Erasmus University of Rotterdam

Erasmus School of Economics
Master Econometrics and Management Science

Master's Thesis

Simulation of the Strabismus Care Pathway at the Rotterdam Eye Hospital

by

Ka Wang Man

Supervisors Erasmus University Rotterdam:
Wilco van den Heuvel
Jeroen van Oostrum

Supervisor Rotterdam Eye Hospital:
Ellen van Vliet

November 2009

Abstract

Every year in the Rotterdam Eye Hospital, about 600 patients are operated for strabismus. They follow a long lasting process until they undergo a possible surgery. This is due to the long access times at various departments of the strabismus care pathway, because demand exceeds capacity. To lower the access times, the effects of different resource allocations on the access times have to be determined. We devise a double-transition model of the logistical system of the strabismus care pathway based on Markov chains. After the simulation of this model with different variables and parameters, the results are analyzed using regressions. It appears that in general, an increase in the capacity level at a certain department decreases the access times of that department. However, the effects on the access times of other departments are not unambiguous. The eye hospital can use these results to decide which resource allocation to implement.

Keywords: simulation, Markov chains, transition probabilities, resource planning, logistical systems, access time, strabismus.

Acknowledgements

What in the beginning seemed to be an endless project, turned into a most interesting study when pieces started to fall into place, and we made breakthrough after breakthrough. For this, I would like to thank everyone who helped and supported me during the writing of my thesis.

First of all, I am grateful to my supervisor of the university, Wilco van den Heuvel. He always provided me with new ideas when certain methods did not work out properly. I would also like to thank my other supervisor of the university, Jeroen van Oostrum, who taught me to focus more on the important aspects of the study. Further, I appreciate the help of Eelco van Asperen and Christiaan Heij of the university, for their help with getting started with the simulation software package Arena and the regression analysis, respectively.

I must also thank to my supervisor at the Rotterdam Eye Hospital, Ellen van Vliet, for providing the data and explaining the logistical system of the strabismus care pathway. Thanks also go to Renske Grootendorst and Ella Haverkamp of the Rotterdam Eye Hospital for providing additional information about the resource allocations.

Further, I express my gratitude to my family for being there whenever I needed them, especially my grandmother for her cooking and her caring.

And finally, I would like to thank a few people at the university who have become friends in the course of years; first of all, Robbert, who has been a good friend since the first day of college, when he told me the name of his favorite football club and player. Thanks also to Remy, Yannis, Michelle and Philippe for their support.

Contents

Chapter 1

Introduction

Every year in the Rotterdam Eye Hospital (REH), about 600 patients are operated for strabismus. Strabismus is a condition in which the eyes are not properly aligned with each other. Usually it originates during childhood, but sometimes it arises at an older age (Nederlands Oogheelkundig Gezelschap, 2005). At the REH, half of the patients with strabismus are children, half are adults.

The Problem

The patients arrive at their respective outpatient clinics, from which they follow a long lasting process until they undergo a possible surgery. In addition, many large fluctuations in the average throughput time can be seen in historical data.

The throughput time of a patient is defined as the time between the moment of the first contact at the eye hospital is made and the moment that the series of treatments of the patient ends.

This definition is more pragmatic than the more conventional one: the time from the planning of the first visit at the pediatric or regular outpatient clinics until the second post-operative checkup after the surgery. Our own definition is easier to work with because by far not all patients will be operated eventually, of which only about a half for strabismus. With the more conventional definition, a throughput time could not even be determined for many patients.

It is assumed that a substantial part of the problem is due to the lack of linking the capacities of the different resources of the hospital with each other. The question is whether it is possible to reduce the access times, by linking the capacities on the different departments — pediatric outpatient clinic, orthoptic department and operating room (OR) — in a better way. Access time is defined as the time between the moment an appointment is made and the moment of this appointment. Access times are typically measured in days or months. In contrast, the waiting time of a patient, which is a far better known and more often-used term in operations research literature, is the time that he or she has to wait in the waiting room before being seen by a doctor. That is, the time that a patient is physically present in the queue before it is his or her turn. However, some researchers seem to use the term 'waiting time' where they actually mean 'access time'. This is the case in Dexter et al. (1999) and Comas et al. (2008), for example.

At the eye hospital, it is known that the capacity of the OR is limited. Hence, here lies the bottleneck of the problem. The other departments are more flexible to be adjusted. However, two of these departments are known to be very busy all the time, and that the demand exceeds the capacity during certain periods. As a consequence, patients of both the pediatric outpatient clinic and the orthoptic department face longer access times than they normally should.

On top of that, the resources are not only for strabismus treatments. Therefore, in this thesis, the emphasis is on these two departments. The types of patients (strabismus, cataract, or other) that make use of these resources should be distinguished, in order to be able to see how changes in capacity and patient flows influence the access times of the patients.

Possible Methods

With this thesis, an attempt is made to give a clear view on the effects of different capacity levels of the different resources on the access times, in order to improve the efficiency of the resource assignments. One possible method that one could think of to do this is by constructing an optimization model. However, because of the complexity of the logistic system — too many options a patient can go through, loops, et cetera — an exact model is not recommended. A better alternative is to use simulation.

One can find much in the literature about simulation in health care. However, most of it is about waiting times in individual units within multi-facility clinics or hospitals, while in the problem of this study, the emphasis is on the access times in the system as a whole. Because of the mutual relations between different departments, it may not be possible to estimate performance measures such as access times and staff utilization rates.

The difficulty of creating a good simulation model is to find the level of detail; The model should not be too complex, but still representative for the reality. In other words, the right tradeoff between simpleness and accuracy is pursued.

There are several ways of simulation. One is, for example, the simulation of a Markov chain or Markov process. A standard Markov chain is a stochastic process that has the Markov property; that is, the state of the system in the future depends only on the present state, and not on past states (Ross, 2003). The difference between Markov chains and Markov processes is that the former has a discrete (that is, finite or countable) state-space, while the latter has a continuous state-space.

Discrete-event simulation is the simulation of a system in which events are simulated chronologically. Because the evolution of the model over time often involves a complex logical structure of its elements, it is difficult to keep track of this evolution so as to determine the quantities of interest. Using a general framework that is built around the idea of these 'discrete events', the relevant quantities of interest of complex logistic networks can be determined (Ross, 2002).

One advantage of simulating integrated systems is that it is a more realistic representation of the system than the simulation of individual units. Therefore, one usually has more confidence in the results. Another benefit is that simulation models are able to deal with several output performance measures that have to be optimized, and hence creating a multi-criteria objective function environment. Jun et al. (1999) wonder why there is a lack of literature in this area, and they give two possible answers:

- the level of complexity and resulting data requirements of the simulation model, and
- the resource requirements, including time and costs.

In an attempt to fill this 'gap', a discrete-event simulation model using elements of Markov processes has been created for this thesis. One of the reasons for this type of simulation is that it is has become increasingly widespread in health care problems. According to Jun et al.(1999), this 'may be attributed to the numerous successful studies reported using simulation to address health care system problems and the ever-increasing sophistication of simulation software packages.'

A model based entirely on Markov chains is not applicable, since the amount of time in a certain state (yet to be defined) is not random. Furthermore, the Markov property, that the next state only depends on the current state and not on the past, may not be valid in the strabismus care pathway. The current state, that is, the previous department that has been finished, does not provide enough information about the patient.

Problem Statement

When the mutual relations between the departments are known, the goal of determining a range of effects of different resource allocations on the access times from which one can choose the best, can be achieved. Therefore, the aim of this study is as follows:

Determining the effects of different resource allocations at the relevant departments of the logistical system of the Rotterdam Eye Hospital's strabismus care pathway so that decisions can be made to decrease access times.

The decision variables in this problem are:

- the weekly number of man-hours at the pediatric outpatient clinic, and
- the weekly number of man-hours at the orthoptic department.

Thus, the decision variables consist of the number of man-hours available at the various departments, measured on a weekly basis. It is assumed that there is sufficient equipment for all possible capacity utilizations attainable. Therefore, the availability of instruments and machinery is not an issue that is dealt with in this study.

There are also parameters that should be chosen. For example, the failure rates of the personnel; if the eye hospital informs the employees about better working postures to prevent RSI, or decides to install a better air ventilation system to prevent sickness, they will be less often absent.

Furthermore, the arrival rate of new patients can be adjusted; if the eye hospital decides that no more new patients are admitted, the arrival rate should be lowered.

The patient routings can be seen as parameters; the path that a strabismus patient follows can be changed if that is necessary.

A side effect of minimizing the access times is that the throughput times are reduced as well. The throughput time is the time from the patient's first contact with the eye hospital and the time that he or she leaves the system, that is, either his or her disease is cured or treatment is stopped at this hospital.

Key question

The key question is derived from the aim of the study. For this study the following central question is formulated:

What are the effects of different resource allocations at the relevant departments of the logistical system of the Rotterdam Eye Hospital's strabismus care pathway on the access times?

To help answering this key question, some sub questions have been derived from it. They are presented hereafter.

Subquestions

1. What methods are known in the literature for optimal allocation of resources in health care?
2. What are the standard paths that each type of patient has to go through?
3. What does the case mix (types of patients) look like?
4. Is the inflow of new patients (and the strabismus patients in particular) at the eye hospital constant?

5. What are the possibilities to adjust the capacities?

6. What causes the fluctuations in the output and throughput times over the year?

7. Where lies the bottleneck of the allocation problem?

8. How are the access times at a particular department affected by changes in the capacity level of that department's resources (direct effect)?

9. How are the access times at a particular department affected by changes in the capacity level of another department's resources (indirect effect)?

Structure of the Thesis

The thesis is structured in the following way: first, in Chapter 2, a context description is given, in which the patient routings and the organizational structure are described. Next, the literature about solving logistical problems in health care is discussed in Chapter 3. Both analytical models and simulation models are discussed. Also, simulation of waiting queues is described, because the logistical system actually is a network of many waiting systems. The used techniques are being analyzed, to find elements that are useful to this study. The data, obtained from different sources within the eye hospital, are described and analyzed in Chapter 4. In Chapter 5, the simulation model that is used is explained. Several scenarios are tested to obtain the effects of different resource allocation policies, of which the results are described in Chapter 6. Regression analysis is performed to analyze the results. Also, recommendations to the eye hospital are provided. In Chapter 7, both the methodology and the simulation results are evaluated, and some possibilities for future research are described. Finally, the conclusions of the study are presented in Chapter 8.

Chapter 2

Context Description

In the first section of this chapter, a general description of the care pathway that a strabismus patient follows is given. A flow chart is used to get a better visualization of it. In this section, the focus is on the patient. Then, in Section 2.2, the same path is analyzed in detail. This section is written from the organization's viewpoint.

2.1 The Patient's Point of View

As already mentioned in the Introduction, the number of children that undergo a surgery in the eye hospital is more or less equal to the number of adults. However, they follow different paths for treatment. Also within these two groups, the patients are not homogenous. One reason is that many patients have other problems with their eyes, besides strabismus. Furthermore, the severeness and perseverance of the malady are of influence on the number of times that a patient visits a particular department. Therefore, in practice the patient routings will deviate from the standard care paths.

The first time an adult visits the hospital, this takes place at the regular outpatient clinics. For children, there is a separate pediatric outpatient clinic, as shown in Figure 2.1. In these clinics, a first diagnosis is made about what ailment(s) the patient is suffering from. It is not unlikely that he or she needs to return to establish the exact disease(s). This happens more often with children than with adults. Of all patients, a (relatively small) portion needs treatment for strabismus. At the orthoptic department (OT), they do all kinds of exercises to practice the possibly lazy eye.

Thereafter, patients of which it is thought that they will be operated eventually, go to the motility clinic, where a planning is made for the surgery by a team consisting of one surgeon, some orthoptists, and a few doctor's assistants. Normally, patients do not have to wait long for continuation to the operating room, but due to capacity problems, the access time can grow to a few months, which makes it necessary to do some temporal OT screenings. About 20 percent of the people at the motility clinic are not put on the waiting list for operations directly. Instead, they get some supplementary OT screenings.

After the surgery and the first and second post-operative checkups, the DBC of the patient is closed. In practice, however, children are being monitored until their 15th birthday. The DBC is the basis of the payment system for hospital care, care in categorical health organizations, and care in the medical mental health care. A DBC is an administrative code that depicts the demand for care (diagnosis) and the total treatment of a patient (http://www.minvws.nl/dossiers/dbc/).

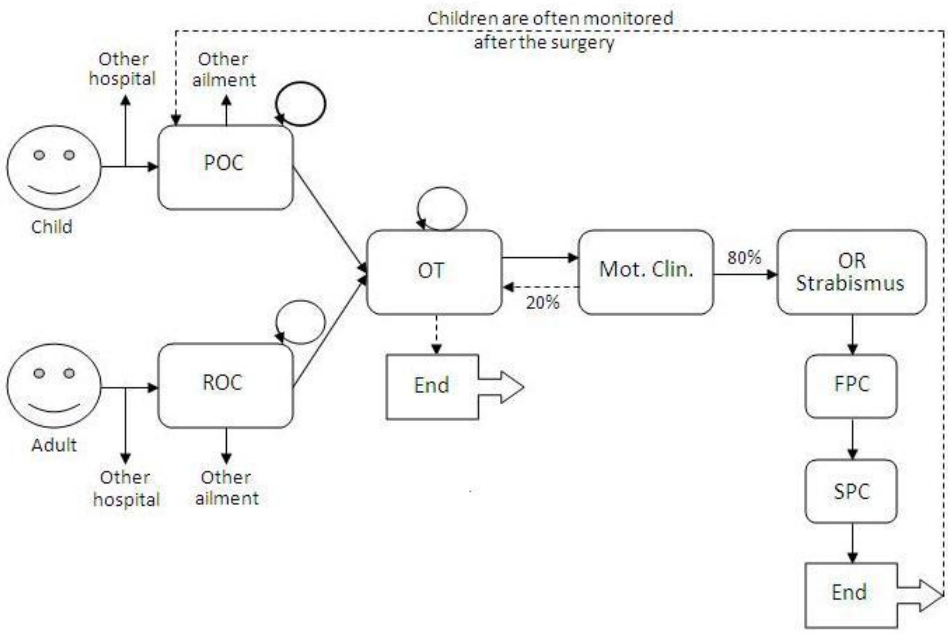

Figure 2.1: Standard Paths for Strabismus Patients at the Rotterdam Eye Hospital. POC. = Pediatric Outpatient Clinic, ROC. = Regular Outpatient Clinics, OT = Orthoptic Department, Mot. Clin. = Motility Clinic, FPC = First Post-operative Checkup, SPC = Second Post-operative Checkup.

2.2 The Organization's Perspective

In this section, we look at the model that was described in the previous section, but now from a different perspective, namely that of the eye hospital.

As said before, the first step in the process is that a person with eye problems makes an appointment for the outpatient clinics. If the person is a child, the appointment is at the pediatric outpatient clinic. The appointment slots are released in phases; visits can be planned at most 17 months ahead. The closer the day to today, the more appointment slots are released:

- 0 – 6 days: 100% released
- 7 – 30 days: 80% released
- 31 – 61 days: 65% released
- 62 days – 17 months: 55% released

The same releasing schedule holds for the outpatient clinics and the orthoptic department. The operating rooms, however, are released three months ahead for the full 100%. At the hospital, all kinds of staff is present to make a diagnosis: orthoptists, eye doctors, surgeons, and doctor's assistants. A surgeon is in fact an eye doctor with the authority to operate. However, the term 'eye doctor' is used only for eye doctors that do *not* have this authority.

If strabismus is diagnosed, an appointment is made with the patient for the orthoptic department. If it is unclear yet, the patient needs to visit the outpatient clinics again. If the diagnosis is that the patient does not have strabismus, he or she leaves the system.

At the orthoptic department, eye muscles are researched. The people who do that are orthoptists. They also decide whether a patient needs a surgery to correct the disabilities of the eye(s). If not, and the patient does not need follow-up checks, he or she leaves the system. If it is unclear, or checkups are necessary, the patient has to revisit this department. And if it is established that the patient has to be operated, an appointment is made for the motility clinic.

Here, a team of orthoptists, doctor's assistants, and a surgeon are gathered with the patient to discuss whether the patient is ready for surgery or not. If the team decides that the patient is not, he or she is supposed to visit the orthoptic department again, and wait for another time. On the other hand, if the team thinks that the patient can be operated, a date is picked. If there is too much time between the meeting at the motility clinic and the planned date of operation, an additional check at the orthoptic department is scheduled, to monitor the status of the patient and avoid complicated situations if it turns out on the date of surgery that the circumstances have been changed. An access time of four months or longer for the surgery is considered 'too long'.

After the operation, two checkups are executed at the orthoptic department, and the patient leaves the system in case it is an adult. If it is a child, he or she is monitored until the 15th birthday. This means that new appointments are made with the orthoptic department. Also, adults for whom the surgery did not go as it should have gone, have to go back to the orthoptic department as well.

The motility clinic and the two post-operative checkups just described take place at the orthoptic department. The post-operative checkups also use the same resources as the orthoptic visits. Therefore, strictly speaking, the term 'department' is not correct to refer to these post-operative checkups. However, due to a lack of a good alternative, we still use it in this thesis. It follows from the context what is meant with 'department'.

Something similar as for the orthoptic department holds for the surgeries. The surgeries can be split into strabismus surgeries and surgeries that are not for treating strabismus. Although all these surgeries take place at the operating rooms, they are seen as two different departments in this thesis.

Chapter 3

Research Literature

In this chapter, some relevant literature about solving health care related problems are presented. Various types of simulation models are described. Also, some articles about analytical optimization in the health sector are discussed.

As already stated in the Introduction, simulation is preferred to exact analytical models when the system under study is very complex. Some real-world problems, namely, are so complicated that models are virtually impossible to solve mathematically. Therefore, one advantage of simulation is that it can handle more complex systems. Pegden et al. (1995) list more benefits, of which some are relevant to this study:

- new policies, operating procedures, decision rules and so on can be explored without disrupting ongoing operations of the real system;
- time can be compressed or expanded whenever it is suitable;
- insight can be obtained about the interaction of variables;
- insight can be obtained about the importance of variables to the performance of the system;
- bottleneck analysis can be performed to indicate where work-in-process are being excessively delayed;
- a simulation model can help in understanding how the system really works instead of how individuals think it operates;
- 'what-if' questions can be answered, which is particularly useful in the design of new systems.

There are various types of simulation models. They can be classified as being static or dynamic, deterministic or stochastic, and discrete or continuous. Examples of these different types can be found in Banks et al. (2001, p. 13–14). A static model represents a system at a particular point in time, while dynamic models represent systems that evolve over time. The simulation of a bank from 9:00 A.M. to 4:00 P.M. is an example of a dynamic model. In deterministic models, there are no random variables. All input variables are known and will lead to a unique set of outputs. Deterministic arrivals would occur at a dentist's office if all patients arrive at the scheduled appointment time. When one wants to include randomness in the model, for instance, that the arrival times of patients are influenced by random factors and hence are unknown, the model is called stochastic. A discrete system means that state variables change only at a discrete set of points in time. The bank is an example of such a system, because the number of customers in the post office changes only when a customer arrives or leaves. A continuous system, on the other hand, is one in which the state variables change continuously. An example is the water level of a lake, which changes during rain and because of evaporation et cetera.

For the problem of this thesis, we have chosen to use discrete-event simulation to analyze and optimize the allocation of resources at the relevant departments of the Rotterdam Eye Hospital. Discrete-event simulation is the simulation of a system in which events are simulated in a chronologically sequence, where each event occurs at a certain point in time and triggers a change in the state of the system. This way, the relevant quantities of interest of complex logistic networks can be determined (Ross, 2002).

The key elements in a discrete-event simulation are variables and events. Three types of variables are generally distinguished (Ross, 2002):

- time variable t,
- counter variables, and
- system state (SS) variable.

The time variable refers to the amount of (simulated) time that has elapsed. Counter variables keep a count of the number of times that certain events have occurred by time t. An example of a counter variable in health care, is the number of patients in the waiting queue. The system state variable describes the 'state of the system' at time t.

An event in a health care system could be defined as the arrival of a patient at a clinic, the departure, the start of a consult, the end of it, et cetera. Whenever an event takes place, the values of the variables just described are updated. Any relevant data of interest are then collected as output. The time is reset, the counter and state variables are made up-to-date, and relevant data is collected. An 'event list' is maintained to determine what the next event is and when it will occur. This event list lists the nearest future events and their time of occurrence. This way, one can follow the system as it evolves over time. Examples can be found in Ross (2002, p. 88–104).

As already mentioned in the Introduction, the lion's share of the literature about simulation addresses problems different from the one of this thesis. Mostly an attempt is made to reduce the waiting time at a single unit of an outpatient department. This is done by Aharonsen-Daniel et al. (1996), for example, who try to solve queuing problems in government outpatient departments in Hong Kong. Their results suggest that simulation can be a helpful tool in the analysis of the management of queues in health care facilities.

