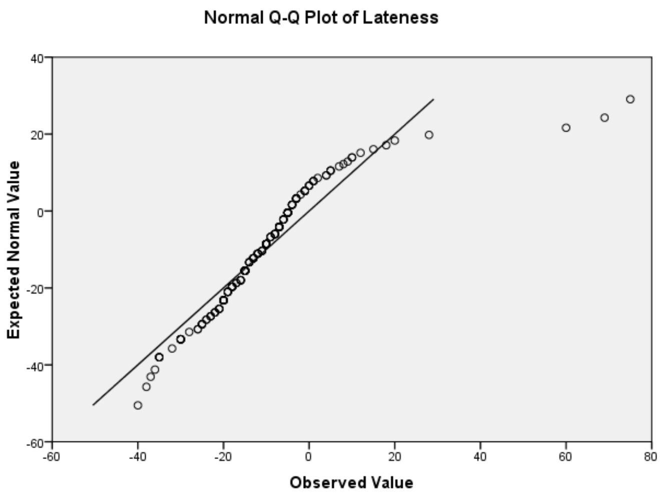

Figure A.2: Q-Q plot comparing data with Normal distribution

B. Schedules

In the figures below the current schedules for each PAC location are given. As becomes clear a lot of different slot types are used. For each specialty a slot type is defined. Besides slot for each slot type, slots for emergencies are planned. These slots cannot be booked earlier then 2 days in advance. Pre-operative screening slots are reserved for all specialties to deal with fluctuation in demand.

The slot types per specialty are divided into slot types for patients with "long" expected surgeries and patient with "short" expected surgeries.

SZ	8:00-9:00						9:00-10:00						10:00-11:00						11:00-12:00					
Monday	Uro	PLAS	Orth	Orth	Jaw	ENT	Orth	ENT	GEN	PLAS	Gyn	Orth	Eye	Preop	GEN	GEN	Neuro	ER	Preop	PLAS	GEN	Orth	Gyn	Preop
Tueday	GEN	GEN	Jaw	Orth	PLAS	PLAS	GEN	Gyn	Uro	PLAS	GEN	Neuro	PLAS	Preop	PLAS	Orth	Eye	PLAS	Preop	Neuro	Gyn	Preop	Eye	ER
Wednesday	Gyn	GEN	Gyn	GEN	PLAS	PLAS	GEN	PLAS	GEN	Preop	PLAS	Gyn	PLAS	PLAS	Uro	ER	Gyn	ER	Gyn	Uro	PLAS	PLAS	PLAS	Preop
Thursday	GEN	GEN	PLAS	Orth	Gyn	PLAS	Orth	Eye	GEN	Uro	GEN	Neuro	GEN	Preop	GEN	Gyn	Orth	ER	Preop	Uro	GEN	GEN	Gyn	Dental
Friday	PLAS	GEN	Gyn	Uro	Orth	PLAS	GEN	GEN	GEN	Uro	GEN	PLAS	Gyn	Preop	Orth	ENT	Gyn	ER	Preop	GEN	Gyn	Orth	PLAS	Preop

	12:00-13:00						13:00-14:00						14:00-15:00						15:00-16:00						16:00-16:20	
Monday							Orth	GEN	Uro	Neuro	GEN	Gyn	ENT	Uro	GEN	PLAS	ER	Orth	ER	Preop	Gyn	Orth	PLAS	GEN	PLAS	Preop
Tuesday							ENT	Eye	ER	Eye	PLAS	PLAS	PLAS	Preop	Gyn	PLAS	PLAS	GEN	ER	Uro	PLAS	PLAS	GEN	Gyn	Eye	Preop
Wednesday	Break						Orth	Orth	Orth	Orth	Orth	Orth	Orth	Orth	Orth	Preop Y	Preop Y	Neuro	ER	Neuro	Eye	Preop Y	Eye	ENT	Eye	Gyn
Thursday							GEN	PLAS	GEN	Preop	Orth	PLAS	Orth	Gyn	GEN	Preop	GEN	GEN	Uro	ER	Uro	PLAS	Neuro	ENT	Preop	Preop
Friday							GEN	GEN	Uro	Neuro	GEN	GEN	Eye	GEN	Preop	Preop Y	Preop Y	Gyn	ER	PLAS	Preop	Preop Y	PLAS	GEN	PLAS	GEN

Figure B.1: PAC schedule at location SZ

WL	8:00-9:00						9:00-10:00						10:00-11:00						11:00-12:00					
Monday	Gyn	GEN	Gyn	Orth	Orth	Eye	Orth	Eye	GEN	Jaw	ENT	Orth	Eye	Preop	Orth	Gyn	GEN	Orth	Preop	GEN	ENT	Jaw	Uro	Preop
Tuesday																								
Wednesday	Orth	Eye	GEN	Gyn	Uro	Jaw	Orth	Eye	PLAS	GEN	Eye	Orth	Eye	Preop	PLAS	Orth	Eye	GEN	Eye	GEN	Preop	Orth	Eye	Dental
Thursday	Orth	PLAS	Orth	Orth	PLAS	Eye	Orth	Eye	Orth	PLAS	Eye	Orth	Eye	Preop	Orth	Orth	Orth	ENT	Uro	Preop	Eye	Neuro	Eye	Preop
Friday	Jaw	Gyn	GEN	Orth	GEN	Orth	Orth	Eye	Gyn	Orth	PLAS	Orth	Eye	Preop	GEN	Orth	Neuro	Eye	Preop	Uro	ENT	ENT	Eye	Preop