Articles that describe simulation models to analyze access times, on the other hand, are very scarce. Elkhuizen et al. (2007) haven't even found one. They use two models to reduce the access time for outpatient departments. The first one is a fairly simple analytical queuing model to obtain rapid global insight into the capacity needed to meet the norm of seeing 95% of all new patients within two weeks. The second is a discrete-event simulation model that calculates the capacity needed to eliminate backlogs and the capacity needed to keep access time within two weeks, capable of handling daily variations in demand and capacity schedules.

One reason that Elkhuizen et al. (2007) did not find any articles that described using simulation models to analyze access time, may be the fact that the term 'waiting time' is often (mis)used when 'access time' is meant. As we already mentioned in the Introduction, Dexter et al. (1999) and Comas et al. (2008) use simulation to analyze access time, although they call it 'waiting time'.

In the former study, simulation is used to model OR scheduling, to determine the appropriate amount of block time to allocate to surgeons and to select the days on which to schedule elective cases, in order to maximize operating room use. In the latter study, the researchers apply discrete-event simulation to analyze the access times for cataract surgeries in Spain using a prioritization system. They compare their results to the access times that are obtained with the routinely used first-come, first-served discipline; it appeared that the prioritization system shortened the access times.

Jun et al. (1999) provide an overview paper about discrete-event simulation in health care clinics. One of their findings is that patient flows are affected by three areas:

- patient scheduling and admissions,
- patient routing and flow schemes, and
- scheduling and availability of resources.

For the years from 1999 on, Jacobson et al. (2006) present a review of publications on discrete-event simulation of health care systems.

A uniform arrival pattern has been compared to highly variable patterns by Smith and Warner (1971). They show that the length of stay at a clinic can be reduced by more than 40% (from 40.6 minutes to 24 minutes) when the patients arrive uniformly. Other scheduling methods have also been investigated. For instance, Smith et al. (1979) used a modified-wave scheduling scheme for an outpatient clinic in order to maximize the number of patients a physician could see while minimizing their waiting time. By scheduling more patients at the beginning of each hour and less at the end, physicians had a buffer for unexpected delays and they could return back to schedule at the end of each hour. This proved to be superior to the uniform scheme, in terms of both patient flow and waiting times.

In addition to the studies about waiting times in outpatient clinics, waiting times for emergency rooms are investigated in several studies. Emergency room settings are different in the sense that patient arrivals can not be planned. One can at best predict how the arrivals are distributed, but obviously not schedule them in the same way as with the outpatient clinics. What *can* be done instead, is controlling the sequence (routing) by which patients are treated. Jun et al. (1999) state that by altering patient routing and flow, it may be possible to minimize waiting time and increase staff utilization rates. Having high utilization rates is another often used goal in the optimization in the health care sector.

When arrival can not be precisely planned, such as in emergency cases just described, one can also schedule the staff in a different way to meet patient demand, as opposed to altering patient routing. There are not many simulation studies devoted to this investigate this reverse side of the problem, but the few that can be found in the literature, such as Alessandra et al. (1978), Mukherjee (1991) and Kumar and Kapur (1989). These studies show that some of the unavoidable variability can be reduced by using the right staff strategies. This can result in higher patient throughput, while keeping staff utilization rates at acceptable levels.

As already indicated, the number of simulation models that have been developed to analyze complex integrated systems is limited. Studies in this area have been conducted by Rising et al. (1973), Swisher et al. (1997) and Lowery and Martin (1992), for instance. The obvious benefit of the simulation of integrated systems is the more realistic representation of the system under study, and hence in the results that are obtained with it. So why is there a lack of literature in this area? According to Jun et al. (1999), the answer may lie in one or both of two issues: (1) the level of complexity and resulting data requirements of the simulation model, and (2) the resource requirements, including time and cost.

Finally, it also seems that there are no studies using Markov chains or Markov processes to reduce access times, or for that matter, waiting times. Takács (1955) and Gaver, Jr. (1959) do investigate waiting times, but they only use single-server models. This makes them unusable for our study.

Chapter 4

Data

In this chapter, the data available for this study is discussed and analyzed. First, a description of the types and contents of the data files is given, together with the modifications made to make them compatible with each other. The data was anonymous, that is, no names were used; only the unique patient IDs were used to identify the patients. Next, the data is summarized using some statistics that can be derived from these data, thereby working with tables and graphs.

4.1 Data Description

The data was provided by the Eye Hospital Rotterdam in electronic form, and contained information about both patients and personnel resources at the hospital from 1 January 2004 until 25 June 2008. The database was from a broadly used system called Ziekenhuis Informatie Systeem (ZIS). The planning system V5 had been used to plan all visits except the surgeries. The appointments in the files present the appointments that have actually taken place. The surgery data were acquired from the so-called OPERA system. Both the visit data and the surgery data were imported by administrative assistants, and approved by their counterparts at the Erasmus University of Rotterdam.

Patient data

Part of the patient data consisted of personal information about all patients who have visited the eye hospital at least once. The patient's gender and date of birth were provided, and every patient was given an ID number. In another data file, information about all visits of all patients within this period was given. This consisted of:

- date of visit
- treatment performer
- workplace
- patient type (regular checkup, checkup child, long checkup)
- contact type

The surgeries were given in a separate file. The data of use were:

- patient ID
- date of surgery
- arrival time at OR
- departure time at OR
- operation code (surgery type)
- surgeon's name

The data files were either in Excel or in text format; .txt files were necessary if the data in question could not fit in one or a few Excel files. All data files were adjusted and imported in the program Matlab, in which further manipulations could be made more easily, such as recoding the data: the raw data consisted of many different combinations of codes, while this information was not relevant for the model of this study. Therefore, new codings were made according to department, personnel type, and visit durations. Also, the data analyses were carried out in Matlab, as well as the simulation output analyses described in Chapter 6.

The provided data files were nearly complete; for instance, the personal information of only 255 out of the 182,482 patients that had visited the eye hospital at least once between January 2004 and June 2008 was not known. For the surgeries file, this information was missing for 72 out of the 36,014 patients. Other, minor, problems were unsorted data, and redundant information, such as the zip code or anesthetic type.

In Matlab, the data files with the non-surgery visits and the surgeries were combined into one matrix. When we looked at the data, it appeared that many patients only visit departments that are not relevant for the strabismus care pathway. From now on, these are called the 'non-strabismus departments'. Also included are the regular outpatient clinics, because no information about the capacities there were given, and we were told to leave them out of our study, although adult strabismus patients usually go through them. Because of these non-strabismus visits, the data had to be adjusted first, in the sense that many patients were removed completely before any analysis was done. After these manipulations, the number of patients, thus with at least one visit at a department that is relevant for strabismus patients, was decreased dramatically, to 23,950. That is, the number of patients was reduced by more than 85%. Only these 23,950 patients are used in this study for calculating statistics and for creating the model.

Some patients still had many non-strabismus visits, and only one or a few appointments at relevant departments. In order to keep the data as efficient as possible, the following was done: if a patient had consecutive non-strabismus visits, only the last one was kept, while the rest was deleted. The access time for the last non-strabismus visit is the sum of the access times of the whole series. For example, if a patient had five visits at the regular outpatient clinics (which are classified as non-strabismus departments), then one appointment at the orthoptic department, and three visits again at the non-strabismus departments, then his or her new routing consisted of only three visits: the fifth non-strabismus appointment (with as access time the sum of the access times of the first five original visits), the one at the orthoptic department, and finally the last of three visits at the non-strabismus departments (its access time being the sum of the access times of the last three appointments). The reason to not remove the visits at unimportant departments altogether was that otherwise the access times could not be calculated correctly. This is important for verifying the quality of the simulation model. The deletion of the appointments at non-strabismus departments was done for the efficiency of the ultimate simulation model, without having effects on the results.

Resource data

The relevant resources for strabismus patients in the eye hospital are the eye doctors, doctor's assistants, and orthoptists. In the pediatric outpatient clinic, as well as in the general outpatient clinics, the patients are mostly seen by eye doctors; sometimes, however, doctor's assistants or orthoptists carry out the consulting-hours. On the orthoptic department, only orthoptists are operative. Surgeries are executed by some of the eye doctors who are licensed to perform surgeries. In this thesis, however, the term 'surgeon' will often be used when it is emphasized that it is about surgeries.

The eye hospital is open from Monday to Friday (except for the emergency department, which is left out of the study). Each day consists of two parts: a morning shift and an afternoon shift. The start and end times of these shifts depend on the particular department. The numbers available of each staff type per shift for the pediatric outpatient clinic and the orthoptic department are shown in Table 4.1 and 4.2, respectively.

Table 4.1: The available resources per shift at the pediatric outpatient clinic.

Day	Shift	# Doctors	# Orthoptists	# Assistants
Monday	Morning	1	1	0
	Afternoon	0	0	0
Tuesday	Morning	1	1	0
	Afternoon*	1	2	0
Wednesday	Morning	0	1	1
	Afternoon	1	1	1
Thursday	Morning	1	2	0
	Afternoon	0	1	0
Friday	Morning	1	1	0
	Afternoon	0	1	1

* Doctor sees at most six patients, and the afternoon ends at 4.00 p.m..

Table 4.2: The available resources per shift at the orthoptic department.

Day	Shift	# Orthoptists
Monday	Morning	4
	Afternoon	5
Tuesday	Morning	6
	Afternoon	6
Wednesday	Morning	3
	Afternoon	3
Thursday	Morning	0
	Afternoon*	1
Friday	Morning	4
	Afternoon	4

* Due to the motility clinic.

Unfortunately, we do not have data on the number of *different* doctors, orthoptists and doctor's assistants and their timetables; we believe that three of each resource type at the pediatric outpatient clinic is a realistic assumption. This is also a practical choice, since it can be easily used in the simulation model that is described in the next chapter.

From Table 4.2 one can see that on Tuesdays, a minimum of six orthoptists is needed. Since we consider this to be a sufficiently realistic number of *different* orthoptists, the rest of the shifts is also divided over these staff members.

Tables 4.3 and 4.4 show the exact schedules of each of the employees as we believe would be reasonably realistic. They are also used in the simulation model of this study. For each cell, a 1 means that the staff member is assigned to that particular shift, and a 0 that he is not.

Table 4.3: The timetable of the resources at the pediatric outpatient clinic.

Day	Shift	D1	D2	D3	O1	O2	O3	A1	A2	A3
Monday	Morning	1	0	0	1	0	0	0	0	0
	Afternoon	0	0	0	0	0	0	0	0	0
Tuesday	Morning	0	1	0	0	1	0	0	0	0
	Afternoon	0	0	1	0	1	1	0	0	0
Wednesday	Morning	0	0	0	1	0	0	1	0	0
	Afternoon	1	0	0	0	0	1	0	1	0
Thursday	Morning	0	1	0	1	1	0	0	0	0
	Afternoon	0	0	0	0	1	0	0	0	0
Friday	Morning	0	0	1	1	0	0	0	0	0
	Afternoon	0	0	0	0	0	1	0	0	1

D = Doctor, O = Orthoptist, A = Doctor's Assistant.

The morning at the pediatric outpatient clinic is from 8.30 a.m. till 11.30 a.m., while the afternoon shift starts at 1.30 p.m. and lasts until 4.30 p.m.. At this department, doctor can see at most 21 patients within one shift, an orthoptist 12, and a doctor's assistant 10. These are fixed numbers because the reserved time for any patient at this division is only dependent on the type of staff member, regardless of the patient characteristics (treatment type, checkup type). The maximum number of patients per week that can be seen at the pediatric outpatient clinic can therefore be calculated to be 306.

Mornings at the orthoptic department are from 8.45 a.m. till 12.30 p.m.,

Table 4.4: The timetable of the resources at the orthoptic department.

Day	Shift	O1	O2	O3	O4	O5	O6
Monday	Morning	1	1	1	1	0	0
	Afternoon	0	1	1	1	1	1
Tuesday	Morning	1	1	1	1	1	1
	Afternoon	1	1	1	1	1	1
Wednesday	Morning	1	0	1	0	1	0
	Afternoon	0	1	1	0	0	1
Thursday	Morning	0	0	0	0	0	0
	Afternoon	1	0	0	0	0	0
Friday	Morning	1	1	1	0	0	1
	Afternoon	1	1	0	1	1	0

O = Orthoptist.

and afternoons from 1.30 p.m. till 4.30 p.m.. At least seven and at most fourteen patients are assigned to an orthoptist at the orthoptic department during one shift. Here, the number of patients that can be seen is more variable, because the allocated time of the visits does depend on the type of treatment or checkup, and this duration is either 15 minutes or 30 minutes. At this department, there are 17 morning shifts and 19 afternoon shifts.

On Thursday afternoons, the motility clinic takes place. Here, one of the strabismus surgeons, a few orthoptists, and the patient will gather to decide whether the patient will be operated in the near future. Because some orthoptists are assigned to it, and because this meeting takes place at the orthoptic department, only one orthoptist is available for consulting-hours.

For the general outpatient clinics, similar information as for the pediatric outpatient clinic and the orthoptic department are not given because these departments are excluded from the model (contained in the non-strabismus departments, of which the data has been adjusted) that is used for this study, as already explained on page 25.

Concerning the OR data, used timetables were provided. Of relevance are the only two strabismus surgeons, who are named Surgeon A and Surgeon B for this thesis. Surgeon A's surgery shifts are on Monday morning and Friday morning; Surgeon B's are Wednesday morning and Thursday morning. Surgeon A's Friday morning shift and Surgeon B's Wednesday morning shift are especially allocated to surgeries on children, although some adults are operated too; their other shifts are for surgeries on both adults and on children. In addition, Surgeon B is also at work at the operating rooms at Mondays, performing cataract surgeries.

4.2 Descriptive Statistics

In this section, a summary of the data obtained from the eye hospital about the visits of the patients between January 2004 and June 2008 is given, as well as of the resource (that is, personnel) data. In the case of the patient data, we should remark that the adjusted data (as described in the previous section) was used for the analysis. Also, the access times at the various departments and the throughput times of the patients are discussed. Graphs are included to help getting a better visualization.

Visits

In the period of which the data is available, 23,950 patients have visited the Rotterdam Eye Hospital at least once. There are 11,584 males and 12,362 females. The genders of the remaining four patients has not been recorded into the database. The group with only one visit within these years is largest (the mode); 4057 patients are reported to have come by once. On average, a patient paid 5.15 visits to the hospital, with a standard deviation of 4.77. The median is 3 and the mode is 2. The distribution of the number of visits is shown in Figure 4.1.

One can see that the distribution is concentrated on the left side, which means that for a random patient, it is more likely to have a smaller number of visits.

The exact distribution of these visits over the various department types is shown in Table 4.5. The pediatric outpatient clinic is visited most often, approximately twice per patient. Further, there happen to be much more orthoptic visits with a duration of 15 minutes than those with a 30-minute span.

One can see in Figure 4.2 that no less than 70% is between 0 and 15 years old. The patients that are much older are the reason that the standard deviation of 23.96 is relatively large compared to the mean of 20.89. Most of the patients are children because the regular outpatient clinics, which are visited by more adults, belongs to the non-strabismus departments, which are partly deleted. Therefore, the patients that do not have appointments at the

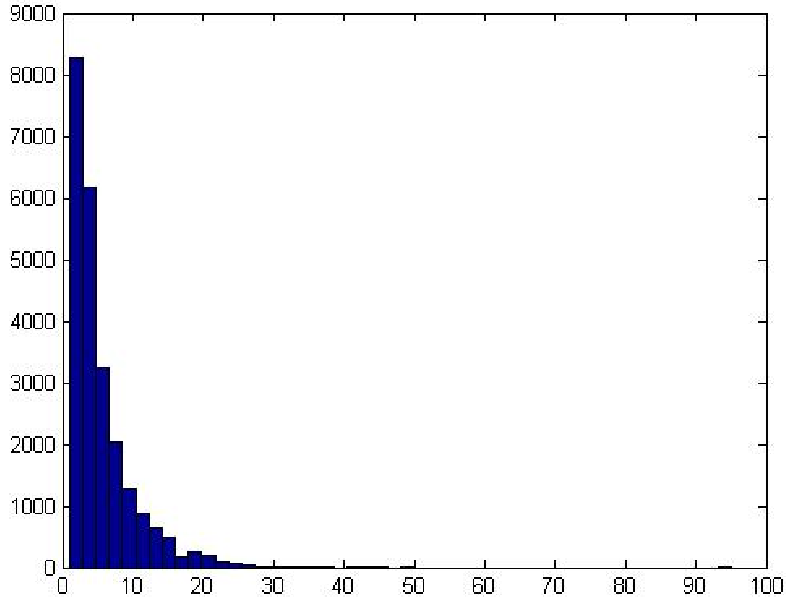

Figure 4.1: Distribution of the number of visits per patient. Number of patients = 23,950, mean = 5.15, standard deviation = 4.77, median = 3, mode = 2.

Table 4.5: The distribution of the visits per patient.

Department	Mean	S.d.
Pediatric Outpatient Clinic	1.98	2.25
Orthoptic Visit 15 minutes	1.09	2.61
Orthoptic Visit 30 minutes	0.62	1.27
Motility Clinic	0.14	0.42
First Post-Operative Checkup	0.11	0.37
Second Post-Operative Checkup	0.11	0.36
OR Strabismus	0.12	0.38
OR Non-Strabismus	0.11	0.42
Irrelevant Departments	0.87	1.33
Total Number of Visits	5.15	4.77

other departments mentioned on page 25, are left out of this statistic, leading to a distorted image of the age composition of the total patient population.

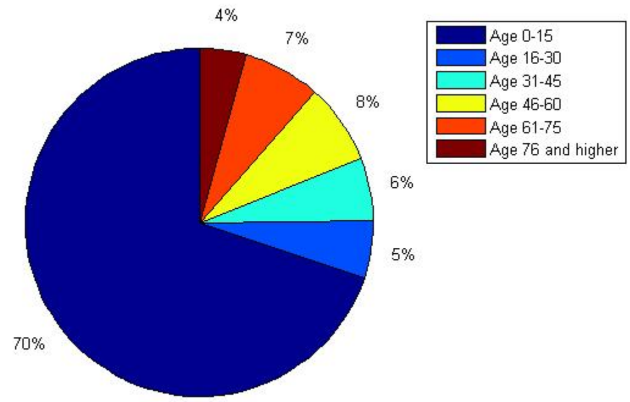

Figure 4.2: Distribution of the age of the patients. Number of patients = 23,950, mean = 20.89, standard deviation = 23.96, median = 9.67, mode = 3.

For the simulation model, which is described in the next chapter, an arrival process for new patients has to be determined. For every patient, the first visit to the eye hospital in the period January 2004 – June 2008 is defined as new; thus, even if a patient has had visits before 2004, he or she is considered new at the time of the first appointment in the mentioned period of time. In Figure 4.3, one can see the number of new patients per day between January 2004 and March 2004. Because in the first few weeks of the sample period, almost every patient is new, the period January 2008 – March 2008 is more reliable. The number of new patients in this period is also plotted. It is clear then that there are approximately 15 new patients per weekday, instead of the 100 at the beginning of the data period.

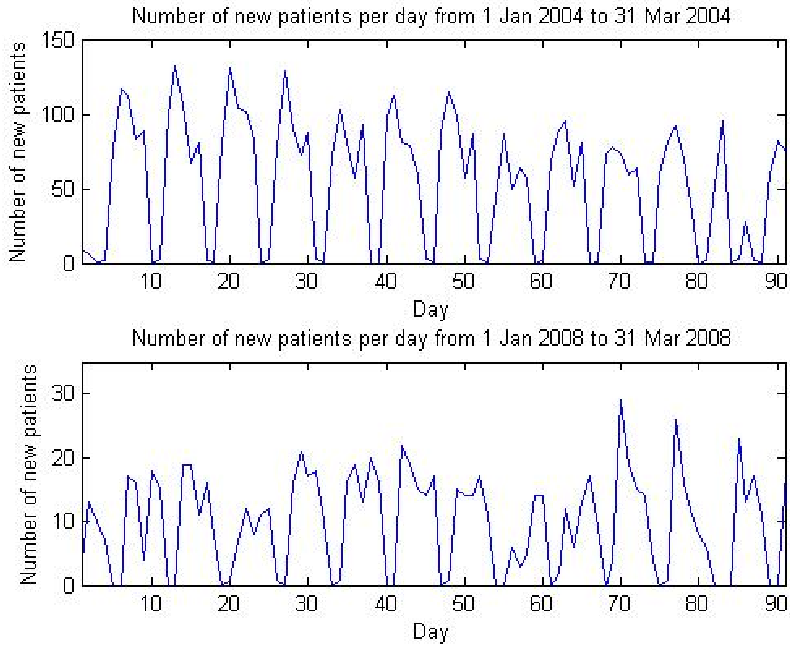

Figure 4.3: Number of new patients per day. Number of patients = 23,950.