	12:00-13:00						13:00-14:00						14:00-15:00						15:00-16:00						16:00-16:20	
Monday							GEN	Orth	GEN	Eye	Dental	GEN	PLAS	PLAS	PLAS	Preop	Orth	Gyn	Neuro	Eye	Uro	GEN	Eye	Eye	Eye	Preop
Tuesday																										
Wednesday	Break						Eye	GEN	Gyn	Jaw	ENT	Orth	Eye	GEN	Orth	Preop	Orth	GEN	ER	Orth	Uro	PLAS	ENT	Eye	Eye	Preop
Thursday							GEN	PLAS	GEN	Eye	Gyn	GEN	PLAS	Neuro	Eye	Preop	Uro	Eye	PLAS	ENT	GEN	Jaw	Eye	Dental	Eye	Eye
Friday							GEN	Preop	GEN	Orth	Preop	GEN	Eye	Preop	GEN	Gyn	Gyn	Preop	PLAS	Preop	Eye	Eye	Eye	Eye	Eye	Eye

Figure B.2: PAC schedule at location WL

Kampen	8:00-9:00						9:00-10:00						10:00-11:00						11:00-12:00					
Friday				Eye	GEN	Gyn	GEN	GEN	Uro	Jaw	Eye	Gyn	ENT	PLAS	GEN	Eye	Orth	ENT	Orth	PLAS	Gyn	Orth	Eye	Eye

	12:00-13:00						13:00-14:00						14:00-15:00						15:00-16:00					
Friday	Break						Gyn	Orth	GEN	Eye	Dental	Uro	Orth	Uro	Jaw	Eye	ENT	Eye	Neuro	Eye	Eye	ENT		

Figure B.3: PAC schedule at location Kampen

C. ASA classification

ASA stands for the American Society of Anesthesiologists. This society developed a classification system to characterize the physical condition of a patient visiting the PAC. The following text is a summary of the text found on the Wikipedia site, searching for "ASA score".

In 1963 ASA adopted a five category physical status classification system for assessing a patient before surgery. A sixth category was later added. These six categories are:

1. A normal healthy patient
2. A patient with mild systematic disease*.
3. A patient with severe systemic disease.
4. A patient with severe systemic disease that is a constant threat to life.
5. A moribund patient who is not expected to survive without the operation.
6. A declared brain-dead patient whose organs are being removed for donor purposes.

The physical status score is followed by "E" if the surgery is an emergency. An emergency is defined as existing when delay in treatment of the patient would lead to a significant increase in the threat to life or body part.

These definitions appear in each annual edition of the ASA Relative Value Guide, and there is no additional information that can be helpful to further define these categories. This results in many possible interpretations of the ASA score definitions.

Due to the nature of the ASA Classification System, patients with ASA Score 5 or 6 will not be present at the PAC.

*A systemic disease is one that affects a number of organs and tissues, or affects the body as a whole [Systematic disease, 2008]

D. Adjustments for the queuing model

To calculate results for the walk-in intervention (intervention 2) some formulas of the queuing model described in Paragraph 4.2 had to be adjusted. The adjustments are stated below.

Since we introduce an extra patient class S we have five patient classes. The index p = [1, 2, 3, 4, 5] refer to the patient classes A, B, N, M, and S.

Formula (1) and (5):

$$\rho_1 = \sum_{p=1}^{5} \rho_{1,p} \tag{38}$$

$$\rho_{1,p} = \frac{\eta_p E(S_{p,1})}{e_1 c_1} \quad for \quad p = [1..5] \tag{39}$$

Formula (9):

$$\lambda_i = \sum_{p=1}^{5} \eta_p \quad for \quad i = 1 \tag{40}$$

Formula (11), (13), and (14):

$$SCV_{A,1} = w_1 \sum_{p=1}^{5} Q_{p,1} SCV_{A,p,1} + 1 - w_1 \tag{41}$$

$$v_1 = \left[\sum_{p=1}^{5} Q_{p,1}^2 \right]^{-1} \tag{42}$$

$$Q_{p,1} = \frac{\eta_p}{\lambda_1} \quad for \quad p = [1..5] \tag{43}$$

Formula (15) and (16):

$$E(S_i) = \frac{1}{\lambda_i} \sum_{p=1}^{5} \eta_p E(S_{p,i}) \quad for \quad i = 1 \tag{44}$$

$$SCV_{S,i} = \frac{1}{\lambda_i E^2(S_i)} \sum_{p=1}^{5} \eta_p E^2(S_{p,i})(SCV_{S,p,i} + 1) - 1 \quad for \quad i = 1 \tag{45}$$

E. Consultation time distribution

We determine the consultation time distribution for ASA 1+2 patients, and ASA 3+4 patients, for each staff type present at the PAC, from the data gathered during our time registration project. We estimate the consultation duration of the secretary with an Exponential distribution with a mean of 2:30 minutes, since we do not have any data concerning the secretary consultation duration. For each staff type, we show the histogram of the consultation duration, the Q-Q plot, and the estimated distribution parameters.

Doctor's assistant

ASA1+2:

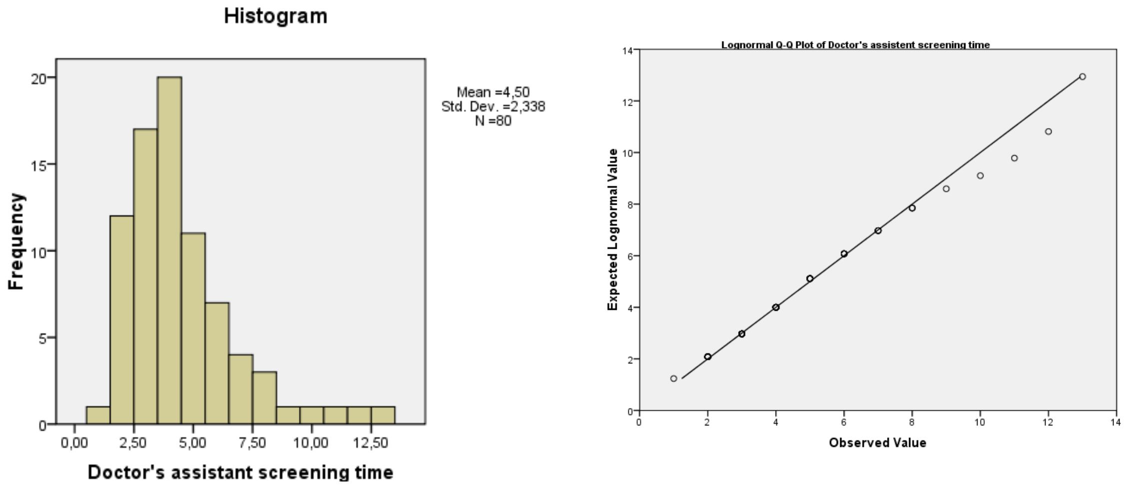

Figure E.1: Histogram and Q-Q plot of ASA 1+2 patient's consultation duration distribution at doctor's assistant

Estimated distribution parameters		
Lognormal distribution	Scale	4.002
	Shape	0.485

Table E.1: Estimated distribution parameters of ASA 1+2 patient's consultation duration distribution at doctor's assistant

ASA 3+4:

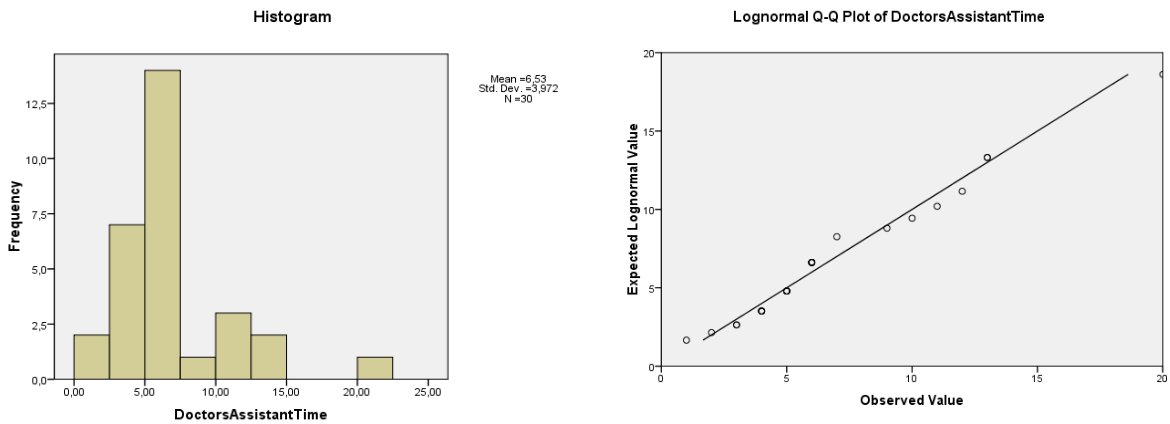

Figure E.2: Histogram and Q-Q plot of ASA 3+4 patient's consultation duration distribution at doctor's assistant

Estimated distribution parameters		
Lognormal distribution	Scale Shape	5.561 0.592

Table E.2: Estimated distribution parameters of ASA 3+4 patient's consultation duration distribution at doctor's assistant

Anesthesiologist

ASA 1+2:

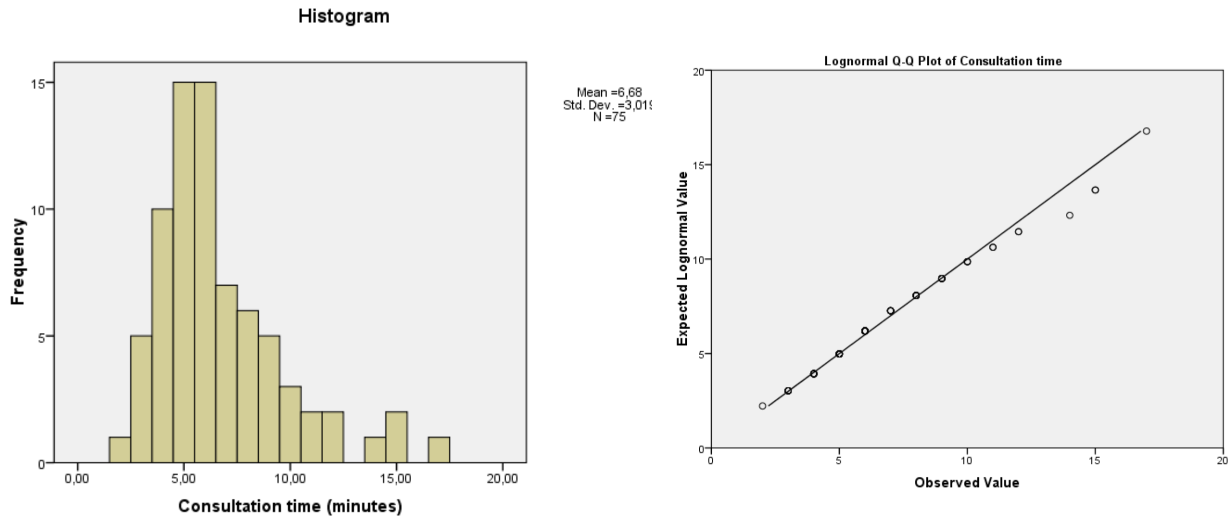

Figure E.3: Histogram and Q-Q plot of ASA 1+2 patient's consultation duration distribution at anesthesiologist

Estimated distribution parameters		
Lognormal distribution	Scale Shape	6.107 0.422

Table E.3: Estimated distribution parameters of ASA 1+2 patient's consultation duration distribution at anesthesiologist

ASA 3+4:

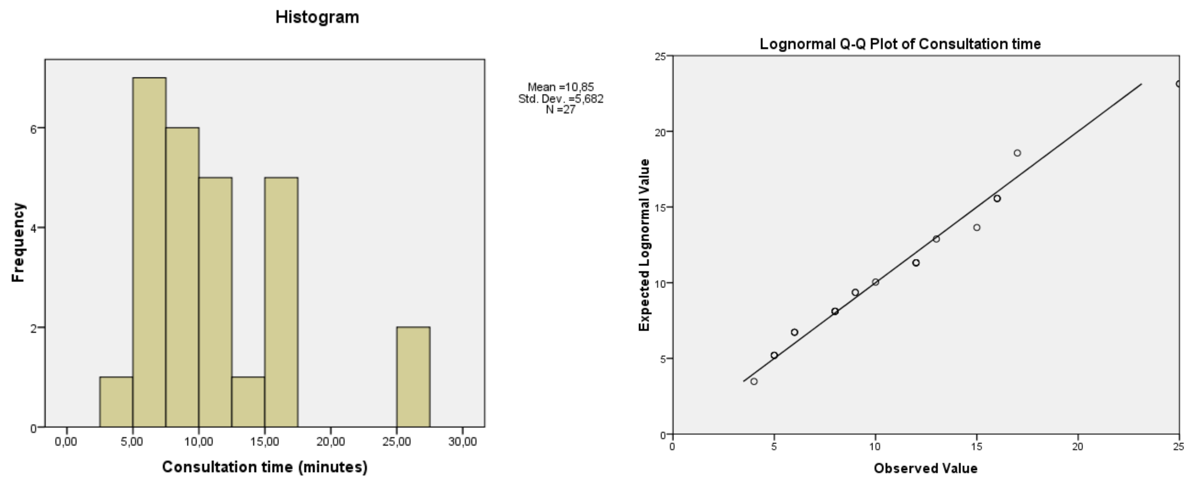

Figure E.4: Histogram and Q-Q plot of ASA 3+4 patient's consultation duration distribution at anesthesiologist

Estimated distribution parameters		
Lognormal distribution	Scale	9.581
	Shape	0.508

Table E.4: Estimated distribution parameters of ASA 3+4 patient's consultation duration distribution at anesthesiologist

PAC nurse

ASA 1+2:

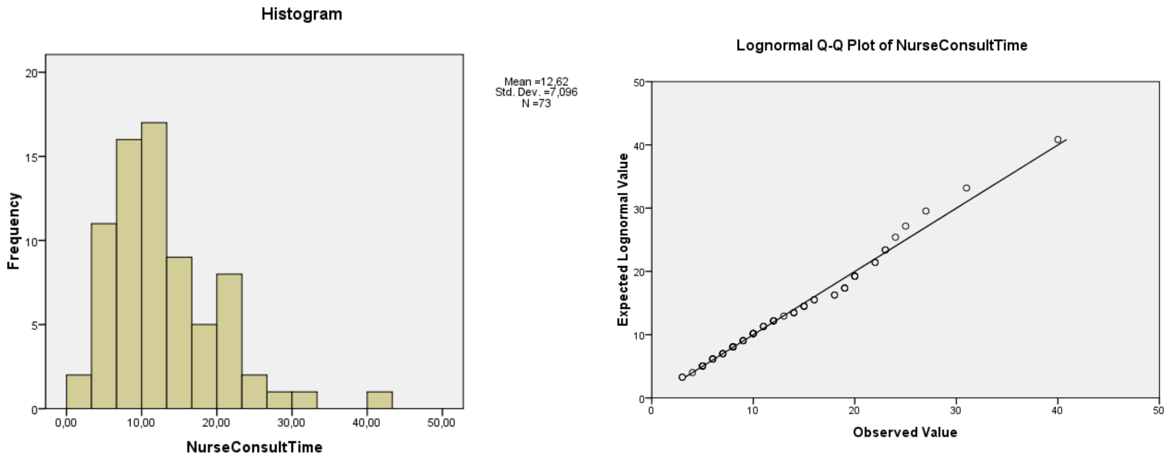

Figure E.5: Histogram and Q-Q plot of ASA 1+2 patient's consultation duration distribution at PAC nurse

Estimated distribution parameters		
Lognormal distribution	Scale	10.880
	Shape	0.555

Table E.5: Estimated distribution parameters of ASA 1+2 patient's consultation duration distribution at PAC nurse

ASA 3+4:

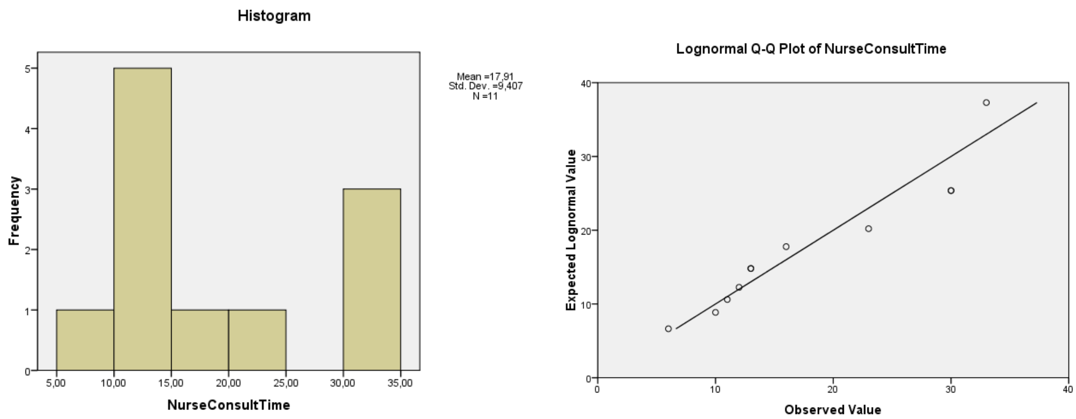

Figure E.6: Histogram and Q-Q plot of ASA 3+4 patient's consultation duration distribution at PAC nurse

Estimated distribution parameters		
Lognormal distribution	Scale	15.734
	Shape	0.542

Table E.6: Estimated distribution parameters of ASA 3+4 patient's consultation duration distribution at PAC nurse

F. Arrival pattern for walk-in design

We model the arrivals of patients through a walk-in setup by aggregating the patients sent to the PAC by each separate OPD. We do this for both PAC locations (SZ and WL). Table F.1 gives an overview of all OPDs and their consultation hours. The number of appointments during these hours can differ, since the number of doctor's available during these consultation hours differs. Therefore the arrival of patients at the PAC from a certain OPD does not have to be the same at days with an equal amount of consultation hours at the OPD.

Location	OPD	Consultation day-parts	Consultation hours
SZ	General surgery	Mon.-Thurs. Fri. morning	8:30-12:00, 13:00-16:00
	Plastic surgery	Mon.-Tue. Wed. afternoon Thurs. afternoon Fri. morning	8:30-12:00, 13:00-16:00
	Gynecology	Mon.-Fri.	8:30-12:00, 13:30-17:00
	Neurosurgery	Mon. Tue. morning Wed. Thurs. morning	9:00-12:00, 13:30-16:00
	Jaw surgery	Mon.-Fri.	8:00-12:00, 13:00-16:00
WL	Orthopedics	Mon.-Tue. Wed. afternoon Thurs.-Fri.	8:00-12:00, 13:00-16:30
	Jaw surgery (Rittersma)	Tue.-Fri.	8:30-12:00, 13:00-16:30
	ENT	Mon.-Fri.	8:30-12:00, 13:00-17:00
	Urology	Mon.-Fri.	8:30-11:30, 13:30-16:00
	Jaw surgery	Mon.-Fri.	8:00-12:00, 13:00-16:00
	Dental surgery	Mon. Wed.-Thurs.	9:00-12:30, 13:30-16:30

Table F.1: OPD consultation hours at both main PAC locations

We assume the chance a patient has to undergo surgery is equal at each consultation block at the OPD. We therefore spread the average number of weekly PAC screenings of a specialty over the OPD consultation hours given in Table F.1 (also accounting for the available capacity during consultation hours at the OPDs). By adding up all the expected number of patients sent to the PAC by all OPDs of one location, we find the total arrivals of patients during a certain time period at the PAC. Figure F.1 and Figure F.2 give an overview of the arrival pattern for both locations.

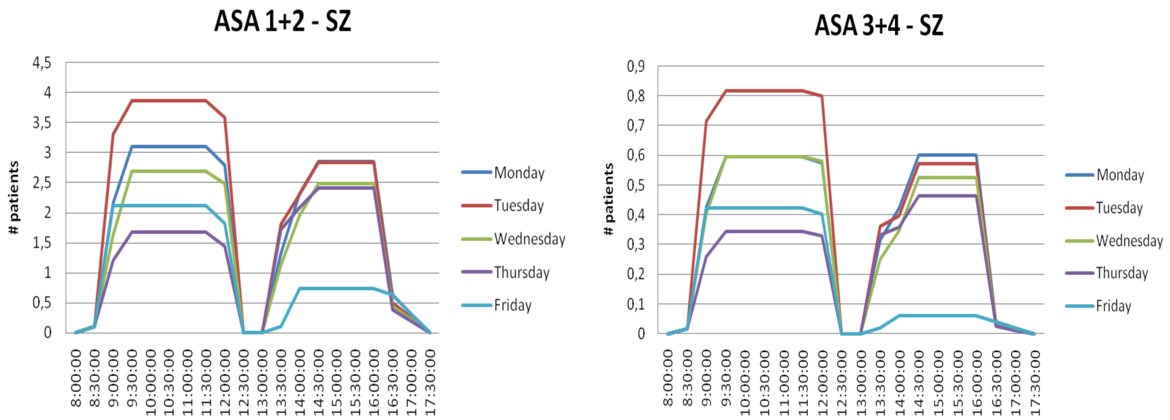

Figure F.1: Arrival patterns for ASA 1+2 patients and ASA 3+4 patients at location SZ

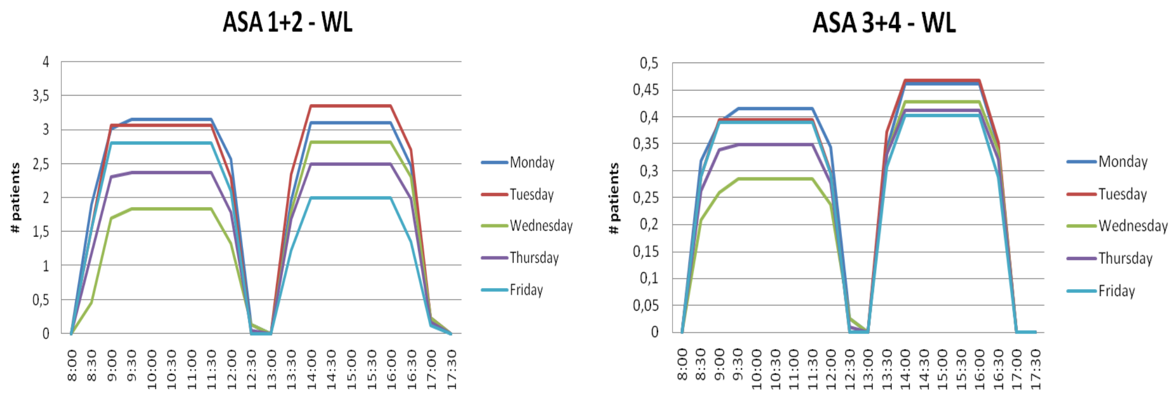

Figure F.2: Arrival patterns for ASA 1+2 patients and ASA 3+4 patients at location WL

We use these arrival patterns for intervention 2.