Surgeries

From January 2004 until June 2008, 35,942 of the original 182,227 patients have been operated in the Rotterdam Eye Hospital. In Figure 4.4, the fraction of each of the various surgery types is represented. One can see that the group with cataract is by far the largest. Strabismus accounts for 2835, or 5% of all surgeries at the eye hospital in the period January 2004 – June 2008.

The average duration of a strabismus surgery is 39 minutes, with a standard deviation of 12 minutes. This is including the time between the arrival at the OR and the start of the surgery, as well as the time from the end of the surgery until the moment that the patient leaves the OR. A non-strabismus surgery performed by a strabismus surgeon has a duration of 30 minutes on average, with a standard deviation of 18 minutes, also measured from the arrival at until the departure from the OR. The latter standard deviation is larger because all surgery types other than strabismus, performed by either one of the two strabismus surgeons, are taken into account.

It appears that 2442 of the 23,950 patients account for the 2835 strabis-

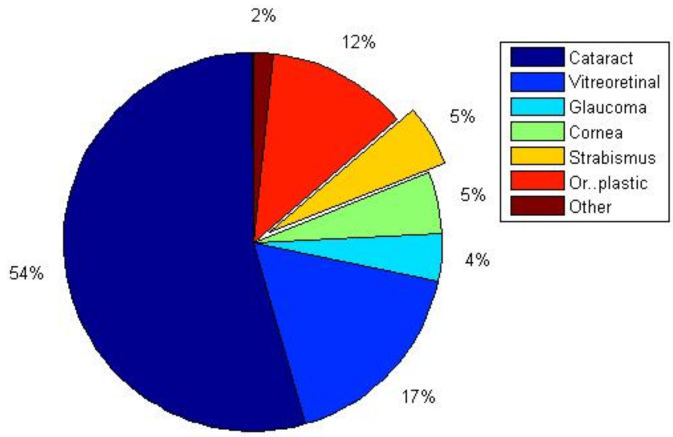

Figure 4.4: Distribution of the various surgery types. Number of surgeries = 54,172.

mus surgeries. Most of these patients (2094) have been operated once on strabismus, while 307 patients have undergone a surgery twice, 37 patients three times, and four patients four times. This means that about 12 strabismus surgeries a week take place in the eye hospital.

Further, there are 1984 patients with at least one non-strabismus surgery performed by either one of the strabismus surgeons. 1326 of them have undergone one non-strabismus surgery, and 606 patients have been operated twice. The remaining 52 patients are distributed as follows: 30 patients with three non-strabismus surgeries, 14 with four, four with five, three with six, and one with eight. This makes a total of 2730 non-strabismus surgeries within the period January 2004 – June 2008.

Number of patients and surgeries per day per department

In Figure 4.5, the number of patients that visit the pediatric outpatient clinic is plotted for the period 1 January 2008 – 29 February 2008. We have chosen this period because it is relatively recent, and hence more relevant than earlier periods. One can see that the number of patients at this department fluctuates during the week, without a standard pattern.

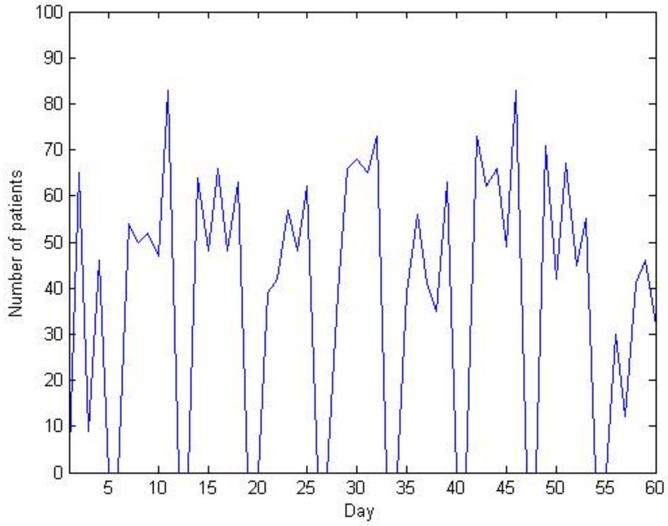

Figure 4.5: Number of patients per day at the pediatric outpatient clinic from 1 January 2008 to 29 February 2008.

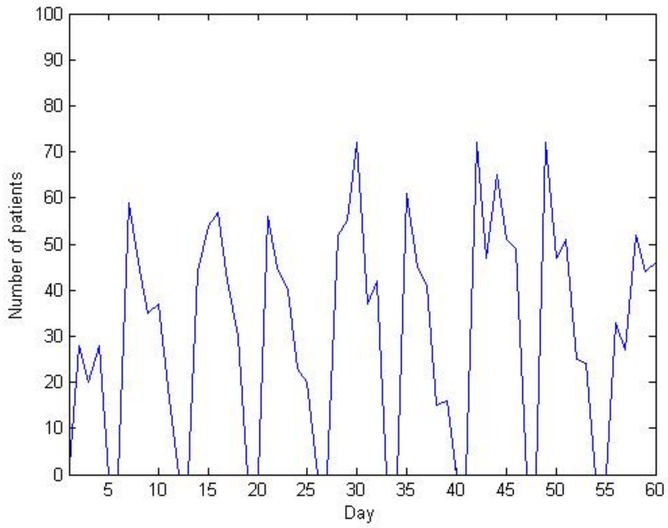

Figure 4.6: Number of patients per day at the orthoptic department (including the post-operative checkups) from 1 January 2008 to 29 February 2008.

For the orthoptic department, a similar plot has been made (see Figure 4.6), and it appears that on Thursdays and Fridays, the number of patients is usually smaller than during the first three days of the week. For Thursdays, this is because there is only one orthoptist at work at this department.

From Figure 4.7, it is clear that the motility clinic takes place once a week, namely, on Thursdays. Approximately 15 patients are seen during the afternoons for which the motility clinic is planned. On the last Thursday of February 2008, there were no appointments. As already mentioned, either Surgeon A or Surgeon B has to be present during this type of visit. However, because both of them were on vacation, there were no visits planned.

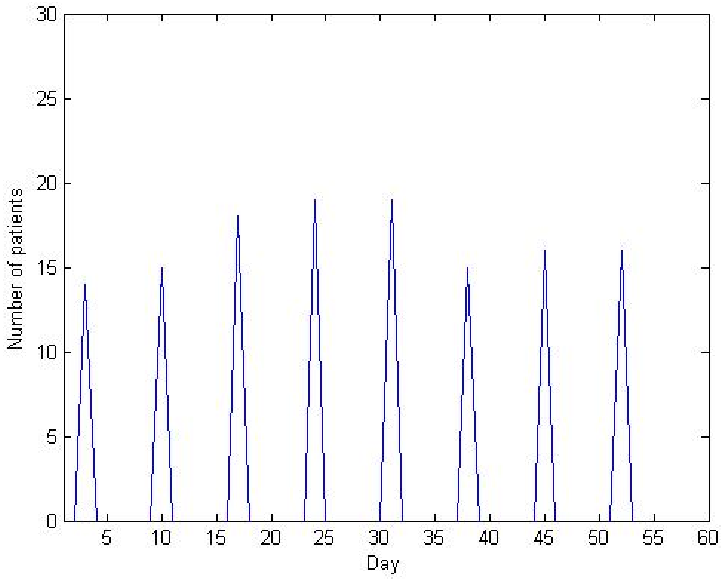

Figure 4.7: Number of patients per day at the motility clinic from 1 January 2008 to 29 February 2008.

The same holds for the surgeries in this week of which they are normally the ones who carry them out. There were no doctors who could replace them for the surgeries in this particular week.

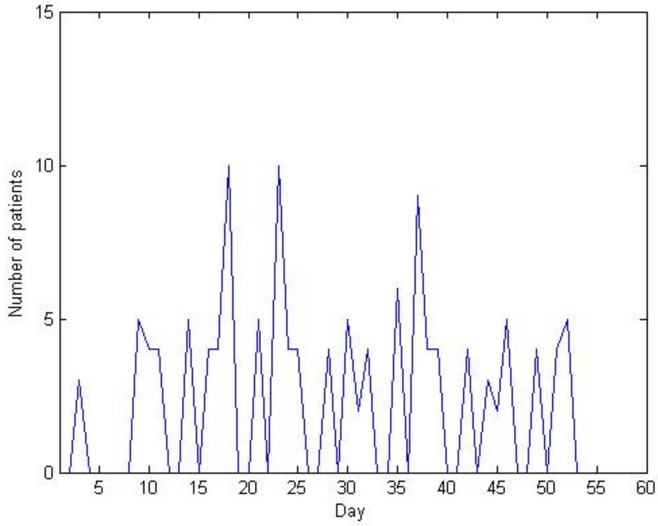

Figure 4.8: Number of strabismus surgeries per day from 1 January 2008 to 29 February 2008.

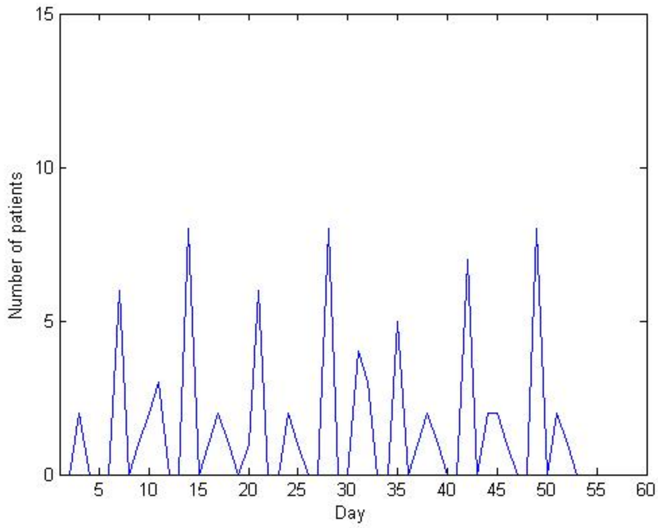

Figure 4.9: Number of other surgeries carried out by Surgeon A or Surgeon B from 1 January 2008 to 29 February 2008.

Access times

The goal of this study is to minimize the access times of the patients in the strabismus care pathway of the eye hospital. For every relevant department in this care pathway, the access times are calculated. Looking at the graphs in Figure 4.10, one can see that the access times of both the pediatric outpatient clinic and the orthoptic department are concentrated on the left side. This means that a shorter access time is more likely than a longer one. The number of visits at the pediatric outpatient clinic is 32,138, while at the orthoptic department the number of appointments is 37,968. One remark should be made: only the access times of the orthoptic visits of 15 and 30 minutes are included; the access times of the motility clinic and the first and second post-operative checkups, although the appointments take place at the orthoptic department, are discussed separately.

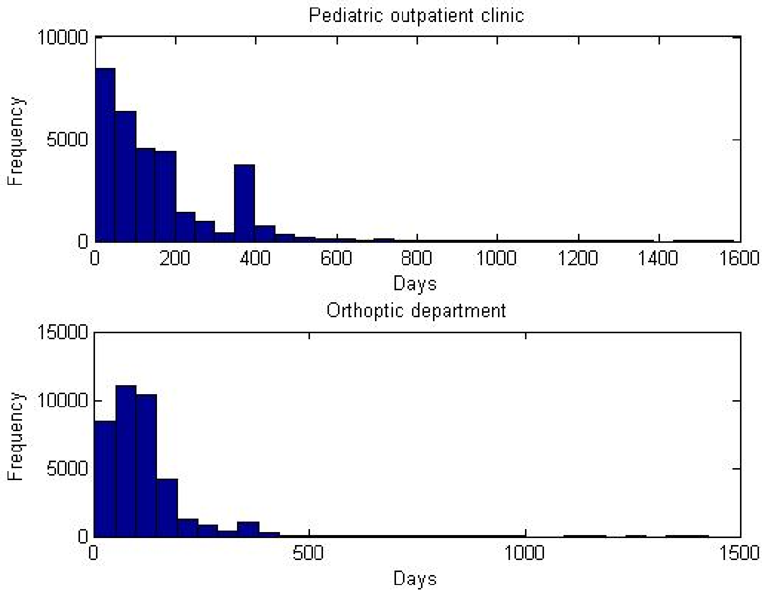

Figure 4.10: Distribution of the access times at the pediatric outpatient clinic and the orthoptic department.

For most children, the time between a previous visit at any department and an appointment at the pediatric outpatient clinic is less than 200 days. The peak at the interval 350–400 days is due to yearly checkups, between which patients apparently do not visit any other department. This is made even more clear in Figure 4.11, where the graph is magnified around the peak. There is a financial reason that the peak starts *after* 365 days, that is, from 366 days on. The eye hospital gets reimbursed for a patient once a year, namely. Therefore, it is preferred that patients visit slightly more than one year later rather than somewhat earlier. The mean access time is 162 days, and the standard deviation is 160. The median is 118 days, while the mode is 371.

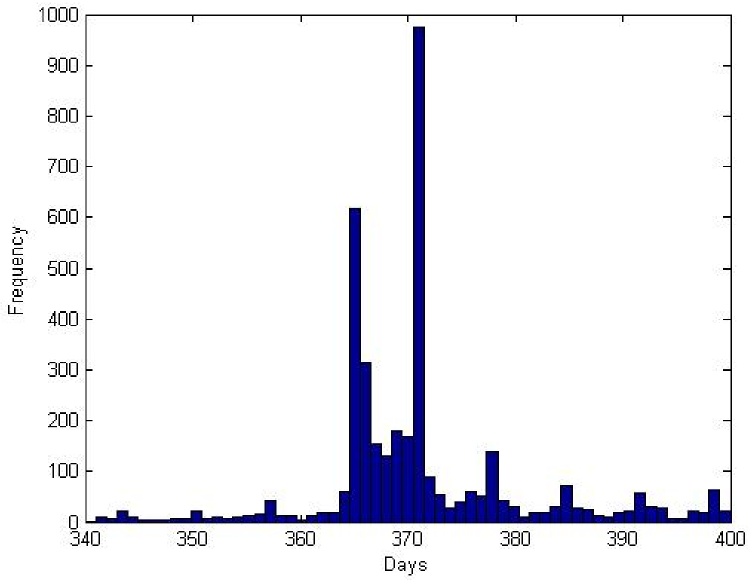

Figure 4.11: Distribution of the access times at the pediatric outpatient clinic around the one-year peak.

By leaving out the data at and beyond the peak, we believe that the statistics that are calculated this way represent the actual access times that are due to capacity restrictions, and not to periodic checkups, in a better, yet not perfect way. The values of these statistics, calculated for the data with access times shorter than 365 days, are 106, 81, 91 and 1, respectively.

For the orthoptic department, the average number of days until an appointment is 109, and the standard deviation is 90, while the median and mode are 93 and 126, respectively. Also at this department, there is a peak around one year's time. Smaller than at the pediatric outpatient clinic indeed, but recognizable nonetheless. Therefore, calculating the statistics for data only with access times shorter than one year gives differences that are less remarkable: the mean would be 99, the standard deviation 67, the median 92, and the mode 126.

As already indicated, the motility clinic and the post-operative checkups were left out in Figure 4.10. Instead, they are shown in the figure below. For the motility clinic, the policy is that 90% of the patients is seen within four months, which seems to be the case. The time between an operation and the first post-operative checkup should be about two weeks, which is indeed where the peak is. As for the second post-operative check, this should be about two months after the first. Again, this can be seen from the figure.

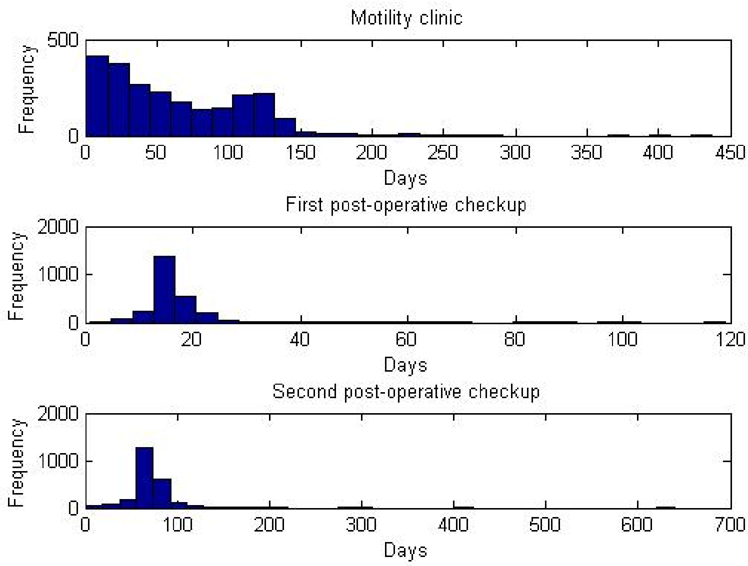

Figure 4.12: Distribution of the access times at the motility clinic and the two post-operative checkups.

The fact that somewhat longer access times are more frequent than somewhat shorter access times can partly be credited to capacity constraints. One can also see access times that are much shorter than the prescribed two weeks for the first, and two months for the second post-operative checkups; these are computed from other visits on, possibly from other ailments, rather than from those just described. The access times that are longer than those described can be explained by several reasons. For example, it is preferred to have the same orthoptist after a surgery as the one who treated the patient before. Since they may not always be available, the appointments are planned later rather than earlier, because the time needed for after the surgery to see the results are those two weeks for the first and two months for the second post-operative checkups. Another reason for longer access times is that *patients* may not always be available; they have their own agendas. The access times that are excessively long (for the first post-operative checkup: over 60 days; for the second: more than 200 days) can be seen as typographical errors.

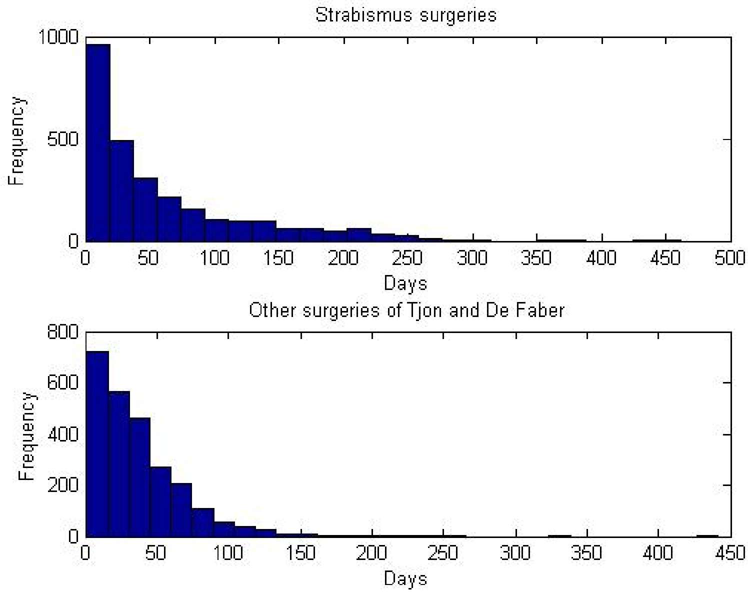

Figure 4.13: Distribution of the access times of the strabismus surgeries and the other surgeries carried out by Surgeon A and Surgeon B.

In Figure 4.13, the access times of the surgeries that are relevant for this study are shown. Most of the strabismus surgeries are performed by either Surgeon A or Surgeon B, except for a few times when both are unavailable. Also with the surgeries, there are access times that are actually too long. Usually, the policy is to plan an extra visit to the orthoptic department, in case the condition of the eyes are changed. For many adults, however, the doctors think that this will not happen, and therefore do not plan an extra appointment for them, even though the time until the surgery is long. These patients are mostly operated only for cosmetic rather than medical reasons.

As already mentioned before, some data were deleted before any analysis was done. This concerned the 'non-strabismus' departments, from the second consecutive visit on. Therefore, we still could calculate the access times of the first of these series. These turned out to be 77.38 days on average, with a standard deviation of 151.30 days.

Failures

Earlier in this chapter, the timetables of the personnel at the pediatric outpatient clinic and the orthoptic department were given. In reality these schedules are of course not always exactly followed, for example because of sickness or vacations.

For the two departments just mentioned, it can not be seen how many failures there exactly are, because there is often more than one staff member at work during a shift. Therefore, when the number of patients seen on that shift is low, it is not possible to know whether this is due to failures or because there are simply not many patients.