G. Simulation model with dynamic arrival rates

An overview of the simulation model used in Paragraph 5.2 is depicted below.

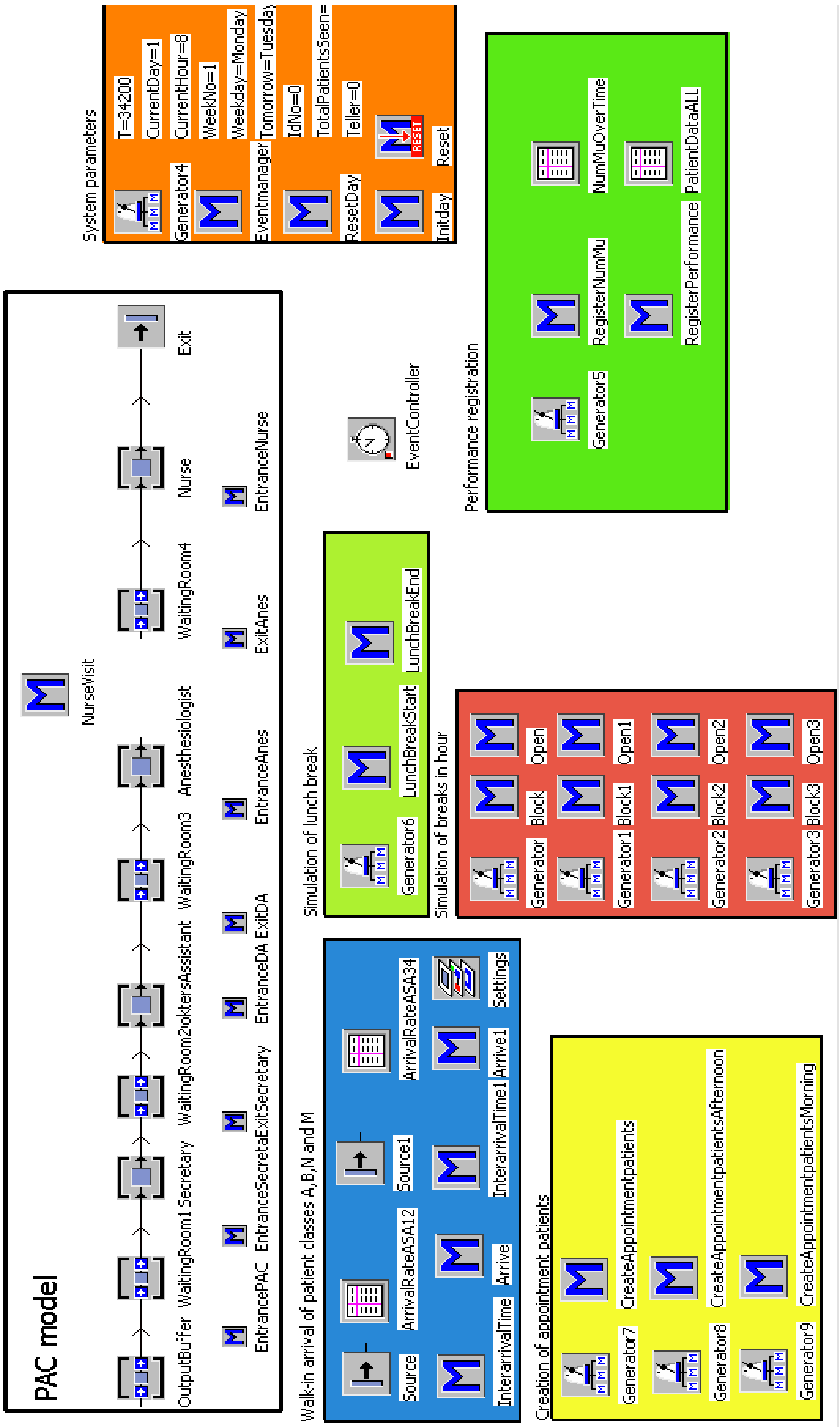

Figure G.1: Overview of the simulation model

H. Proposed pre-operative process

The pre-operative process as it is proposed by the management of the pre-operative department is depicted in Figure H.1.