For the motility clinic, this is different. There is only one team at a time at work (on Thursday afternoons). This team sees one patient at a time. Therefore, if there is a Thursday without any patients at the motility clinic, it is almost certain that it is a failure. The only other explanation is that there are no patients who need to have an appointment, but this is highly improbable. For this reason, we have assumed that whenever there are no patients at a Thursday afternoon at the motility clinic, there is a failure. Out of the 234 Thursdays in the data, there are 42 without any patients; a failure rate of 0.1795. If we define two or more successive Thursdays without a patient as one 'down period', there are 32 of them, with an average length of 1.25 week and a standard deviation of 0.62 week. The 'up periods', which are defined analogically, have an average length of 5.85 weeks, with a standard deviation of 5.76 weeks. Figure 4.14 shows a histogram of the lengths of the up periods.

The same can be done for Surgeon A. The failure rates on Mondays and Fridays are 0.1373 and 0.2661, respectively. This surgeon has 58 down periods. For the calculation of the length of these periods, we have deleted all days except the Mondays and Fridays, and then counted the number of consecutive days without surgeries. This leads to an average down period length of 1.59 working days, with a standard deviation of 1.06. The up periods have a duration of 6.34 working days on average, while the standard deviation is 5.87 working days. In Figure 4.15, a histogram of the lengths of the up periods is shown.

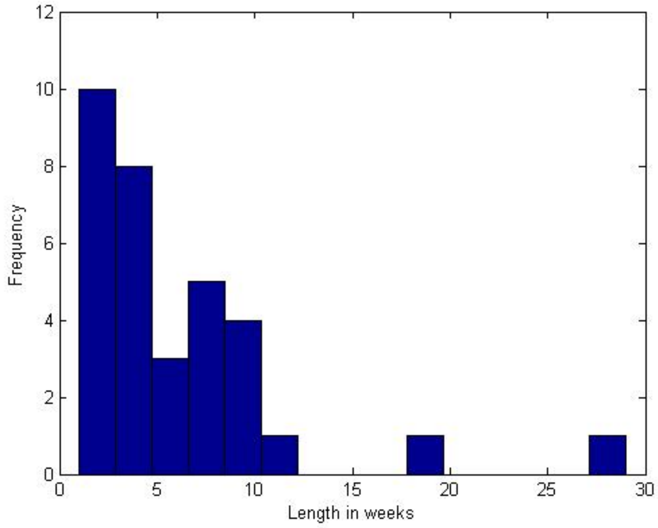

Figure 4.14: Distribution of the lengths of the up periods at the motility clinic.

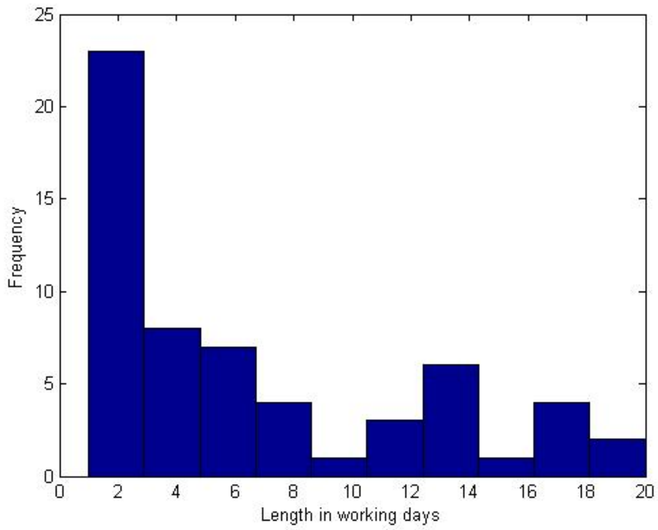

Figure 4.15: Distribution of the lengths of the up periods at the operating rooms for Surgeon A.

For Surgeon B, this could not be done, because in the period of which the data was available, he does not work really regularly. Thursdays are his fixed working days. Before November 2007, he worked mostly also on Tuesdays, and sometimes on Wednesdays. From that month on, this was reversed; the other working day became mostly Wednesday, and and incidentally Tuesdays. Therefore, we have not calculated the same statistics for this surgeon. We did calculate the failure rate of Surgeon B's Thursdays, which is 0.2232.

Chapter 5

Methodology

In this chapter, the used methodology for this study is explained. We have chosen simulation as the tool to solve the studied problem. The first three sections of this chapter together describe how reality is approached as well as possible. In Section 5.1, the decision to choose simulation is justified. Next, in Section 5.2, various aspects of the simulation model are described, including the double transitions that were used, the inputs and outputs of the model, and the assumptions that have been made. The implementation of this model is explained in more detail in Section 5.3. Finally, in Section 5.4, the different scenarios that are carried out are described. This section has the purpose to help answering the research question.

5.1 The Choice for Simulation

In Chapter 2, the strabismus part of the eye hospital was described, both from the patient's perspective and from the organization's viewpoint. In order to obtain the effects of the inputs on the outputs, the model had to be implemented.

The rationale behind the choice for simulation as the tool to solve the studied problem is that the problem is too complex to be solved by other means. As already mentioned in Chapter 2, in practice patients often do not follow these patient routings exactly. There are many loops in the model since patients can visit the departments over and over again. Furthermore, there are many patients that have a disease other than strabismus, but use some of the same resources. Also, the varying capacity and failures add to the complexity of the problem. One can consider to pose some restrictions in order to achieve a smaller set of possible patient routings, but this would cause the model to be less realistic. In the next section it is explained how this problem was dealt with.

5.2 The Simulation Model

The simulation model does not represent the model that was described in Chapter 2 precisely, because the reality was simplified too much, in the sense that many patients do not follow the 'standard' routings exactly. Therefore, we have decided to use transition probabilities based on the real patient routings, as is explained in more detail below. Also, the inputs and outputs of the model are described in this section.

Double Transitions

In order to approach reality best, the exact patient routings that can be found in the data should be taken for the simulation. One could, for example, assign the routing of a patient in the data set randomly whenever a new patient is generated. This well-known technique, called bootstrapping, would be ideal to apply. However, Arena, the simulation software package that we used for our simulation model, was not useful in this respect; there are simply too many patients in the data set. The patient routings had to be stored in a matrix, with in each row the codes of the visited department of one patient. Therefore, the size of the matrix is the number of patients in the data set by the highest number of visits over all these patients, which would be $23,950$ x $96 = 2,299,200$ cells. However, the maximum size of a matrix is only 100,000 cells (which also makes the project file very slow to even open), so we had to devise another method to simulate patient routings that are as close to reality as possible.

We came up with the application of transition probabilities to determine the next visit of a patient. The department that is visited next is decided by chance, dependent on the department of only the last visit. In other words, a Markov process is used to describe the transitions. These probabilities are determined from the real data. For example, it follows from the data that if the previous visit was at the pediatric outpatient clinic, the probability that the next visit is at the orthoptic visit with a duration of 15 minutes is 14.64%, the chance that it is again at the pediatric outpatient clinic is 44.55%, and so on, while there is also the possibility that the patient will not visit the eye hospital again and thus leaves the system with 25.52% chance.

However, because we do not believe that the next department only depends on the last visit, but rather on the visits before as well, we decided to use double transitions. That is, we made the next department dependent on not only the last visit, but also on the visit before the last visit. Defined in this way, it is not a Markov process. However, it can be transformed into a Markov process by defining the states in the following way (Ross, 2003):

- state 0 if both the last visit and the visit before the last are at the pediatric outpatient clinic,
- state 1 if the last visit is at the orthoptic department with duration 15 minutes and the visit before that at the pediatric outpatient clinic,
- and so on.

We verified that the double-transition model is better than the single-transition model by running a few simulations of both models with unlimited capacity, so that there are no queues and everybody can be treated immediately. In fact, we defined the simulation model to be such that no resources are needed. In Table 5.1, one can see that for both models the average number of visits per department of a patient are very close to the actual data. However, the standard deviations of the double-transition model are closer to the real data. Only for the standard deviation of the total number of visits per patient, the single-transition model performs better.

Furthermore, a pragmatic approach had been used to confirm our statement that the double-transition model is more realistic than the single-transition model. In the previous chapter, on page 31, it was already said that there are about 15 new patients per day on average at the eye hospital. The results in the tables are from simulations with an arrival rate of gamma(7,3). We simply started with an arrival rate of 15 (actually, gamma(6,2.5)), and continued to increase it until one of the two simulations gave results that were close to the real data.

This appeared to be the case with the double-transition model. One can see in Table 5.2 that, in general, the means are slightly closer to the actual data than the means of the single-transition model are. Certainly it will not make the simulation results less realistic, and therefore we have chosen to use double transitions for this study. The standard deviations are somewhat lower than the real data (except for the motility clinic). This is because there are no resources used, and therefore there are no failures that can add fluctuations in the capacities.

Table 5.1: The number of visits per department per patient.

Department	Statistic	Data	Single	Double
Pediatric Outpatient Clinic	Mean	1.98	1.98	1.98
	S.d.	2.25	2.05	2.08
Orthoptic Visit 15 min.	Mean	1.09	1.09	1.09
	S.d.	2.61	1.93	2.60
Orthoptic Visit 30 min.	Mean	0.62	0.62	0.61
	S.d.	1.27	1.09	1.16
Motility Clinic	Mean	0.14	0.14	0.14
	S.d.	0.42	0.40	0.40
First Post-operative Checkup	Mean	0.11	0.11	0.11
	S.d.	0.37	0.35	0.36
Second Post-operative Checkup	Mean	0.11	0.11	0.11
	S.d.	0.36	0.34	0.35
OR Strabismus	Mean	0.12	0.12	0.12
	S.d.	0.38	0.36	0.36
OR Non-Strabismus	Mean	0.11	0.11	0.11
	S.d.	0.42	0.37	0.40
Irrelevant Departments	Mean	0.87	0.87	0.86
	S.d.	1.33	1.13	1.19
Total	Mean	5.15	5.16	5.13
	S.d.	4.77	4.86	4.97

The difference between our double-transition model and a Markov model is that the amount of time that a patient spends in a certain state, is not determined by pure randomness; it is rather determined by the length of the waiting queue and the available capacity of the resources, which contain random elements.

As already said before, the next department that a patient visits (if any will be visited) is determined by chance. The probabilities that are used for every possible transition are taken from the real data. By doing this, it was secured that the data was not 'smoothed'. In reality, not all patients follow the model as described in Chapter 2. This is because in the real world, there are many circumstances that are not exactly as how they 'should' be. Furthermore, by using these transition probabilities, the probability of something unusual happening is as great as in the real data.

For example, there are patients that visit the pediatric outpatient clinic

Table 5.2: The number of visits per department per day.

Department	Statistic	Data	Single	Double
Pediatric Outpatient Clinic	Mean	40.46	40.27	40.38
	S.d.	20.85	7.82	8.20
Orthoptic Department*	Mean	39.41	39.01	39.43
	S.d.	18.32	7.16	7.03
Motility Clinic	Mean	13.90	13.83	13.80
	S.d.	7.46	8.55	8.50
OR Strabismus	Mean	2.68	2.97	2.99
	S.d.	2.83	1.95	1.98
OR Non-Strabismus	Mean	2.53	2.92	2.87
	S.d.	3.19	1.93	1.99
Irrelevant Departments	Mean	49.32	17.50	17.66
	S.d.	20.94	4.70	4.88

* The orthoptic department includes the orthoptic visits of 15 and 30 minutes, and the first and second post-operative checkups.

after a visit to the orthoptic department. Also, some children are circling around in the pediatric outpatient clinic for a long time before they go to the next stage.

Another reason why the patient routings are not really predictable, is that there are also patients that use the same resources, for other problems than strabismus. The routings of these patients are also included in the model, because they affect the capacity of the resources. Their routings, however, are less 'standard' than the paths of the 'ordinary' strabismus patients. In other words, we have chosen to use empirical data because it is more realistic; 'abnormal' patient routings will be present in the simulation.

Model Inputs and Outputs

Each model needs inputs that can be used in the process, in order to generate outputs. What the inputs and the outputs of a model are, is dependent on the resources one has, and the goal one wants to achieve.

For the model of this study, there are several sorts of input:

- First, of course, the timetables of the personnel. Together with their productivity (how many of each appointment type per hour the staff members can handle), the resource capacity is determined.

- Further, the probabilities for the next visit have to be assigned. In other words, the patient routings can be seen as input.

- The user of the model can also choose the patient scheduling rule. The most logical way is to appoint patients on a first-come, first-served basis.

- The choice of the distributions for the failures can also be of influence on the outputs. The higher the failures, the fewer patients can be seen, so the access times would become higher.

- Finally, the arrival process of new patients at the eye hospital can be changed in order to see what the effects of using different arrival processes are.

As already mentioned in the Introduction, the ultimate goal of this study is to reduce the access times of the departments in the strabismus care pathway.

The access time, that is, the time between the moment that the appointment is made and the moment of the appointment itself, depends on a lot of things. Firstly, of course, the access time is influenced by the available resources; the fewer the resources, the lower the capacity will be, and the longer the access time. Further, appointments are normally made on a first-come-first-served basis, but also depending on when patients are available, and the time until the next visit that the hospital thinks necessary.

The throughput time of a patient measures the time that a patient needs to go through the whole system. It is simply the time between the moment that the appointment for the first contact at the eye hospital is made and the moment that the patient leaves the system.

Model assumptions

The word ‘model’ has many different meanings. One of the definitions used by the Oxford English Dictionary (www.oed.com) is the following: ‘A simplified or idealized description or conception of a particular system, situation, or process, often in mathematical terms, that is put forward as a basis for theoretical or empirical understanding, or for calculations, predictions, etc.; a conceptual or mental representation of something.’ The keyword here is 'simplified'; in order to keep the simulation model simple and hopefully not too unrealistic, we decided to make the following assumptions:

1. All appointments are planned on a first-come, first-served basis.
2. All appointment slots in the future are available.
3. There is no seasonality.
4. Orthoptists at the pediatric outpatient clinic are not the same as those at the orthoptic department.
5. Surgeons at the OR are not the same as the doctors at the pediatric outpatient clinic.
6. The resources at the motility clinic are seen as one resource entity.

The first assumption, that appointments at the eye hospital are planned on the first possible opportunity has several implications. First, there are no periodic checkups. In the real world, some patients are seen on a regular basis, for example, once every six months or once every year. However, the data is not such that it can be directly derived whether an appointment involves a periodic checkup or not. The graphs of the access times in Chapter 4 show some half-yearly and yearly peaks, but these are underestimations of the real periodic checkups, because if a patient visits the eye hospital between the periodic checkups, the access time will be shortened.

Another consequence that the appointments are planned on the first available opportunity, is that the degree of urgency is not taken into account. In reality, sometimes people are planned earlier because their need for help is more urgent than that of other patients.

Furthermore, patients do not always have time for a visit; they have their own agendas, which implies that they may prefer an appointment at a later point in time rather than the first available time of the eye hospital.

Also, we assume that all appointment slots in the future, which were described in Section 2.2, are available. We have made this assumption both because it is not possible to implement these appointment slots, and because it does not matter; our first assumption will automatically force the visits at the next available point in time.

The third assumption is that there is no seasonality. This means that it is not predetermined when the eye hospital is busier or less busy than in other time periods. In the real world, both the arrival rate and the capacity decrease during the summer, which is mainly because of vacations of both the personnel and the patients. Since it is not possible to have different timetables for vacation periods and normal periods in Arena, we have not included seasonality in the model. However, this does not have to be a big problem; since both the arrival rate and the available capacity decrease, the effects will cancel out to some extent. The same holds for the distributions of the failures.

In reality, orthoptists work at both departments. However, we assume that the orthoptists at the pediatric outpatient clinic are not the same people as those at the orthoptic department. This decision was made because of practical issues; in Arena, schedules and failures are resource-dependent, but not department-dependent. The implication of this is that the failures of orthoptists are independent; for example, if an orthoptist who in reality works at the pediatric outpatient clinic on Monday and Wednesday, and at the orthoptic department on Tuesday and Thursday, gets sick on Monday for a week, both departments should decrease in capacity. However, since our assumption is such that there are two different resources, only one of them gets sick for a week, and the capacity of only one department is decreased.

It is possible to assign one resource to two different departments, but this resource will be at both departments during his or her working-hours. Since it is unrealistic that an orthoptist switches multiple times a day between two departments, we have not considered this option.

Analogically, the surgeons at the OR are not the same as the doctors at the pediatric outpatient clinic, although in reality, they do make part of the team of doctors at that department.

The sixth assumption is that the motility clinic resources, consisting of a team of orthoptists, doctor's assistants and one surgeon, is one resource entity. This is for practical purposes, since the members of this team work at exactly the same time of the week (Thursday afternoon). Furthermore, the size of the team varies per patient. This assumption will not have severe implications, because the failures at the motility clinic as a whole are known, as was described in the previous chapter.

5.3 Implementation

In this section, the implementation of the model described in the previous section is explained in more detail. We show how the patients flow through the system, and how the resources are implemented exactly.

Because the data set consisted of all visits from January 2004 until June 2008, the routings of some patients were not complete. The problem is that it is not clear exactly for which patients this is the case. Therefore, the simulation model could not be such that all generated patients start at the outpatient clinics, as they should have done in theory. Hence, whenever a patient is generated, he or she must have the possibility to start at any department. Of course, the possible path that the patient takes from then on could lead to anywhere again. This can be seen in Figure 5.1.

A new patient is generated in the block at the left top corner of the figure. Then, a patient number and the first start time are assigned to this patient. The first start time is the point in time that the patient is created, and is used to calculate the throughput time when he or she leaves the system. Also, the number of visits at each department of the patient is set to 0. Furthermore, other statistics are made to keep track of the patient's number of visits at the various departments.

There are two types of start times in the model: one is the first start time just mentioned. The other type is the time from which on the access time of a visit is calculated. Hence, this second type is updated every time the patient visits a department in the eye hospital. So only when a new patient is generated, both types have the same value.

Then, the department that is visited next is determined. Based on the last two visits of this patient, the probabilities to visit any of the departments are known. This concept of using the information of the last two visits instead of only the last one and the rationale behind it is explained in the previous section.

Depending on whether there is staff available and the number of patients that came earlier to the particular department, a patient can be helped directly, or he or she has to wait in the queue. In this model, patients are treated on a first-come-first-served basis. This is different from what happens in reality, since in the real world, patients are not always available whenever there is capacity. Also, there are many periodic checkups that require a pa-

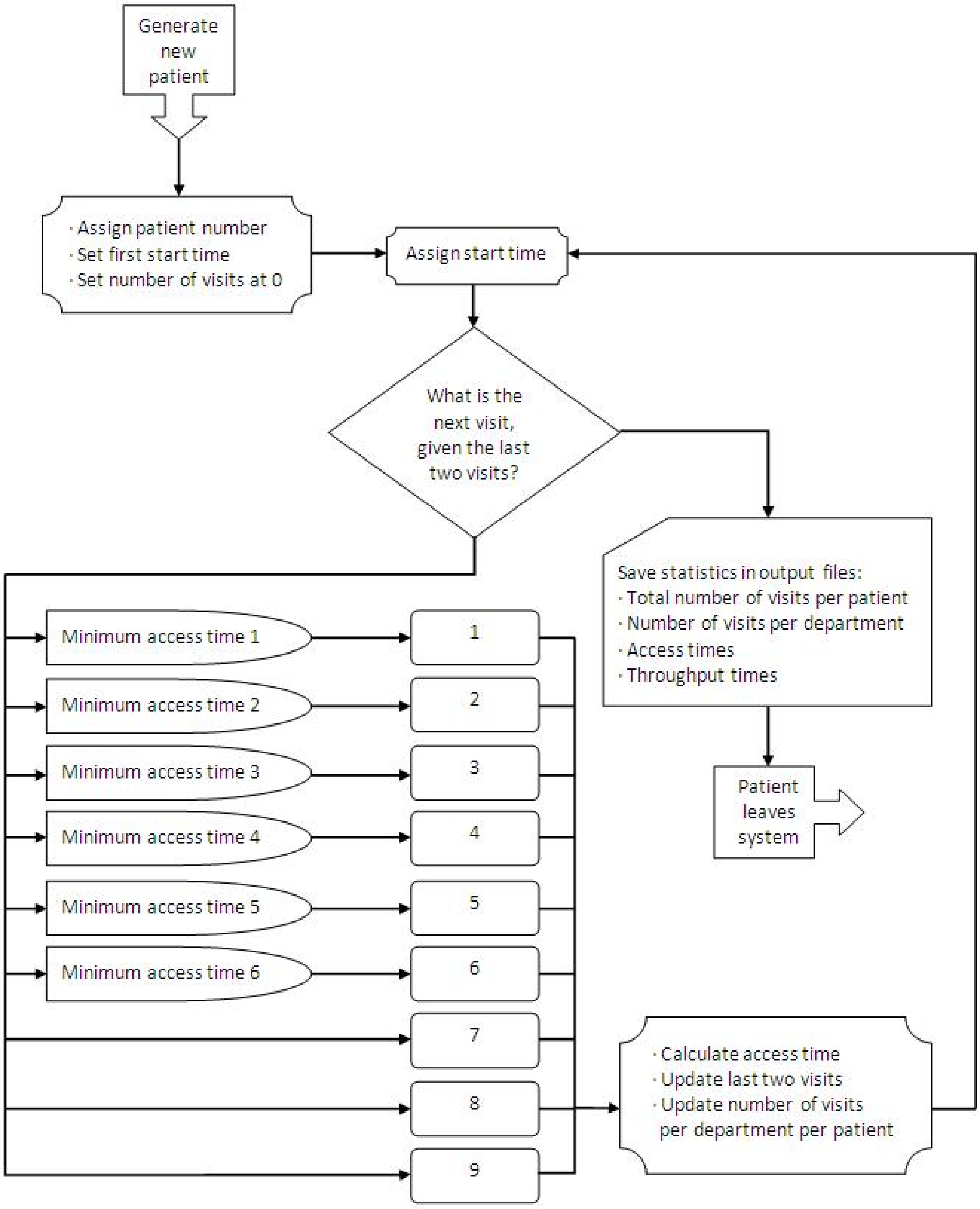

Figure 5.1: The simulation model in Arena.
1 = Pediatric outpatient clinic, 2 = Orthoptic visit 15 minutes, 3 = Orthoptic visit 30 minutes, 4 = Motility clinic, 5 = First post-operative checkup, 6 = Second post-operative checkup, 7 = OR strabismus, 8 = OR non-strabismus, 9 = Non-strabismus departments.

tient to come back after a certain period of time. Therefore, the simulation results cannot be interpreted directly. In Chapter 6, it is explained how this problem was dealt with.

One can see that six of the nine departments are preceded by a block with a minimum access time. This is because the eye hospital finds it necessary to have a certain period of time between two visits. For instance, a post-operative checkup one day after surgery itself is too short; complications are usually observable only after about two weeks. Because the minimum access times do not have to be the same for every department, there are six of these blocks instead of one. There are no minimum access times for the surgeries and the irrelevant departments, the latter mainly because they are a combination of different departments and therefore likely to have different minimum access times within this group. Later in this section, we describe how we handled this.

Absences of employees, whether they represent sickness or vacations, are modeled by defining distributions for the lengths of the periods that they are working (uptimes), and for the period lengths that they are not working (downtimes).

At the pediatric outpatient clinic, which is labeled '1' in the figure, the resources consist of doctors, orthoptists, and doctor's assistants, each with their respective productivity, as was described in the previous chapter. When a patient arrives at this department, he or she is assigned to one of the staff members. Using a 'cyclic' selection rule, it is determined to which one exactly.

At the orthoptic department, orthoptists are the only qualified resources. As already explained in Assumption 4 of the previous section, these employees are not the same as those at the pediatric outpatient clinic. Furthermore, they are implemented individually, as we described above. Because the orthoptic visits of 15 and 30 minutes, and the first and second post-operative checkup all take place at the orthoptic department and use the same resources, these four visit types *are* assigned to the same set of orthoptists.

All surgeries in our study are performed by either one of the two strabismus surgeons, whether it is a strabismus surgery or not. Therefore, also in the simulation model the patients are operated by the same resource set (consisting of the two surgeons).

As we said before, the surgeries have no minimum access time in the simulation model because they do not have one in reality. Some of the non-strabismus departments, however, do require such periods of time, which differ per department. We decided to use the distribution of the access times from the real data as the time that patients spend at the non-strabismus departments. Since there are no resources needed here, this is the same as assigning an access time from that distribution, and then let the patients go the 'non-strabismus departments' module, where they never have to wait in a queue and leave at the same time as they arrive. The only difference would be that there will be an extra block in the figure, while the effect is exactly the same.

After a visit of patient, the access time of the visit is calculated. This is just the time between the start time and the current time, minus the process time (that is, the time duration that the patient is actually being treated). Also, the locations of the last two visits and the number of visits per department of the patient are updated. Then, the start time for the next appointment is already set on the time that patient leaves the department that he or she just visited, for the calculation of the access times. Subsequently, the department that is visited next is determined, and the process just described is repeated until this patient does not need to go to the eye hospital again. The statistics are collected and saved into output files then and the patient leaves the system.

The output files are then converted into .txt files, which are imported into Matlab, in which the relevant statistics are calculated. The results are described in the next chapter.

Implementation issues

A remark should be made concerning the resources in the simulation model: all staff members are modeled individually. This way, all of them can have different timetables, and the failures are independent of each other. In Arena one cannot just define one resource type consisting of *independent* instances; when there is a failure, all instances of that resource type is unavailable. Therefore, we tackled this problem by modeling every employee separately. By naming them 'doctor 1', 'doctor 2', 'orthoptist 1', 'orthoptist 2' et cetera, one can still see that they are of the same type. The failure rates, as we described earlier in this thesis, are implemented by choosing distributions for the lengths of the up and down periods. These distributions are fixed during simulation. This means that we cannot have different distributions for the summer period and the rest of the year.

Further, Table 4.1 showed that on Tuesday afternoon, only six patients can be seen. In Arena, however, it was not possible to temporarily decrease the 'productivity' of a resource.

Sometimes, when a shift ends, it can happen that a patient is being treated at that exact moment. In Arena, one needs to choose one of three options for this so-called 'schedule rule': *Preempt*, *Wait* or *Ignore*. With the *Preempt* option, the resource stops immediately whenever a shift ends; the treatment of the patient is stopped, and will continue when the resource becomes available again. Since this is highly unrealistic, we decided to use another schedule rule. Both the *Wait* and the *Ignore* option have the property that the resource finishes treating the current patient, and stops directly after this. The difference is that with the *Ignore* option, the next shift of this employee starts at the scheduled time, while with the *Wait* option, he or she starts the next scheduled shift with a delay equal to the previous overtime. We have chosen the *Ignore* option because we believe it is more realistic. In the figure below, the three options are represented graphically.

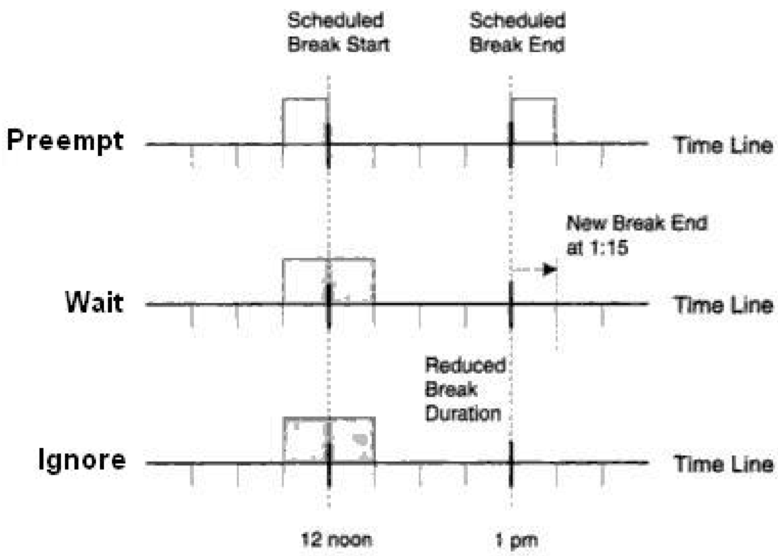

Figure 5.2: The Preempt, Wait and Ignore Schedule Rules. *Source*: Kelton et al. (2010).

5.4 Scenarios

The outputs of a model are dependent on the inputs. For this study, we want to know what the effects are for the access times (and throughput times) if the capacities of the pediatric outpatient clinic and the orthoptic department are changed. These are the only two departments of which the capacities can be modified, since the capacity levels of both the motility clinic and the operating rooms can not be increased. Also, it can be interesting to see what happens if the extent to which the personnel are absent is changed. These absences are called failures. We have decided to run a number of simulations to capture the effects of all these adjustments. For every decision variable (the capacities) and parameter set (failure rates), we have defined three levels, namely low, medium and high. This gives 3x3x3=27 simulations. These 27 simulations can be seen as different scenarios; *what happens if the capacity of a particular department or failure rate is changed?* Since we think it is not desired to *lower* the capacities on the two relevant departments, we define the capacities used in practice as 'low'. The extent of the failures, on the other hand, are not really something one can decide upon, so we define the observed failures as 'middle', by which we can see what happens when the resources are more often or less often unavailable. Because the sickness absences can only be reduced *indirectly*, for example by means of better working positions to prevent RSI, we do not consider the failure levels to be decision variables.

In the previous chapter the timetables of the personnel at the pediatric outpatient clinic and the orthoptic department were given. They showed that in that model, there are three different doctors, three different orthoptists and three different doctor's assistants at the pediatric outpatient clinic. As mentioned above, this is considered as 'low' capacity. For the 'middle' and 'high' capacity level we have taken four and five of these resources, respectively. We think that this is an increase in capacity that is reasonably realistic to achieve in practice. In Table 5.3, it is shown how these resources are exactly scheduled. We learned from prior testing that there are no significant differences in the number of visits per day and the access times if the personnel is scheduled in a different way, with preservation of the *number* of a particular resource type during a shift. In other words, it does not matter whether a doctor is planned on Monday morning and Monday afternoon, or on Tuesday afternoon and Friday morning. In the end, we have decided to spread the resources over the week, although we could have allocated them randomly as well.

Table 5.3: The timetable of the extra resources at the pediatric outpatient clinic.

Day	Shift	D4	O4	A4	D5	O5	A5
Monday	Morning	0	0	0	0	1	0
	Afternoon	1	1	0	0	1	0
Tuesday	Morning	0	0	0	1	0	0
	Afternoon	0	0	0	0	0	0
Wednesday	Morning	0	1	0	0	0	1
	Afternoon	0	1	0	0	0	0
Thursday	Morning	0	0	0	0	0	0
	Afternoon	0	0	0	1	0	0
Friday	Morning	0	0	1	0	1	0
	Afternoon	1	0	0	0	1	0

D = Doctor, O = Orthoptist, A = Doctor's Assistant.

As for the orthoptic department, there are six different orthoptists working. One orthoptist is added for the 'middle' capacity level, and another one for the 'high' capacity level. In Table 5.4, the scheduling of these resources is presented.

Table 5.4: The timetable of the extra resources at the orthoptic department.

Day	Shift	O7	O8
Monday	Morning	1	1
	Afternoon	0	1
Tuesday	Morning	0	0
	Afternoon	0	0
Wednesday	Morning	1	1
	Afternoon	1	1
Thursday	Morning	0	0
	Afternoon	1	0
Friday	Morning	1	1
	Afternoon	1	1

O = Orthoptist.

Also, the failure rates should be chosen; as mentioned before, in Arena, this is done by defining the distributions for the uptimes and the downtimes. We distinguish three possible levels for this purpose. The distributions in Chapter 4 are considered as 'middle'. The following table provides the three levels that are used in the simulations.

Table 5.5: Distributions of failures.

State	Resource Type	Low	Middle	High
Up	Doctors	exp(50)	exp(40)	exp(30)
Up	Orthoptists	exp(50)	exp(40)	exp(30)
Up	Motility Clinic	gam(1.03,37)	gam(1.03,28.38)	gam(1.03,20)
Up	Surgeons	gam(1.17,18)	gam(1.17,13.58)	gam(1.17,10)
Down	Doctors	exp(10)	exp(10)	exp(10)
Down	Orthoptists	exp(10)	exp(10)	exp(10)
Down	Motility Clinic	gam(4.04,1.55)	gam(4.04,1.55)	gam(4.04,1.55)
Down	Surgeons	gam(2.24,1.77)	gam(2.24,1.77)	gam(2.24,1.77)

Since we wanted to be able to change the failure rates, but still keep the model realistic, we have chosen the above values for the low and high failures. Further, one can see that only the parameters of the uptimes are changed. This is because we believe that it is more likely that the durations of absences will not be very different than the choices that we have made. Reducing and enhancing the uptimes in fact means that the frequency of failures becomes higher and lower, respectively.

Chapter 6

Results

In this chapter, the results of this study are presented. First, the base case is extensively discussed. Thereafter, the most important results of the other simulations are discussed and compared with each other in Section 6.2. In Section 6.3, the results are analyzed in a more formal way, using regression analysis. Finally, in Section 6.4, our recommendations to the eye hospital are presented.

One remark should be made before we present the results: all simulation runs have a duration of 10 years, of which the first half is seen as a warm-up period. The statistics are therefore collected from the last five years of the simulation data. Actually, for all departments we looked at the plots of the access times at all departments, and it appeared that after about one year, there was no upward trend anymore, which indicates that our warm-up period is more than sufficient. There are some fluctuations in access times in later years, but since the trend is constant, we believe that this is not a problem for our analysis.

6.1 Base Case

The base case is the simulation run in which the real schedules of the personnel are used as input. The failure rates for the different departments were given in Table 5.5 (middle level) in the previous chapter. As already said, the failure rates of the motility clinic and the surgeons are calculated from the data, while those of the pediatric outpatient clinic and the orthoptic department are estimated. However, in Arena the user has to assign the distributions of the durations of the working periods (uptime) and the durations of the absence periods (downtime). We have chosen the gamma distributions for both the uptime and the downtime of the motility clinic as well as those of the surgeons. Based on Figures 4.14 and 4.15, there is not really a good distribution that fits the data. However, we believe that the gamma distribution is the best choice that can be made. For the base case, the used uptime and downtime durations can be found in Table 5.5 at the middle level part. The chosen arrival rate is such that the number of visits per day at the different departments in the simulation approximate reality. It turned out that this is the case if the number of *new* patients that arrive at the eye hospital per day is distributed as gamma(7,3).

The results of the base case simulation are shown in the following tables, together with the real data statistics. As can be seen, there are four simulation runs performed. This is not only for this base case, but for all scenarios in the previous chapter, because there are some fluctuations. The means can then be compared to the statistics of the real data. Table 6.1 provides the number of visits per department per *working* day. For the motility clinic, this means that the data are per Thursday, while Wednesday is not a working day for the surgeons. The statistics for the orthoptic visits of 15 and 30 minutes, and the first and second post-operative checkups are taken together because they use the same resources. Although the strabismus and non-strabismus surgeries make use of the same surgeons, their statistics are given separately, because this way, we can distinguish the strabismus and non-strabismus patients that undergo a surgery.

Table 6.1: The number of visits per department per day in the base case.

Department	Data	Mean	Run 1	Run 2	Run 3	Run 4
Pediatric Outpatient Clinic	40.46	40.17	40.17	39.90	40.35	40.24
	(20.85)	(13.95)	(13.50)	(13.56)	(13.96)	(14.77)
Orthoptic Department*	39.41	39.08	39.24	38.89	39.19	39.01
	(18.32)	(20.05)	(20.33)	(19.81)	(20.14)	(19.91)
Motility Clinic	13.90	14.11	13.85	14.52	14.14	13.93
	(7.46)	(6.95)	(7.41)	(6.13)	(7.02)	(7.24)
OR Strabismus	2.68	2.80	3.06	3.02	2.18	2.95
	(2.83)	(2.25)	(2.20)	(2.26)	(2.30)	(2.22)
OR Non-Strabismus	2.53	2.70	2.95	2.82	2.17	2.86
	(3.19)	(2.26)	(2.23)	(2.24)	(2.32)	(2.27)
Non-Strabismus Departments	17.45	17.65	17.63	17.56	17.71	17.72
	(9.06)	(4.28)	(4.38)	(4.13)	(4.39)	(4.23)

* Includes the orthoptic visits of 15 and 30 minutes, and the first and second post-operative checkups. Standard deviations are given between parentheses.

One can see that most of the simulation results are reasonably close to the statistics of the real data. The simulation means of the surgeries are somewhat larger than those of the real data. They differ relatively more from each other than the statistics of the other departments. Further, most of the standard deviations are lower than the real standard deviations. But, all in all, we can say that reality is approached reasonably well.

Table 6.2 shows how often a patient visits the different departments on average before he or she leaves the system. When compared to the statistics of the real data, it can be concluded that the results of the simulation are reasonably realistic, although the simulation results are slightly smaller.

Table 6.2: The number of visits per department per patient in the base case.

Department	Data	Mean	Run 1	Run 2	Run 3	Run 4
Pediatric Outpatient Clinic	1.98	1.93	1.95	1.92	1.93	1.92
	(2.25)	(2.02)	(2.03)	(2.02)	(2.02)	(2.02)
Orthoptic Visit 15 min.	1.09	0.99	1.00	0.98	0.98	0.99
	(2.61)	(2.41)	(2.44)	(2.40)	(2.40)	(2.39)
Orthoptic Visit 30 min.	0.62	0.58	0.59	0.58	0.58	0.59
	(1.27)	(1.11)	(1.12)	(1.12)	(1.11)	(1.11)
Motility Clinic	0.14	0.13	0.13	0.13	0.12	0.13
	(0.42)	(0.38)	(0.39)	(0.38)	(0.38)	(0.38)
First Post-operative Checkup	0.11	0.10	0.10	0.10	0.10	0.10
	(0.37)	(0.34)	(0.34)	(0.34)	(0.33)	(0.34)
Second Post-operative Checkup	0.11	0.10	0.10	0.10	0.10	0.10
	(0.36)	(0.33)	(0.34)	(0.33)	(0.32)	(0.33)
OR Strabismus	0.12	0.11	0.11	0.11	0.10	0.10
	(0.38)	(0.34)	(0.35)	(0.34)	(0.34)	(0.34)
OR Non-Strabismus	0.11	0.11	0.11	0.11	0.11	0.11
	(0.42)	(0.39)	(0.40)	(0.39)	(0.38)	(0.39)
Non-Strabismus Departments	0.87	0.82	0.83	0.82	0.82	0.83
	(1.33)	(1.15)	(1.15)	(1.15)	(1.14)	(1.14)
Total	5.15	4.87	4.92	4.84	4.84	4.87
	(4.77)	(4.63)	(4.70)	(4.62)	(4.61)	(4.61)

Standard deviations are given between parentheses.

These two tables actually serve to confirm that the simulation model and the chosen parameters are justifiable. Therefore, we can now concentrate on the outputs that are important for this study, namely, the access times.

In Table 6.3, one can see that it is obvious that the access times of the simulation absolutely do not match the real access times, even though these real access times are converted to get them comparable with the simulation results. That is, we have multiplied the actual data by 5/7 to eliminate the weekends, since we only simulated weekdays. Despite these adjustments, the simulation statistics still do not resemble the real data. The explanation for this is our assumption that the appointments in the simulation model are planned at the first possible opportunity, as already described in Sections 5.2 and 5.3. This has a several implications that lead to smaller access times.

Table 6.3: The access times per department in the base case.

Department	Data	Mean	Run 1	Run 2	Run 3	Run 4
Pediatric Outpatient Clinic	109.64	20.81	20.78	20.76	20.79	20.91
	(114.05)	(1.39)	(1.34)	(1.27)	(1.48)	(1.49)
Orthoptic Department 15 min.	90.48	20.33	20.36	20.29	20.38	20.30
	(64.00)	(0.63)	(0.71)	(0.52)	(0.73)	(0.57)
Orthoptic Department 30 min.	45.99	20.47	20.49	20.43	20.51	20.44
	(62.67)	(0.63)	(0.71)	(0.52)	(0.72)	(0.57)
Motility Clinic	34.92	29.45	32.39	28.76	27.57	29.07
	(37.07)	(8.50)	(11.78)	(8.59)	(5.54)	(8.08)
First Post-operative Checkup	10.89	11.55	11.60	11.51	11.57	11.52
	(5.45)	(1.57)	(1.61)	(1.52)	(1.64)	(1.54)
Second Post-operative Checkup	47.46	78.98	79.39	79.01	79.08	78.43
	(21.83)	(25.52)	(25.70)	(25.14)	(26.07)	(25.16)
OR Strabismus	42.41	2.79	3.31	2.61	2.66	2.59
	(45.63)	(2.69)	(3.09)	(2.56)	(2.63)	(2.48)
OR Non-Strabismus	24.80	2.73	3.13	2.55	2.67	2.57
	(23.68)	(2.71)	(3.00)	(2.55)	(2.64)	(2.63)
Non-Strabismus Departments	55.27	53.68	54.14	54.00	53.21	53.38
	(108.07)	(128.51)	(129.56)	(129.70)	(129.25)	(125.54)
Total Time in System	322.81	123.59	126.02	122.78	122.97	122.60
	(348.50)	(153.56)	(156.66)	(153.78)	(153.68)	(150.11)

Standard deviations are given between parentheses.

First of all, as already mentioned in Chapter 5, there are periodic checkups in reality. This means that the access times of these visits can be one year, for example, while there is enough capacity at the particular department in a much earlier stadium.

Also, because the model does not take urgency into account, the access times of the patients who need urgent help can become longer than in reality would be, although this is (partly) compensated by the access times of the people who are planned a bit earlier because there are no urgent patients that 'jump the queue'.