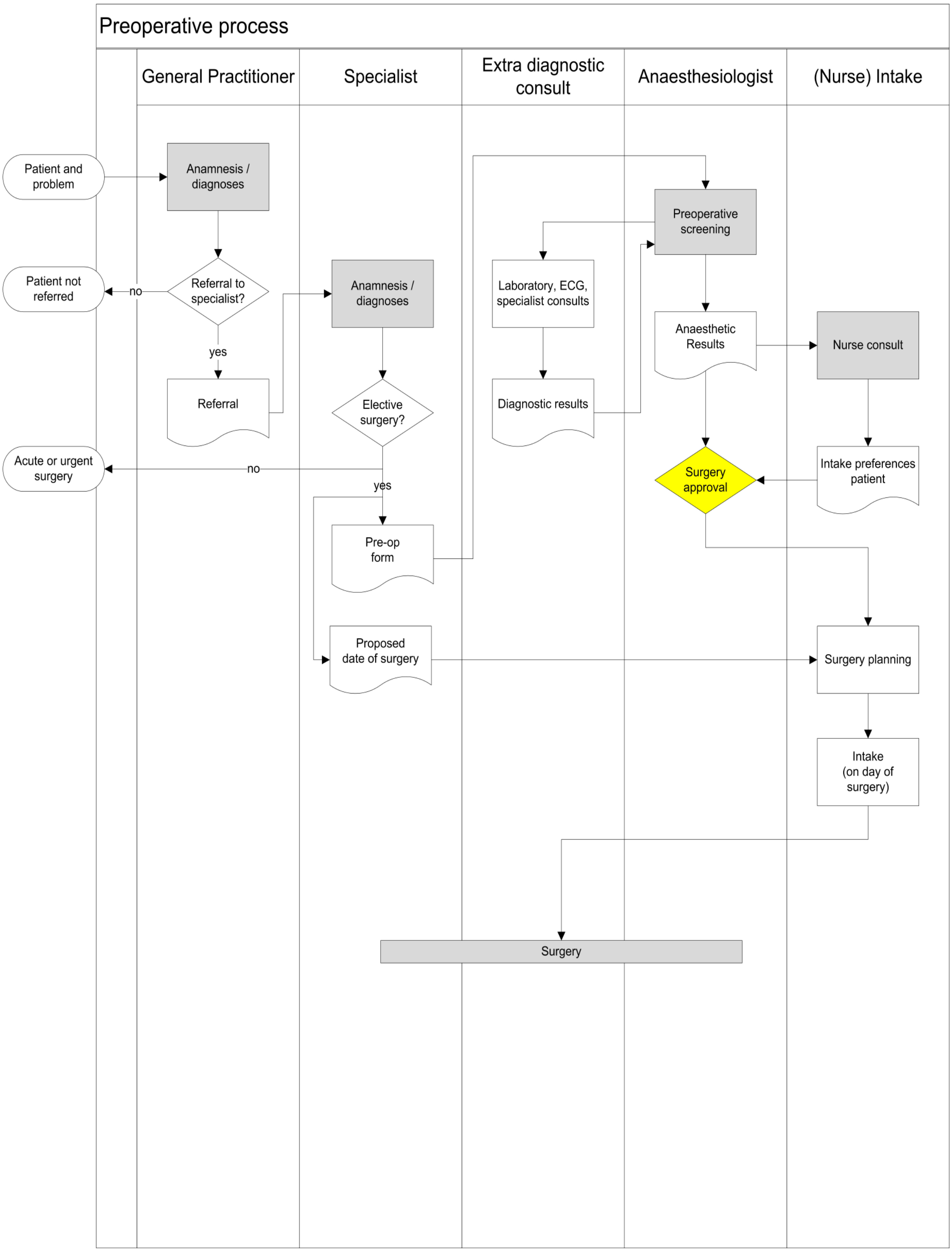

Figure H.1: Proposed pre-operative process

I. Excel queuing simulation tool

To be able to determine the effect of changing OPD consultation hours and capacity on the patient arrivals at the PAC in a walk-in design we have developed an excel tool that gives a global overview of the expected patient arrival pattern over the week, and calculates the expected performance in peak hours. In this Appendix we discuss the tool and show how to use it.

The tool consists of nine worksheets. However, the four last worksheets (the red worksheets) are only used for calculations and should not be changed. Figure I.1 shows the relevant worksheets.

Figure I.1: Relevant worksheets in excel tool

Settings
In the worksheet settings, the settings of the OPDs can be changed. We can set at which parts of the week consultation sessions are planned, and what the start and end times of these consultation sessions are. Furthermore, we can set the patient mix for each OPD. We also have to set what percentage of all patients of a certain patient class is seen by the PAC nurse for each PAC location. Figure I.2 gives an overview of the settings worksheet.

Arrival data WL and SZ
The second and third worksheet consists of the arrivals per half hour. In principle this data is calculated from the settings worksheet. The only thing that may be adapted is the average number of arrivals per half hour for each specialty. The current value is based on the current patient arrivals.

Arrival pattern
The next worksheet gives the arrival pattern for each patient class for PAC location WL and SZ. These arrival patterns are useful to see what the expected workload will be at the PAC over time. The management of the PAC could adapt the deployment of staff to this pattern.

Simulation
In the simulation worksheet the settings for the PAC are set. The consultation characteristics for each staff type can be defined by the average and standard deviation. Furthermore, the effective time and the number of available staff per staff specialty can be set. Also, the speed of the anesthesiologist, the number of ASA 3+4 patients seen outside busy walk-in hours, and the screening demand can be set (100% = current demand). The results part of this worksheet gives the expected performance of the PAC in peak hours. This is compared to the current design in the figures. Figure I.3 gives an overview of the simulation worksheet.

Locatie Sophia

Poliblokken

	Consultatie blokken									
	Maandag		Dinsdag		Woensdag		Donderdag		Vrijdag	
Specialisme	Ochtend	Middag	Ochtend	Middag	Ochtend	Middag	Ochtend	Middag	Ochten	Middag
Chirurgie	1	1	1	1	1	1	1	1	1	0
Plastische chirurgie	1	1	1	1	0	1	0	1	1	0
Gynaecologie	1	1	1	1	1	1	1	1	1	1
Neurochirurgie	1	1	1	0	1	1	1	0	0	0
Kaak chirurgie	1	1	1	1	1	1	1	1	1	1

Patientenmix

	ASA categorie	
Specialisme	ASA 1+2	ASA 3+4
Chirurgie	75,00%	25,00%
Plastische chirurgi	87,50%	12,50%
Gynaecologie	93,75%	6,25%
Neurochirurgie	84,75%	15,25%
Kaak chirurgie	84,75%	15,25%

	Preop verpleegkundige	
	NEE	JA
ASA 1+2	58,10%	41,90%
ASA 3+4	60,61%	39,39%

Politijden

Specialisme	Start ochtend	Einde ochtend	Start middag	Einde middag
Chirurgie	8:30	12:00	13:00	16:00
Plastische chirurgie	8:30	12:00	13:00	16:00
Gynaecologie	8:30	12:00	13:30	17:00
Neurochirurgie	9:00	12:00	13:30	16:00
Kaak chirurgie	8:00	12:00	13:00	16:00