Finally, patients have their own agendas too. It might be that someone only has time on one particular weekday, while the department of the appointment is full for the next few weeks on that particular day of the week. In practice, both the patient's and the resource's availabilities are compared to each other, and a date is picked that suits both. In the simulation model, however, this was not done, because we could not tell from the data which visits could have been assigned earlier and exactly how much earlier, if the planning only depended on resource capacity.

Although the simulated access times are totally different from the real access times, they can still be useful: in the next section, the access times of the 27 simulations described in Section 5.4 are compared with those of the base case simulation. By analyzing relative instead of absolute outcome differences, we are still able to draw helpful conclusions for the real-world problem.

6.2 Scenario Results

In this section, the results of the simulations of Section 5.4 are examined. The relative differences with respect to the base case results are discussed. We decided to analyze the relative discrepancies, because the absolute values of the simulated outcomes are not directly interpretable, as explained above.

To recapitulate, there are three levels of capacity at the pediatric outpatient clinic and the orthoptic department. Furthermore, the failure rates of the staff can take on one of three different levels, of which the middle one is the level that resembles the failure rates found in the data. The effects of the different pediatric outpatient clinic capacity levels, those of the different orthoptic department capacity levels, and the effects of the different failure levels are analyzed separately.

In the previous section, three output measures of the base case simulation were shown. Two of them, namely the number of visits per department per *day* and the number of visits per department per *patient*, are neither dependent on the capacity levels nor on the failure levels, as long as we are in a steady state. Hence, there are only minor differences between the results of these output measures of the 27 scenarios, due to the random components of the simulation model. Therefore, we decided not to present them, and instead focus on the outputs that do change with the capacity and failure settings: the access times. The access times are the most important outputs of this study, since the aim of the thesis is to determine the effects of resource allocations so that they can be decreased.

In Tables 6.4, 6.5 and 6.6, the relative differences in access times at all departments of the 27 scenarios with respect to the base case are shown. Because the base case is one of these scenarios, we present the absolute access times, subtracted by the minimum access times, instead of displaying a column with zeros. For the visits at the pediatric outpatient clinic, there is a minimum access time of 20 days. (As said before, in the simulation model, a week consists of five days, so a minimum access time of 20 days actually means four weeks.) The same holds for the orthoptic visits of 15 and 30 minutes and the motility clinic. For the first and second post-operative checkups, the minimum access times are not constants, but they are triangle(8,10,15) and triangle(40,45,150) distributed, respectively. A triangular distribution triangle(a,b,c) is a continuous probability distribution with a lower limit a, mode c and upper limit b (Evans et al., 2000). The probability density function is as follows:

$$f(x|a,b,c) = \begin{cases} \frac{2(x-a)}{(b-a)(c-a)} & \text{for } a \leq x \leq c \\ \frac{2(b-x)}{(b-a)(b-c)} & \text{for } c \leq x \leq b \\ 0 & \text{otherwise} \end{cases}$$

We have used a conservative approach to subtract the minima of the minimum access times, that is, eight days for the first post-operative checkups and 40 days for the second post-operative checkups.

The notation ‘x/y/z’ in the header rows of the tables has the following meaning: x is the capacity level at the pediatric outpatient clinic, y the capacity level at the orthoptic department, and z is the failure level. For instance, the scenario ‘l/l/m’ represents the base case; the capacity levels at the pediatric outpatient clinic and the orthoptic department are low, while there is a middle failure level, as defined in Section 5.4.

Table 6.4: The relative differences in access times of simulations 1–9 with respect to the base case.

Department	l/l/l	**l/l/m***	l/l/h	l/m/l	l/m/m	l/m/h	l/h/l	l/h/m	l/h/h
POC	-16.1	**0.81**	-30.3	-25.1	-7.9	143.7	-49.5	36.8	134.6
	(-20.9)	**(1.39)**	(-23.6)	(-11.6)	(-16.8)	(86.6)	(-43.8)	(34.8)	(91.3)
OT 15 min.	-8.7	**0.33**	6.8	-56.4	-42.6	-1.1	-68.0	-62.5	-50.9
	(-10.0)	**(0.63)**	(19.8)	(-54.2)	(-38.7)	(14.4)	(-63.9)	(-60.6)	(-47.2)
OT 30 min.	-6.6	**0.47**	4.4	-42.5	-33.3	-7.7	-54.0	-51.5	-43.9
	(-9.8)	**(0.63)**	(18.5)	(-47.5)	(-35.0)	(10.3)	(-56.7)	(-55.2)	(-44.8)
Mot. Clin.	-4.7	**9.45**	-17.2	-12.2	3.0	376.0	-32.5	70.2	205.7
	(-20.8)	**(8.50)**	(-18.8)	(-9.9)	(-9.3)	(79.2)	(-34.7)	(30.2)	(113.9)
FPC	-1.1	**3.55**	0.7	-5.8	-4.7	-1.0	-6.9	-6.8	-6.1
	(-1.0)	**(1.57)**	(4.3)	(-4.7)	(-4.1)	(3.2)	(-5.2)	(-6.4)	(-5.5)
SPC	0.7	**38.98**	-0.5	-1.3	-1.0	-0.3	-1.5	-2.3	-1.0
	(-0.1)	**(25.52)**	(-0.3)	(0.0)	(-0.4)	(-0.5)	(-0.5)	(-1.3)	(-0.5)
OR Strab.	9.5	**2.79**	-9.2	-24.7	17.2	54.0	-32.1	3.8	184.2
	(18.1)	**(2.69)**	(-4.8)	(-17.2)	(26.4)	(59.3)	(-26.7)	(5.4)	(137.6)
OR Non-Strab.	8.4	**2.73**	-11.0	-26.1	14.2	56.3	-33.4	4.8	185.6
	(15.7)	**(2.71)**	(-6.6)	(-19.7)	(22.0)	(58.8)	(-28.6)	(3.0)	(137.7)
Non-Str. Depts.	0.5	**53.68**	-0.3	-0.7	-1.3	-1.1	0.2	-0.3	-1.7
	(-0.4)	**(128.51)**	(0.3)	(-0.2)	(-2.0)	(-1.1)	(0.0)	(-1.1)	(-1.7)
Total Time	0.4	**123.59**	-0.3	-0.9	-0.6	3.0	-0.9	0.5	2.5
in System	(0.6)	**(153.56)**	(0.9)	(-0.7)	(-0.9)	(2.3)	(-0.4)	(-0.1)	(1.7)

*Base case. All numbers in this column are expressed in days. All other values are expressed in percentages.
POC = Pediatric Outpatient Clinic, OT = Orthoptic Department, Mot. Clin. = Motility Clinic, FPC = First Post-operative Checkup, SPC = Second Post-operative Checkup, OR Strab. = OR Strabismus, OR Non-Strab. = OR Non-Strabismus, Non-Str. Depts. = Non-Strabismus Departments.
Relative differences of the standard deviations are given between parentheses.

Table 6.5: The relative differences in access times of simulations 10–18 with respect to the base case.

Department	m/l/l	m/l/m	m/l/h	m/m/l	m/m/m	m/m/h	m/h/l	m/h/m	m/h/h
POC	-82.8	-83.8	-69.8	-86.8	-83.3	-70.3	-86.8	-83.1	-67.0
	(-79.1)	(-82.4)	(-58.9)	(-83.4)	(-82.6)	(-64.9)	(-85.8)	(-81.6)	(-55.8)
OT 15 min.	8.9	14.1	136.0	-58.5	-55.7	-41.9	-69.7	-64.0	-53.0
	(8.1)	(26.4)	(127.7)	(-50.9)	(-54.2)	(-39.7)	(-63.4)	(-53.7)	(-35.0)
OT 30 min.	5.9	10.0	98.5	-43.7	-42.1	-33.9	-54.7	-50.4	-42.1
	(7.2)	(26.6)	(129.1)	(-45.2)	(-48.2)	(-37.4)	(-56.2)	(-47.4)	(-29.1)
Mot. Clin.	-16.5	33.1	525.2	-14.4	40.5	231.3	-9.5	16.3	253.7
	(-29.0)	(19.8)	(75.7)	(-22.0)	(20.5)	(97.2)	(-10.7)	(9.9)	(125.4)
FPC	1.1	1.1	13.3	-5.9	-6.0	-4.4	-6.3	-6.4	-5.2
	(2.6)	(6.5)	(35.3)	(-5.7)	(-4.4)	(-3.9)	(-4.8)	(-4.4)	(-1.8)
SPC	0.0	0.0	-0.1	-0.8	-1.0	-0.7	-0.7	-1.8	-0.7
	(-0.6)	(-1.3)	(-1.7)	(-1.3)	(-0.6)	(-1.2)	(-0.3)	(-0.8)	(-0.2)
OR Strab.	-15.1	15.1	156.8	-25.9	7.9	83.4	-25.1	40.9	55.0
	(-3.0)	(24.4)	(150.8)	(-20.3)	(4.9)	(69.7)	(-20.3)	(50.7)	(54.8)
OR Non-Strab.	-12.9	17.0	158.0	-28.0	7.3	82.9	-27.7	37.9	49.0
	(-1.3)	(23.1)	(148.9)	(-22.9)	(4.9)	(66.2)	(-22.4)	(46.2)	(45.3)
Non-Str. Depts.	-0.7	0.5	-0.8	-0.2	0.1	-0.3	-0.3	-0.8	0.4
	(-1.4)	(0.2)	(-2.1)	(-0.7)	(0.5)	(0.8)	(-1.1)	(-1.6)	(0.6)
Total Time	-0.8	-0.4	3.5	-1.5	-0.5	0.4	-1.1	-0.5	1.0
in System	(-0.4)	(0.3)	(4.7)	(-0.8)	(0.1)	(1.8)	(-0.5)	(-0.3)	(2.0)

All values are expressed in percentages.
POC = Pediatric Outpatient Clinic, OT = Orthoptic Department, Mot. Clin. = Motility Clinic, FPC = First Post-operative Checkup, SPC = Second Post-operative Checkup, OR Strab. = OR Strabismus, OR Non-Strab. = OR Non-Strabismus, Non-Str. Depts. = Non-Strabismus Departments.
Relative differences of the standard deviations are given between parentheses.

Table 6.6: The relative differences in access times of simulations 19–27 with respect to the base case.

Department	h/l/l	h/l/m	h/l/h	h/m/l	h/m/m	h/m/h	h/h/l	h/h/m	h/h/h
POC	-91.3	-89.3	-86.1	-91.5	-90.4	-87.5	-91.5	-89.9	-83.9
	(-90.3)	(-87.8)	(-84.5)	(-90.4)	(-88.9)	(-86.3)	(-90.7)	(-88.9)	(-81.0)
OT 15 min.	21.8	-7.0	50.4	-62.6	-54.4	-27.6	-72.2	-70.2	-64.5
	(98.2)	(-0.9)	(38.5)	(-58.8)	(-49.7)	(-10.5)	(-66.0)	(-64.0)	(-59.5)
OT 30 min.	26.8	-4.2	32.7	-46.2	-41.4	-22.5	-56.1	-55.2	-51.5
	(116.6)	(0.7)	(35.3)	(-51.1)	(-45.4)	(-7.5)	(-57.7)	(-56.6)	(-54.1)
Mot. Clin.	-37.0	40.7	169.2	10.2	2.3	127.8	-33.7	3.6	97.9
	(-40.9)	(30.5)	(93.6)	(0.2)	(-8.8)	(41.7)	(-32.6)	(-4.1)	(24.2)
FPC	3.3	-0.5	4.3	-6.6	-4.8	-3.1	-7.2	-7.0	-6.4
	(36.6)	(0.8)	(7.1)	(-6.5)	(-4.2)	(0.1)	(-6.4)	(-5.8)	(-5.7)
SPC	0.0	-0.1	0.0	-0.4	-1.5	-0.2	-0.9	0.6	-1.7
	(-0.4)	(-0.4)	(-0.3)	(0.1)	(-1.3)	(-0.4)	(-0.1)	(0.0)	(0.4)
OR Strab.	-20.8	31.2	70.0	-30.1	8.7	105.8	-25.7	10.5	92.3
	(-9.5)	(38.7)	(66.5)	(-28.9)	(9.4)	(91.3)	(-21.2)	(11.6)	(81.3)
OR Non-Strab.	-22.0	34.4	74.3	-31.0	6.6	102.9	-25.8	9.1	92.5
	(-12.7)	(41.3)	(70.9)	(-30.6)	(6.8)	(87.7)	(-20.9)	(8.2)	(78.9)
Non-Str. Depts.	-0.2	-0.3	-0.6	0.0	-0.1	0.4	-1.3	-1.7	-0.9
	(0.0)	(-1.4)	(-1.8)	(-0.4)	(-1.6)	(0.0)	(-1.8)	(-2.5)	(-1.7)
Total Time	-0.9	-0.3	-0.1	-1.1	-1.1	0.2	-1.6	-0.7	0.2
in System	(-0.1)	(0.4)	(0.6)	(-0.1)	(-0.9)	(0.5)	(-1.1)	(-0.2)	(0.4)

All values are expressed in percentages.
POC = Pediatric Outpatient Clinic, OT = Orthoptic Department, Mot. Clin. = Motility Clinic, FPC = First Post-operative Checkup, SPC = Second Post-operative Checkup, OR Strab. = OR Strabismus, OR Non-Strab. = OR Non-Strabismus, Non-Str. Depts. = Non-Strabismus Departments.
Relative differences of the standard deviations are given between parentheses.

Failure levels

Positive numbers in the tables indicate longer access times than in the base case, negative numbers mean shorter access times. The differences are expressed in percentages. For example, the pediatric outpatient clinic in the 'l/l/l' scenario produces access times that are 16.1% shorter than in the base case. This means that the access times at this department are 0.68 days if the failure levels are lowered from 'middle' to 'low' level and keeping all other things equal. Since we would expect lower access times, we are surprised to see that they become higher for both surgery types. On the other hand, this could be caused by the high variations in the throughput rate of the other departments that are visited before the surgeries; a high variance in the throughput rate at the motility clinic, for example, can lead to a long waiting queue at the OR because patients go too fast through the motility clinic.

The access times for the post-operative checkups remain approximately the same. We think that this is due to the fact that only a part of the minimum access times are subtracted instead of the entire minimum access time for every individual visit. The total time that a patient spends in the system also stays at about the same level. This is because the absolute levels are compared, without subtracting the minimum access times. The reason for this is that every individual visits different departments, and if we subtract the minimum access times, it does not make sense anymore to compare the resulting total values.

Looking at scenario 'l/l/h', we again see that some of the numbers have negative signs where we would expect that with a higher failure rate, waiting lists would be longer, and therefore access times would become higher. However, if we look at the other simulations, we see that if the capacity levels at the pediatric outpatient clinic and the orthoptic department are kept at the same level, a higher failure rate *does* give higher access times.

Because this is less easy to see, we have summarized the results in Table 6.7. The interpretation of the columns is as follows. The header row indicates the capacity level of one department or the failure level. Given that value, there are nine scenarios with the other two decision variables (although strictly spoken, the failure rate is a parameter rather than a decision variable) taking on different values. Of these nine scenarios the means of the access times are taken. For example, the column 'P=l' consists of the means of the access times of the nine 'l/y/z' simulations in the three tables above, where 'y' and 'z' can take on all values. Likewise, the notation 'P=m' stands for the nine 'm/y/z' scenarios in those tables, and so on.

In this table, it is easier to see that moving from a low failure level to a middle failure level causes the average access times of all departments to increase, except for the second post-operative checkup and the non-strabismus

Table 6.7: Summary of the relative differences in access times of the scenarios with respect to the base case.

Department	BC*	P=l	P=m	P=h	O=l	O=m	O=h	F=l	F=m	F=h
POC	**0.81**	20.7	-79.3	-89.0	-61.0	-44.4	-42.3	-69.0	-54.6	-24.1
	(1.39)	(10.7)	(-74.9)	(-87.6)	(-58.6)	(-48.7)	(-44.6)	(-66.2)	(-54.9)	(-30.8)
OT 15 min.	**0.33**	-31.5	-20.4	-31.8	24.7	-44.5	-63.9	-40.6	-38.1	-5.1
	(0.63)	(-26.7)	(-15.0)	(-19.2)	(34.2)	(-38.0)	(-57.0)	(-29.0)	(-32.8)	(0.9)
OT 30 min.	**0.47**	-26.1	-17.0	-24.2	18.6	-34.8	-51.1	-30.1	-29.8	-7.3
	(0.63)	(-24.5)	(-11.2)	(-13.3)	(36.0)	(-34.1)	(-50.9)	(-22.2)	(-28.9)	(2.3)
Mot. Clin.	**9.45**	65.4	117.8	42.3	77.0	84.9	63.5	-16.7	23.3	218.8
	(8.50)	(14.4)	(31.9)	(11.5)	(12.2)	(21.0)	(24.6)	(-22.3)	(9.9)	(70.2)
FPC	**3.55**	-3.5	-2.1	-3.1	2.5	-4.7	-6.5	-3.9	-3.9	-0.9
	(1.57)	(-2.2)	(2.1)	(1.8)	(10.2)	(-3.4)	(-5.1)	(0.5)	(-2.4)	(3.7)
SPC	**38.98**	-0.8	-0.6	-0.5	0.0	-0.8	-1.1	-0.5	-0.8	-0.6
	(25.52)	(-0.4)	(-0.9)	(-0.3)	(-0.6)	(-0.6)	(-0.4)	(-0.4)	(-0.7)	(-0.5)
OR Strab.	**2.79**	22.5	32.5	26.9	26.4	21.8	33.7	-21.1	15.0	88.0
	(2.69)	(22.0)	(34.6)	(26.6)	(31.3)	(21.6)	(30.4)	(-14.3)	(19.1)	(78.5)
OR	**2.73**	22.1	31.5	26.8	27.4	20.6	32.4	-22.1	14.6	87.8
Non-Strab.	**(2.71)**	(20.3)	(32.0)	(25.5)	(31.0)	(19.2)	(27.5)	(-15.9)	(17.3)	(76.4)
Non-Str.	**53.68**	-0.5	-0.2	-0.5	-0.2	-0.4	-0.7	-0.3	-0.4	-0.6
Depts.	**(128.51)**	(-0.7)	(-0.5)	(-1.3)	(-0.7)	(-0.5)	(-1.2)	(-0.6)	(-1.1)	(-0.8)
Total Time	**123.59**	0.4	0.0	-0.6	0.1	-0.2	-0.1	-0.9	-0.4	1.2
in System	**(153.56)**	(0.4)	(0.8)	(0.0)	(0.8)	(0.1)	(0.2)	(-0.4)	(-0.2)	(1.7)

*Base case. All numbers in this column are expressed in days. All other values are expressed in percentages.
BC = Base Case, POC = P = Pediatric Outpatient Clinic, OT = O = Orthoptic Department, Mot. Clin. = Motility Clinic, FPC = First Post-operative Checkup, SPC = Second Post-operative Checkup, OR Strab. = OR Strabismus, OR Non-Strab. = OR Non-Strabismus, Non-Str. Depts. = Non-Strabismus Departments, F = Failures.
Relative differences of the standard deviations are given between parentheses.

departments. Although the access times at these departments decrease, these reductions are negligible (smaller than 1%). The reason that the access times at the non-strabismus departments seem to be independent is obvious: there is no capacity used, and the access times are randomly drawn from a predetermined distribution, independent of failure rates, as was described in Section 5.3. For the second post-operative checkup, it is less clear why the access times seem to be independent from the failure level. We believe this is due to the way we defined the minimum access times, namely with a triangular distribution. Because of the conservative approach to subtract only the lower limit of this distribution, we obtain access times that consist of a part that is caused by resource capacities, and a random minimum access time part. This results in high access times, only a small part of which is influenced by capacity and failure levels, and the rest by random luck.

When moving from middle to high failure rates, the access time increases are even stronger. For example, the relative change for the strabismus surgeries when the failure rates are increased from low to middle level is 45.8% ($100\%(15.0-21.1)/(100-21.1) \approx 45.8\%$). If the failure level goes from middle to high, this number is 63.4% ($100\%(88.0-15.0)/(100+15.0) \approx 63.4\%$). These numbers can also be found in Table 6.8, in which these arithmetic calculations are made for all changes in capacity and failure levels. It appears that only the non-strabismus departments show a small decrease in access times, but, as explained above, this is purely due to randomness.

Table 6.8: Changes by increasing capacity and failure levels in terms of percentage.

Department	POC	POC	OT	OT	F	F
From→to	l→m	m→h	l→m	m→h	l→m	m→h
POC	-82.8	-47.0	42.8	3.8	46.8	67.1
	(-77.3)	(-50.7)	(23.9)	(8.0)	(33.5)	(53.5)
OT 15 min.	16.2	-14.3	-55.5	-34.9	4.3	53.2
	(16.0)	(-5.0)	(-53.8)	(-30.7)	(-5.4)	(50.2)
OT 30 min.	12.4	-8.7	-45.0	-24.9	0.5	32.0
	(17.6)	(-2.4)	(-51.6)	(-25.4)	(-8.6)	(43.9)
Mot. Clin.	31.7	-34.6	4.5	-11.6	48.0	158.6
	(15.2)	(-15.4)	(7.8)	(3.0)	(41.3)	(55.0)
FPC	1.5	-1.0	-7.0	-1.9	0.0	3.1
	(4.4)	(-0.4)	(-12.4)	(-1.8)	(-3.0)	(6.3)
SPC	0.2	0.2	-0.8	-0.3	-0.3	0.2
	(-0.5)	(0.6)	(-0.1)	(0.3)	(-0.3)	(0.2)
OR Strab.	8.2	-4.3	-3.6	9.8	45.8	63.4
	(10.3)	(-6.0)	(-7.3)	(7.2)	(39.0)	(49.9)
OR Non-Strab.	7.7	-3.6	-5.3	9.9	47.0	63.9
	(9.8)	(-4.9)	(-9.0)	(6.9)	(39.5)	(50.4)
Non-Str. Depts.	0.3	-0.3	-0.2	-0.3	-0.1	-0.1
	(0.1)	(-0.7)	(0.2)	(-0.7)	(-0.4)	(0.3)
Total Time	-0.4	-0.6	-0.4	0.2	0.5	1.6
in System	(0.4)	(-0.8)	(-0.6)	(0.0)	(0.2)	(1.8)

POC = Pediatric Outpatient Clinic, OT = Orthoptic Department, Mot. Clin. = Motility Clinic, FPC = First Post-operative Checkup, SPC = Second Post-operative Checkup, OR Strab. = OR Strabismus, OR Non-Strab. = OR Non-Strabismus, Non-Str. Depts. = Non-Strabismus Departments, F = Failures.

Relative differences of the standard deviations are given between parentheses.

Pediatric outpatient clinic capacity

In the columns ‘P=l’, ‘P=m’ and ‘P=h’ of Table 6.7, the data are averaged over the pediatric outpatient clinic capacity levels ‘low’, ‘middle’ and ‘high’, respectively. For the pediatric outpatient clinic itself, it is immediately clear that an increase from a low to middle capacity level leads to a sharp decrease in access times: $100\%(-79.3 - 20.7)/(100 + 20.7) \approx -82.8\%$, which can be evaluated in Table 6.8. Going from a middle to high capacity level, we obtain a further, although somewhat smaller, decrease of 47.0%. This is not very surprising, since with a middle capacity level, the access times are already shortened considerably.

For the other departments, the indirect effects of these capacity changes are not this straightforward. It seems that the access times first *in*crease when moving from low to middle capacity, and then *de*crease when going from middle to high capacity. This holds for both orthoptic visits, the motility clinic, the first post-operative checkups, both surgery types and the non-strabismus surgeries. Only the second post-operative checkups register longer access times, but as explained above, these results are not very indicative for measuring consequences of capacity adjustments.

Still, at first sight, it seems strange that the middle capacity level provides longer access times than the low capacity level. In order to understand this, we should remind that the changes are in the capacity of the pediatric outpatient clinic, where the access times are shortened, as we would expect. On the other hand, the increases of the access times at the other departments can be caused by the high variations in the throughput rate at the pediatric outpatient clinic, which leads to high input rates for the other departments; can lead to a long waiting queue at these other departments because go too fast through the pediatric outpatient clinic. We believe that this is a plausible explanation for the fact that the indirect effects have a different sign than the direct effect on the access times.

If the capacity at the pediatric outpatient is expanded from middle to high, the effects seem to decrease again, to approximately the same level as with a low capacity level. Unfortunately, we do not have a plausible explanation for this.

Orthoptic department capacity

If the capacity level at the orthoptic department is increased, the access times of all appointments that share those same resources (the orthoptic visits of 15 and 30 minutes, and both post-operative checkups) decrease. For the orthoptic visits this effect is the most substantial. If we compare the effects of going from low to middle capacity with going from middle to high capacity for the four visit types that use these resources, we see that the former are larger.

The influence that these capacity changes have on the access times at the other departments is not unambiguous; for both level changes, some departments experience longer access times, while other departments produce shorter access times. The access times at the pediatric outpatient clinic increase with no less than 42.8% when going from a low to middle capacity level at the orthoptic department. When the capacity level is set to high, the increase is only 3.8% compared to the middle capacity level. At the motility clinic, the access times *in*crease if the capacity is adjusted from low to middle, but they *de*crease when the capacity is increased from middle to high. For both the strabismus and the non-strabismus surgeries, the opposite is true; first, the access times decrease, but they increase if the capacity is expanded further.

Interpretation throughput times

Because of the assumption of first-come-first-served, and the presence of different minimum access times at different departments, it is very difficult to interpret the total time that patients spend in the system. However, since the throughput time of a patient depends on the access times, it will become shorter if the access times decrease.

6.3 Regression Analysis

In the previous section, the results of the simulations were analyzed, and conclusions were drawn in a somewhat informal way. We did not check whether the results were significant, or how the access times exactly depend on the capacity levels. In this section, we deal with these questions by performing a regression analysis for each department individually. First, we justify the variables that are used in the regressions. Thereafter, the results of the regression models are explained.

Justification regression variables

As dependent variables, we take the mean access times expressed in days of all departments of nine of the simulation runs described in Section 6.2. We do not take all 27 scenarios because the failure rates are left out of the analysis, since there is not a good way to assign values to the three failure levels. Hence, only the simulations with a middle failure level are included in the analysis, of which there are nine. Because the explanatory variables that we do use are (functions of) the pediatric outpatient clinic and the orthoptic department, we have nine different configurations. As already explained, the numbers in Tables 6.4, 6.5 and 6.6, are averages, each over four simulation runs. This means that 36 observations are used in each regression. In our regression analysis, we use these values instead of the means. These values can be found in Table A2 in the Appendix.

The required minimum access times are subtracted from the mean access times of the simulations, as was done for the base case results in Section 6.2.

The capacity levels of the pediatric outpatient clinic are expressed as the maximum number of patients that can be seen during a week at that department. These numbers are calculated by multiplying the number of shifts per resource type by the corresponding productivity. For a low capacity level at the pediatric outpatient clinic, this means that the capacity is 6x21 + 11x12 + 3x10 = 288 patients in a week. For the middle and high level, the capacity is 376 and 476, respectively.

For the orthoptic department, this could not be done because not all visits here have the same duration; appointments can have a duration of either 15 or 30 minutes. Therefore, we had to come up with another way of valuing the capacity levels at this department. We decided to take the total available time within a week, expressed in quarters of an hour, because that is the duration of a short visit. This makes the way that the capacity levels at the two departments are measured, somewhat comparable. Since there is only one resource type, there are no differences in productivity at the OT. Moreover, the morning shift is longer than the afternoon shift; therefore, the number of shifts during a week would not be a good measure of the capacity level at the orthoptic department. Expressed in quarters of an hour, there is a capacity of 483 quarters of an hour per week for the low level, 564 quarters of an hour per week for the middle level, and 645 quarters of an hour per week for the high capacity level.

Furthermore, the product of the capacity levels of the two departments just mentioned is used in the regressions as explanatory variables, to see whether there is a combined effect of the two capacity levels.

Also, for some regressions, the reciprocals or squared values of the two capacity levels are used instead of the levels themselves.

Regressions

In this section, the regression models and outputs are described. Because the regressions are performed per department, we discuss the models and outputs for each department separately as well. The non-strabismus departments, however, are left out of the analysis, since their access times are not really useful for interpretation. The statistical package EViews 6.0, which is well-known and broadly-used by econometricians, is used for the regression analysis. In the regressions, we work with a significance level of 10%.

Pediatric outpatient clinic

In Figure 6.1, the access times of the pediatric outpatient clinic are plotted against the capacity levels of the pediatric outpatient clinic and the orthoptic department. From the first plot, it is clear that if the capacity at the pediatric outpatient clinic increases, the access times will decrease. Also, the fluctuations become smaller. In the second plot, it seems that there is a small positive effect of the OT's capacity level on the POC's access times, although it is not directly clear whether it is significant or not.

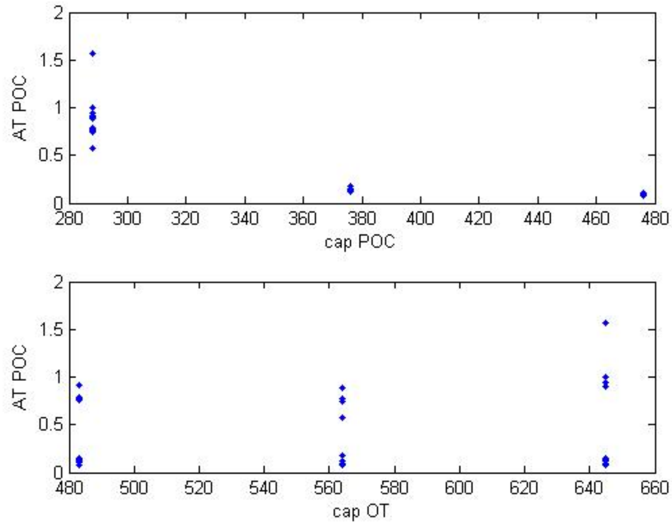

Figure 6.1: Access times of the pediatric outpatient clinic vs. capacity levels of the pediatric outpatient clinic and the orthoptic department.

In order to see whether the effects are significant, and if so, what these effects exactly are, we wanted to use the following linear model (linear in the parameters):

$$\bar{y}_i = \beta_0 + \beta_1/x_{1i} + \beta_2 x_{2i} + \beta_3 x_{2i}/x_{1i} + \varepsilon_i,$$

where $\bar{y}_i$ is the mean pediatric outpatient clinic's access time of the i'th scenario, x_{1i} is its capacity level, and x_{2i} is the capacity level of the orthoptic department for the i'th scenario, $i = 1, \ldots, 36$. These meanings for x_{1i} and x_{2i} also hold for the remainder of this section, and $x_{1i} > 0$ and $x_{2i} > 0$ for all i. We use the reciprocal of the POC's capacity level because we observe in Figure 6.1 that the marginal effect becomes less negative if the capacity increases. This can be explained by the idea that the access time for an individual at a department depends proportionally on the ratio of the number of patients already waiting and the capacity of that department.

Further, the capacity of the OT is used as an explanatory variable, because we believe, based on the results of Section 6.2, that it may influence the access times at the POC; the number of patients waiting for a particular department is influenced by how fast people go through prior appointments, possibly at other departments. Because we also wonder whether there is a joint effect of the capacity levels at both departments, a cross-variable consisting of the product of the OT's capacity level and the reciprocal of the POC's capacity level is included in the model as an additional explanatory variable.

The regression method that has been used is least squares. We believe that this makes sense because the access time depends linearly on the reciprocal of the POC's capacity.

The output of the regression, however, showed that only the cross-variable is significant at a 10% significance level. We decided to use the method of backward elimination to get significant effects. This method starts with the full model, and in each step, the least significant variable is deleted (except for the constant), after which the model with the remaining variables is estimated. This procedure is repeated until all regressors are significant (Heij et al., 2004).

The model that results after the application of the backward elimination method is the following:

$$\bar{y}_i = \beta_0 + \beta_2 x_{2i} + \beta_3 x_{2i}/x_{1i} + \varepsilon_i.$$

So only the reciprocal of the capacity level of the POC itself has been deleted. This may seem strange, but if we take a closer look, we see that it still influences the access times, through the cross-variable. A possible explanation for the fact that the reciprocal of the capacity level of the POC was not significant, is that there is multicollinearity between the variables x_1 and x_2/x_1.

The output of the new model is shown in Table 6.9.

Table 6.9: Regression output for the pediatric outpatient clinic. Method: Least Squares.

Parameter	Coefficient	Std. Error	P-value
β_0	0.020842	0.261617	0.9370
β_2	-0.002371	0.000530	0.0001
β_3	1.087717	0.095294	0.0000
R^2	0.800079		
P-value (F-statistic)	0.000000		

Model: $\bar{y}_i = \beta_0 + \beta_2 x_{2i} + \beta_3 x_{2i}/x_{1i} + \varepsilon_i$. $\bar{y}$ = POC's mean access time, x_1 = POC's capacity level, x_2 = OT's capacity level.

After estimation of the parameters, the relations between the regressors and the independent variable are known. Because of the use of the reciprocal of the POC's capacity level in the cross-variable, the direction of the effect of additional capacity on the POC's access times depends on the current capacity level in the following way:

$\frac{\partial \bar{y}}{\partial x_1} = -1.087717 x_1^{-2} x_2$.

The negative sign indicates that for any positive value of the OT's capacity level, an increase in the POC's capacity level yields a reduction in the access times; Furthermore, from this formula, it can be concluded that for large values of the OT's capacity level (x_2), the effect of the POC's capacity level (x_1) on the POC's access times becomes larger (that is, $\frac{\partial \bar{y}}{\partial x_1}$ becomes more negative). Also, the form of the function indicates that if the POC's capacity level is already high, *additional* capacity has a smaller effect on the access times. We believe that these two results are logical.

The negative value of β_2 in Table 6.9 means that the OT's capacity level has a negative effect on the POC's access times, which is another conclusion than we had in the previous sections. However, the OT's capacity level also appears in the cross-variable, which has a positive effect. This means that it is not directly clear what sign the effect of OT's capacity has. We would expect that the OT's capacity level has a positive effect on the POC's access time; the higher the variation in the throughput of the OT, the longer the waiting list for the POC (because some patients will go to the POC after they have visited the OT), and the longer the access times at the POC will be. To determine the conditions under which this is true, we take a look at the partial derivative of the POC's access time $\bar{y}$ with respect to the OT's capacity level x_2:

$\frac{\partial \bar{y}}{\partial x_2} = -0.002371 + 1.087717/x_1.$

From this function, we can see that the OT's capacity level has a positive effect on the POC's access time when the POC's capacity level x_1 is lower than $1.087717/0.002371 \approx 458.76$. Since this value is close to the high capacity level, which is 476 patients that can be seen per week, we conclude that our claim is true for most of the values in the range of our study.

Orthoptic visits with duration 15 minutes

From now on, the scatter plots can be found in the Appendix, because we want to include only the most important figures and tables in the main text. The access times of the orthoptic visits with duration 15 minutes are negatively correlated with the OT's capacity level, as can be seen in Figure A1; the higher the capacity, the lower the access times. Also, this marginal effect becomes less negative when the capacity increases. Therefore, we again use the reciprocal of the capacity level of the department where the visits take place of which we are analyzing the access times (the orthoptic visits take place at the OT). Because of the results of Table 6.8, we believe that the resource capacity at the POC may influence the access times of the orthoptic visits with duration 15 minutes in a quadratic way. For this reason, the POC's capacity level and its squared value are included in the model, as well as the product of the capacity level of the POC and reciprocal of the OT's capacity level, to determine the joint effect. So the model that we start with is the following:

$$\bar{y}_i = \beta_0 + \beta_1 x_{1i}^2 + \beta_2 x_{1i} + \beta_3/x_{2i} + \beta_4 x_{1i}/x_{2i} + \varepsilon_i,$$

where $\bar{y}_i$ is the mean access time of orthoptic visits with duration 15 minutes of the i'th scenario, and x_{1i} and x_{2i} are defined as above. After applying the backward elimination method, with which the cross-variable, then the POC's capacity, and finally the latter's squared value are deleted, the following model remains:

$$\bar{y}_i = \beta_0 + \beta_3/x_{2i} + \varepsilon_i,$$

with the regression output given in Table 6.10.

Table 6.10: Regression output for the orthoptic visits with duration 15 minutes.

Method: Least Squares.

Parameter	Coefficient	Std. Error	P-value
β_0	-0.593731	0.084623	0.0000
β_3	445.3325	46.73973	0.0000
R^2	0.727523		
P-value (F-statistic)	0.000000		

Model: $\bar{y}_i = \beta_0 + \beta_3/x_{2i} + \varepsilon_i$.

$\bar{y}$ = mean access time of orthoptic visits with duration 15 minutes, x_2 = OT's capacity level.

One can see that β_3 takes on a positive value. This is plausible, since this means that a higher capacity at the OT leads to shorter access times for the orthoptic visits. The derivative is given by $\frac{\mathrm{d}\bar{y}}{\mathrm{d}x_2} = -\beta_3 x_2^{-2}$, which indicates that the effect is diminishing.

Orthoptic visits with duration 30 minutes

The reasoning being the same as for the orthoptic visits of 15 minutes, we start with the model $\bar{y}_i = \beta_0 + \beta_1 x_{1i}^2 + \beta_2 x_{1i} + \beta_3/x_{2i} + \beta_4 x_{1i}/x_{2i} + \varepsilon_i$, where $\bar{y}$ is now the access time of orthoptic visits with duration *30* minutes. Unfortunately, also for this visit type, we end up with the model

$$\bar{y}_i = \beta_0 + \beta_3/x_{2i} + \varepsilon_i.$$

The regression output, shown in Table 6.11, is quite similar to the output for the orthoptic visits with duration 15 minutes. The derivative is given by $\frac{\mathrm{d}y}{\mathrm{d}x_2} = -497.2672 x_2^{-2}$. It is not surprising that the results of these two visit types look like each other, since their patients use the same resources, and the entire minimum access time (20 days) are subtracted for both. Later on in this section, we explain the consequences of not subtracting the *entire* minimum access time.

Table 6.11: Regression output for the orthoptic visits with duration 30 minutes.

Method: Least Squares.

Parameter	Coefficient	Std. Error	P-value
β_0	-0.565603	0.082622	0.0000
β_3	497.2672	45.63449	0.0000
R^2	0.777398		
P-value (F-statistic)	0.000000		

Model: $\bar{y}_i = \beta_0 + \beta_3/x_{2i} + \varepsilon$.

$\bar{y}$ = mean access time of orthoptic visits with duration 30 minutes, x_{2i} = OT's capacity level.

Motility clinic

For the motility clinic, we use another model, because the resources for this type of visit are neither the POC's resources nor the OT's; the resources of the motility clinic consist of a team of surgeons, orthoptists and doctor's assistants, who are not the same employees as at the POC and the OT, as was explained in Section 5.2. However, since the input rate of patients for the motility clinic depends on the variance of the throughput rates of other departments, it is possible that the access times at the motility clinic are influenced by the capacity levels of the POC and the OT. Based on Table 6.7 and Figure A3, we start with the following model $\bar{y}_i = \beta_0 + \beta_1 x_{1i}^2 + \beta_2 x_{1i} + \beta_3 x_{2i}^2 + \beta_4 x_{2i} + \beta_5 x_{1i} x_{2i} + \varepsilon_i$, where $\bar{y}$ is the access time of the motility clinic. The resulting model after backward elimination is

$$\bar{y}_i = \beta_0 + \beta_2 x_{1i} + \beta_3 x_{2i}^2 + \beta_5 x_{1i} x_{2i} + \varepsilon_i.$$

In Table 6.12, the regression output is given. To determine for which values the effects of the capacity level of each of the two departments are positive or negative, the partial derivatives have to be calculated. The partial derivative with respect to x_1 is $\frac{\partial \bar{y}}{\partial x_1} = \beta_2 + \beta_5 x_2$, while the partial derivative with respect to x_2 is $\frac{\partial \bar{y}}{\partial x_2} = 2\beta_3 x_2 + \beta_5 x_1$.

This gives that $\frac{\partial \bar{y}}{\partial x_1} > 0$ if $x_2 < 0.184283/0.000335 \approx 550.10$, which is somewhere in the middle of their respective range, near the middle capacity level. This is somewhat unexpected, since we would think that x_1 always has a positive effect on the motility clinic's access time.

Table 6.12: Regression output for the motility clinic.
Method: Least Squares.

Parameter	Coefficient	Std. Error	P-value
β_0	-23.91421	13.51576	0.0864
β_2	0.184283	0.067471	0.0102
β_3	0.000116	$4.08 \cdot 10^{-5}$	0.0078
β_5	-0.000335	0.000119	0.0082
R^2	0.208611		
P-value (F-statistic)	0.055041		

Model: $\bar{y}_i = \beta_0 + \beta_2 x_{1i} + \beta_3 x_2^{2i} + \beta_5 x_{1i} x_{2i} + \varepsilon_i$.
$\bar{y}$ = mean access time of the motility clinic, x_1 = POC's capacity level, x_2 = OT's capacity level.

Further, $\frac{\partial \bar{y}}{\partial x_2} > 0$ if $x_2 > 0.000335 x_1/(2 \cdot 0.000116) \approx 1.44 x_1$. This means that the effect of x_2 depends on the relative difference between x_1 and x_2. If the POC's capacity level is low, all values of the OT's capacity level in the range of our study will have a positive effect on the motility clinic's access times. If the POC's capacity is of middle level, the OT's capacity has a positive effect if it is higher than 542.93, which is slightly lower than the middle level. Finally, if the POC's capacity level is high, then all of the OT's capacity levels in our range have a negative effect on the access times. These results are unexpected, since we would think that x_2 always has a positive effect on the motility clinic's access time.