Locatie Weezenlanden

Poliblokken

	Consultatie blokken									
	Maandag		Dinsdag		Woensdag		Donderdag		Vrijdag	
Specialisme	Ochtend	Middag	Ochtend	Middag	Ochtend	Middag	Ochtend	Middag	Ochten	Middag
Orthopedie	1	1	1	1	0	1	1	1	1	1
Rittersma	0	0	1	1	1	1	1	1	1	1
KNO	1	1	1	1	1	1	1	1	1	1
Oogheelkunde	1	1	1	1	1	1	1	1	1	1
Urologie	1	1	1	1	1	1	1	1	1	1
Kaakchirurgie	1	1	1	1	1	1	1	1	1	1
Bijz. Tandheelkunde	1	1	0	0	1	1	1	1	0	0

Patientenmix

	ASA categorie	
Specialisme	ASA 1+2	ASA 3+4
Orthopedie	92,86%	7,14%
Rittersma	84,75%	15,25%
KNO	100,00%	0,00%
Oogheelkunde	65,52%	34,48%
Urologie	84,75%	15,25%
Kaakchirurgie	84,75%	15,25%
Bijz. Tandheelkund	84,75%	15,25%

	Preop verpleegkundige	
	JA	NEE
ASA 1+2	58,10%	41,90%
ASA 3+4	60,61%	39,39%

Politijden

Specialisme	Start ochtend	Einde ochtend	Start middag	Einde middag
Orthopedie	8:00	12:00	13:00	16:30
Rittersma	8:30	12:00	13:00	16:30
KNO	8:30	12:00	13:00	17:00
Oogheelkunde	8:00	12:00	13:00	16:30
Urologie	8:30	11:30	13:30	16:00
Kaakchirurgie	8:00	12:00	13:00	16:00
Bijz. Tandheelkunde	9:00	12:30	13:30	16:30

Figure I.2: Overview of the settings worksheet of the excel tool

Settings

Patientengroei (100% is huidig (2007))	100%
% ASA 3+4 patienten gezien op afspraak	70%
Snelheid anesthesioloog (1 = gemiddeld)	1

Patienten groep		Gemiddelde screeninsduur				Standaard deviatie			
		Secretaresse	DA	Anesthesioloog	Verpleegkundig	Secretaresse	DA	esthesiolo	Verpleegkundige
A	ASA 1+2, geen verpleegkund	0:04:00	0:04:30	0:06:41		0:04:00	0:02:20	0:03:01	
B	ASA 3+4, geen verpleegkund	0:04:00	0:06:32	0:10:51		0:04:00	0:03:58	0:05:41	
N	ASA 1+2, verpleegkundige	0:04:00	0:04:30	0:06:41	0:12:37	0:04:00	0:02:20	0:03:01	0:07:06
M	ASA 3+4, verpleegkundige	0:04:00	0:06:32	0:10:51	0:17:55	0:04:00	0:03:58	0:05:41	0:09:24
S	Alleen afspraak maken	0:05:00	-	-	-	0:05:00	-	-	-

	Effectieve tijd per uur	Aantal aanwezig
Secretaresse	0:50:00	1
DA	0:50:00	1
Anesthesioloog	0:55:00	1
Verpleegkundige	0:55:00	1

Resultaten

Sophia

Inloop	Bezettingsgraad	Verwachte wachttijd	Gem . lengte wachtrij
Secretaresse	0,59	0:07:14	0,87
DA	0,59	0:06:05	0,64
Anesthesioloog	0,80	0:19:22	2,05
Verpleegkundige	0,62	0:16:40	0,74

Patienten groep	Totale Preop duur
ASA 1+2, geen verpleegkundige (A)	0:47:52
ASA 3+4, geen verpleegkundige (B)	0:54:04
ASA 1+2, verpleegkundige (N)	1:17:09
ASA 3+4, verpleegkundige (M)	1:28:39
Alleen afspraak maken (S)	0:11:21

Weezenlanden

Inloop	Bezettingsgraad	Verwachte wachttijd	Gem . lengte wachtrij
Secretaresse	0,55	0:05:58	0,67
DA	0,56	0:05:22	0,54
Anesthesioloog	0,76	0:15:20	1,56
Verpleegkundige	0,59	0:14:44	0,62

Patienten groep	Totale Preop duur
ASA 1+2, geen verpleegkundige (A)	0:41:51
ASA 3+4, geen verpleegkundige (B)	0:48:03
ASA 1+2, verpleegkundige (N)	1:09:12
ASA 3+4, verpleegkundige (M)	1:20:42
Alleen afspraak maken (S)	0:10:04

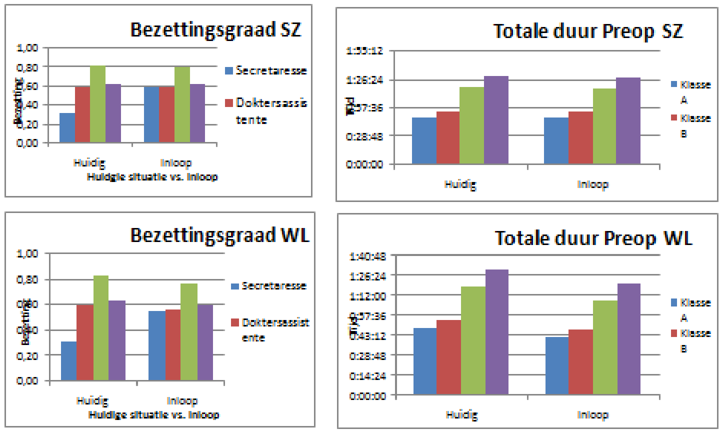

Figure I.3: Overview of the simulation worksheet of the excel tool