First post-operative checkup

Because the first post-operative checkups use the OT's resources, we expect to see a similar scatter plot of the FPC's access times against the OT's capacity level to the scatter plots of the orthoptic visits against the OT's capacity level. Figure A4 shows that this is indeed the case. However, the values of the access times are higher (around 3.5 days); this is due to the triangular distribution of *minimum* access times, and what is subtracted from the total access times. In Section 6.2, we explained that we have used a conservative approach, which means that the minimum value of this triangle (8 days) is subtracted from the access times. This means that the resulting access times are not entirely caused by capacity problems, but partly due to randomness. Nevertheless, we believe that we can start with the same model as for the orthoptic visits: $\bar{y}_i = \beta_0 + \beta_1 x_{1i}^2 + \beta_2 x_{1i} + \beta_3/x_{2i} + \beta_4 x_{1i}/x_{2i} + \varepsilon_i$, because Table 6.8 seems to indicate that there is quadratic relation between the POC's capacity and the FPC's access time. In this model, $\bar{y}$ represents the

FPC's access time. After carrying out the backward elimination procedure, the variables x_1/x_2, x_1 and x_1^2 are successively deleted, so that we end up with

$$\bar{y}_i = \beta_0 + \beta_3/x_{2i} + \varepsilon_i.$$

Not surprisingly, the positive sign of β_3 indicates that a higher capacity at the OT will lead to shorter access times for the FPC.

Table 6.13: Regression output for the first post-operative checkups.
Method: Least Squares.

Parameter	Coefficient	Std. Error	P-value
β_0	2.548882	0.080242	0.0000
β_3	479.7295	44.31979	0.0000
R^2	0.77508		
P-value (F-statistic)	0.000000		

Model: $\bar{y}_i = \beta_0 + \beta_3/x_{2i} + \varepsilon_1$.
$\bar{y}$ = FPC's mean access time, x_{2i} = OT's capacity level.

Second post-operative checkup

Although the second post-operative checkups also use the OT's resources, the scatter plot of the SPC's access times against the OT's capacity level is not like those of the other visit types that take place at the OT, as can be seen in Figure A5. Therefore, we start with the following model:

$$\bar{y}_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{1i} x_{2i} + \varepsilon_i,$$

where $\bar{y}$ is the access time of the SPC. Based on Table 6.8, we have no reason to assume that the SPC's access times are affected by the squared values of the POC's capacity level. In Table 6.14, one can see that all variables in the model are significant. Note, however, that they are just significant; if we had used a significance level of 1%, none of the variables would have been significant.

To determine for which values the effects of the capacity level of each of the two departments are positive or negative, the partial derivatives have to be calculated, as we did for the motility clinic. The partial derivative with respect to x_1 is $\frac{\partial \bar{y}}{\partial x_1} = \beta_1 + \beta_3 x_2$, and we would expect this value to be positive for all values of x_2. Since $\frac{\partial y}{\partial x_1} > 0$ only for $x_2 > 0.020347/3.88 \cdot 10^{-5} \approx 524.41$, which is between the low and middle capacity level of the OT, x_1 has a positive effect on $\bar{y}$ for most values of x_2 in the range that we have studied.

Table 6.14: Regression output for the second post-operative checkups. Method: Least Squares.

Parameter	Coefficient	Std. Error	P-value
β_0	47.89817	4.381838	0.0000
β_1	-0.020347	0.011303	0.0813
β_2	-0.017424	0.007716	0.0309
β_3	$3.88 \cdot 10^{-5}$	$1.99 \cdot 10^{-5}$	0.0598
R^2	0.204966		
P-value (F-statistic)	0.058834		

Model: $\bar{y}_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{1i} x_{2i} + \varepsilon_i$.
$\bar{y}$ = SPC's mean access time, x_1 = POC's capacity level, x_2 = OT's capacity level.

On the other hand, we would expect the partial derivative with respect to x_2, $\frac{\partial \bar{y}}{\partial x_2} = \beta_2 + \beta_3 x_1$, to be negative for all values of x_1. Since $\frac{\partial \bar{y}}{\partial x_2} < 0$ only for $x_1 < 0.017424/3.88 \cdot 10^{-5} \approx 449.07$, which is near the high capacity level of the POC, we can conclude that x_2 has a negative effect on $\bar{y}$ for most values of x_1 in the range of our study.

OR Strabismus

For the strabismus surgeries, we do not expect the capacity levels of the POC and OT to have much influence on the access times. The first reason is that they do not use the same resources as the POC and OT. However, this may not be sufficient, as we saw at the motility clinic; there, other resources are used as well, but all variables were sufficient due to the variance in the throughput rates of other departments that are visited before the motility clinic. These departments do take place at the POC or OT and use those resources. On the other hand, the visit to the eye hospital before the surgery is normally at the motility clinic, although there are exceptions; some patients need an extra orthoptic visit, as was described in Section 2.1. This means that the variation in the throughput rates of the departments that are visited before the motility clinic, is already smoothed when patients go to the OR for the strabismus surgery. Starting with the model $\bar{y}_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{1i} x_{2i} + \varepsilon_i$, with $\bar{y}$ being the access time of the strabismus surgeries, and applying the backward elimination method, we indeed see that none of the variables are significant. Apparently, the fraction of patients going from the orthoptic visits to the surgery is too small.

OR Non-Strabismus

The non-strabismus surgeries differ from the strabismus surgeries in the sense that the motility clinic is not visited before the surgeries. By far most of the patients arrive from the non-strabismus departments (probably the regular outpatient clinics), and there are also some patients arriving from the pediatric outpatient clinic. Starting with the $\bar{y} = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{1i} x_{2i} + \varepsilon_1$, with $\bar{y}$ being the access time of the non-strabismus surgeries, and applying the backward elimination method, we again end up with none of the variables significant. Apparently, the POC's and the OT's capacity levels do not have significant effects on the access times of the surgeries; the number of patients that arrive from the POC and undergo a non-strabismus surgery is too small.

6.4 Recommendations

In Section 6.2, the simulation results were provided and analyzed in a more informal way. Then, in Section 6.3, we have performed regressions to determine the effects of the capacity levels of the pediatric outpatient clinic and the orthoptic department on the access times of all departments of our study, except for the non-strabismus departments. It appears that some departments are influenced by the capacity level of one department, and other departments by the capacity of both departments; and there are also departments that seem not to be affected by either department's resource capacity. In the remainder of this section, the results of the previous sections are summarized, and the recommendations for the eye hospital are given.

Naturally, it depends on the wants and the needs of the eye hospital what we would recommend to do. Of course, shorter access times are more preferable, but based on our findings, we conclude that if the capacity of only one department is increased, the access times at that particular department become shorter, but at the same time, the access times of some of the other departments may become longer.

If it is possible for the eye hospital to cheaply lower the failure rates (for example, by informing employees about better working postures to prevent RSI and thus sickness absences), this should be done, no matter how the capacity levels at the separate departments are changed. *In general*, the effect will be that access times at all departments decrease. In Table 6.8, one can see that a higher failure rate will increase the access times of most of the departments, so a lower failure rate leads to shorter access times; only the second post-operative checkups show a decrease when the failure rates goes from low to middle level. There are exceptions, though; for instance, the POC's access times of scenario 'l/l/h' are lower than those of the base case ('l/l/m'). We believe that we have just been unlucky that the base case has produced slightly higher access times than we would expect.

On the other hand, if we assume that the failure levels cannot be lowered by the eye hospital, there are nine different scenarios in our study left to choose from, namely the 'x/y/z' scenarios in Tables 6.4, 6.5 and 6.6 with x and y taking all possible levels and z = m fixed.

From the regressions in the previous section we know that the pediatric outpatient clinic' access times are influenced by the resource capacity of both the POC itself and the OT, in the form of the capacity level of the OT and the product variable of that capacity level and the reciprocal of the POC's capacity. For most values of the POC's capacity level, it holds that a higher capacity at the OT leads to longer access times, and an increase in the POC's capacity level gives shorter access times in a diminishing way.

The access times of the orthoptic department, on the other hand, are influenced only by the reciprocal of the capacity level of the OT itself, except for the second post-operative checkup; for that visit type, the capacity levels of both departments and their product are all significant. A higher level of the OT's capacity gives shorter access times of the orthoptic visits with duration 15 and 30 minutes, and the first post-operative checkup, although the effect is diminishing. An increase in the OT's capacity also leads to shorter access times at the SPC for most of the values of the POC's capacity that are in the scope of study. The POC's capacity level, on the other hand, has a positive effect on the SPC's access times.

Further, it seems that the access times of the motility clinic are influenced by the squared values of the capacity levels. In Table 6.15, the signs of all these effects on the access times are summarized.

Table 6.15: Summary of the effects of the capacity levels on the access times.

Department	Cap. POC	Cap. OT
Pediatric outpatient clinic	−	+*
Orthoptic visits 15 minutes	0	−
Orthoptic visits 30 minutes	0	−
Motility clinic	+/−**	+/−***
First post-operative checkup	0	−
Second post-operative checkup	+****	−*****
OR Strabismus	0	0
OR Non-Strabismus	0	0

\+ = positive effect, − = negative effect, 0 = no significant effect.
* Positive for low and middle capacity levels at the POC, negative for high level.
** Positive for the values of the OT's capacity in approximately the lower half of the studied range, negative for the upper half.
*** Positive if the OT's capacity is higher than $1.44x_1$, negative otherwise.
**** Positive for middle and high capacity levels at the OT, negative for low level.
***** Negative for low and middle capacity levels at the POC, positive for high level.

Using this table, resource allocation decisions can be more easily made by the eye hospital; with one quick glance, the consequences can be determined. The access times of the surgeries are not affected by either department's capacity level. For all other types of visit, a simultaneous increase to high capacity levels at the POC and the OT yields only shorter access times, except for the SPC; there, a high value of the POC's capacity is undesired because it will increase the access times, and it causes the OT's capacity to have a positive effect as well. If the POC's capacity level is somewhere close to but higher than the middle level, the latter problem does not hold anymore. However, this will cause the OT's capacity level to have a positive effect on the POC's access times. However, this positive effect is compensated by the negative effect that the POC's own capacity level has. Compared to the current situation (the base case, with low capacity levels at both departments), the POC's access times are still decreased.

Furthermore, we see from the table that the OT's capacity level has a negative effect on the access times of all departments except for the surgeries, as long as the POC's capacity level is close to but higher than the middle level. Since we also know that the effects are diminishing, and that higher capacity means higher costs for the eye hospital, our recommendation is to increase the capacity level of both the POC and the OT to a level somewhere between their respective middle and high levels.

If the budget is higher, we would recommend the eye hospital to further increase the OT's capacity, although the motility clinic's access times may increase, dependent on the exact values of x_1 and x_2. On the other hand, if the budget is lower, our advice would be to increase only the POC's capacity level somewhat; this gives a reduction in the POC's and the SPC's access times. However, the motility clinic's access times will increase if it is increased too much. One option then is to increase the POC's capacity up to the level for which the motility clinic's access times start to increase again. If we assume that the POC's access times more important than the motility clinic's, which we deem reasonable, it would also be a good solution to increase the POC's capacity somewhat further.

Chapter 7

Discussion

This chapter consists of two parts. First, the used methodology and results are evaluated. Thereafter, recommendations for future research are given.

7.1 Evaluation

For this study, a simulation model was constructed to simulate the logistical network of the strabismus care pathway in the Rotterdam Eye Hospital. Since bootstrapping was not possible with Arena, the software package that the eye hospital used for simulations, we came up with the idea of using double transitions to model how patients flow through the system. We showed that this is a reasonable alternative for this purpose, and that it is preferred above the single-transitions model. In the remainder of this section, the model assumptions made in Section 5.3 and the way we interpreted the results in Section 6.2, are evaluated.

Evaluation of the model assumptions

Because it was not clear from the data for every individual visit which part of the access time lengths was due to capacity problems, and which part to medical issues, we assumed a first-come-first-served policy in our model. The consequence of this choice was that the results were not directly interpretable; only the available capacity affects the access times, while in the real world, there are also other reasons for longer access times. For instance, there are no periodic checkups. Some patients are seen on a regular basis, once or twice a year, for example. In these cases, the access times of 6 or 12 months are not because of limited capacity, but because it makes no sense to have an earlier visit if there are no complications. Furthermore, patients have their own agendas too, which means that they may not be available at the first possible opportunity of the particular department of the eye hospital.

However, because these 'problems' are more or less independent from the capacity levels of the relevant departments, the focus should not be on the absolute values; even if there would be infinite capacity, the periodic checkups still remain the same. Therefore, we believe that it is the relative differences that are observed when capacity levels are changed, that we should pay attention to.

We also assumed that there is no seasonality, because it is not possible to change the distribution of new patient arrivals and the timetables of the employees temporarily. As we already explained in the text, however, this does not have to be a problem because not only will the arrival rate decrease in the summer; also the resources will decrease, so that the effects will partly to some extent.

Finally, in practice there are resources who work at different departments on different shifts. The two surgeons in this thesis also have consulting-hours at the pediatric outpatient clinic, and the orthoptists work at both the orthoptic department and the pediatric outpatient clinic. In the simulation model, we assumed that these are different resources at different departments. The consequence is that whenever a failure occurs with one of these employees (sickness absences, vacations), only one department is affected. The capacity level at the other department will remain the same.

On the other hand, the fact that these employees are independent in the model also means that the probability of a failure is twice as high. Hence, although the impact of a failure is reduced, the higher probability that it occurs causes the effects to be canceled out.

Evaluation of the way of interpretation of the results

At the end of Section 6.1, we concluded that the simulation results should not be interpreted directly, because the access times were too small due to the model assumptions. Instead of analyzing the absolute outcomes, we therefore looked at the relative differences in outcomes, expressed in percentages. However, in the literature about simulating access times (which are called waiting times, while we made a distinction between these two terms), we did not encounter interpretation decisions like ours; one reason was that there was little to be found about studies investigating problems in which there are periodic visits, as we do. Further, in some studies the access times that are weighted by priority score. This is the case in Comas et al. (2008), for instance, where a priority score is given by an ophthalmologist, depending on the urgency and other attributes. As described in Chapter 3, they apply discrete-event simulation to analyze the access times for cataract surgeries in Spain using a prioritization system. These results are compared to the routinely used first-come, first-served discipline; it appeared that the prioritization system shortened the access times.

There are two reasons why we have not used prioritization in our study. The most obvious one is that we lack the information to do that. Since we do not know the urgency of any of the visits to the eye hospital, we would not have been able to compare the results in a fair way. This would lead to principally the same problem that we faced, namely that of simulation results that are not directly comparable with real data.

Another reason why we did not take prioritization rules into account is that Comas et al. (2008) compare two different planning systems, and keep capacity at the same levels, while the Rotterdam Eye Hospital, on the other hand, wanted to know the effects of capacity changes. Using another prioritization system is therefore merely an idea for future research.

In Section 6.3, we have performed regressions to analyze the results. The models that we have used were based on the (informal) analysis in Section 6.2 and on the scatter plots of the access times versus the capacity levels. Not all variables in the model with which we started were significant, and therefore the method of backward elimination was applied. In general, we believe that the regression outputs are plausible as long as the capacity levels are reasonably realistic.

7.2 Recommendations for Future Research

In this section, a few possibilities for future research are provided. Some ideas are somewhat radical, others are mere extensions of our study.

In Chapter 5, we described bootstrapping as the ideal way to obtain realistic patient routings for the simulation model. Although we believe that we captured the most important paths with our double-transition model, one can improve this particular element of the simulation by using another program than Arena, that can handle this large amount of data, to simulate the whole logistical system of the eye hospital. However, we are not sure whether this will be a worthy investment in time and effort. Assuming that it is undesired to create a new simulation model from scratch using another software package, we prefer the following ideas for further research.

As a small extension of our study, one can also look at the effects if the capacity level of the orthoptists at the pediatric outpatient clinic is *decreased*, while *increasing* the capacity at the orthoptic department, or the other way around. This shows whether the current allocation of resources is efficient or not.

Another possible extension is to change the parameters of the transition probabilities so that the patient routings are closer to the standard patient routings that the eye hospital wants strabismus patients to follow, to see what the consequences are. The challenge is to keep these transition probabilities still realistic; in many cases, is not possible to let patients follow the standard patient routings, as explained in Chapter 2.

Due to the assumption of a first-come, first-served policy, we obtained simulated access times that are much smaller than those in reality. As we discussed in the previous section, one could try another prioritization system for the planning of appointments. As has been done by Comas et al. (2008), the access times could be weighted by priority score based on urgency. This way, it may be possible to shorten the access times without adjusting the capacity levels at the eye hospital.

Further, it may be possible to think of an idea that also takes into account that the access times that patients experience in reality are partly due to medical reasons and their own agendas.

Finally, it may also be interesting to test whether the Markov property is indeed invalid for the single-transition model, and (more) valid for the double-transition model that we have used, to evaluate the reliability of the simulated patient routings.

Chapter 8

Conclusion

In this thesis, we have described the problem that the Rotterdam Eye Hospital faced and asked us to find a solution for. To recapitulate, the key question of our study was:

What are the effects of different resource allocations at the relevant departments of the logistical system of the Rotterdam Eye Hospital's strabismus care pathway on the access times?

To answer this question, the logistical system of the strabismus care pathway was mapped out. The decision variables and parameters were made clear, as well as the current situation. A double-transition model based on Markov processes, with the amount of time spent in a certain state determined by the waiting queue length and the available resource capacity, had been devised. Next, this model was implemented in the simulation software package Arena, and the effects of capacity level changes at the pediatric outpatient clinic and the orthoptic department on the access times of all relevant departments of the strabismus care pathway were investigated. Also, the influence of different failure rates on the access times were studied. First, the results were analyzed in a somewhat informal way, just by looking at the average results of the simulations; thereafter, regressions were performed to model the relationships between the capacity levels and the access times.

The results of the 27 different scenarios could not be said to be unambiguous. This is because in general, the direct effects of the capacity changes on the access times are negative (that is, higher capacity leads to shorter access times), while the sign of the indirect effects depend on the capacity level of the other department.

It is then up to the eye hospital to decide which scenario is the most favorable. If the budget allows it, we would recommend to increase the capacity level of both the POC and the OT to a level somewhere between their respective middle and high levels. If the budget is even higher, we would advise to further increase the OT's capacity, although the motility clinic's access times may increase, dependent on the exact values of the capacity levels at the POC and the OT. On the other hand, if the budget is lower, our recommendation would be to increase only the POC's capacity level somewhat, since it will decrease the POC's access time considerably, while the access times of the other departments are unaffected or are slightly lowered. Finally, if it is not too costly for the eye hospital to lower the failure rates, this should be done anyhow, regardless of the chosen changes in capacity levels.

References

Alessandra, A.J., Grazman, T.E., Parameswaran, R. and Yavas, U. (1978). Using simulation in hospital planning. *Simulation, 30*, 62–67.

Aharonsen-Daniel, L., Paul, R.J. & Hedley, A.J. (1996). Management of queues in out-patient departments: the use of computer simulation. *Journal of Management in Medicine, 10.6*, 50–58.

Banks, J., Carson II, J.S., Nelson, B.L. & Nicol, D.M. (2001). *Discrete-Event System Simulation.* Prentice-Hall, Inc., New Jersey.

Comas, M., Castells, X, Hoffmeister, L., Román, R., Cots, F., Mar, J., Gutiérrez-Moreno & S.Espallargues, M. (2008). Discrete-event simulation applied to analysis of waiting lists. Evaluation of a prioritization system for cataract surgery. *Value in Health, 11*, 1203–1213.

Elkhuizen, S.G., Das, S.F., Bakker, P.J.M. & Hontelez, J.A.M. (2007). Using computer simulation to reduce access time for outpatient departments. *Quality and Safety in Health Care, 16*, 382–386.

Evans, M., Hastings, N. & Peacock, B. (2000). *Statistical Distributions.* Wiley, New York.

Gaver, Jr., D.P. (1959). Imbedded Markov chain analysis of a waiting-line process in continuous time. *The Annals of Mathematical Statistics, 30*, 698–720.

Heij, C., De Boer, P., Franses, P.H., Kloek, T. & Van Dijk, H.K. (2004). *Econometric Methods with Applications in Business and Economics.* Oxford University Press, Inc., New York.

Jacobson, S.H., Hall, S.N., Swisher, J.R. (2006). Discrete-Event Simulation of Health Care Systems. In: Hall, R.W. (Ed.). *Patient Flow: Reducing Delay in Healthcare Delivery*, 210–252. Springer, New York.

Jun, J.B., Jacobson, S.H. & Swisher, J.R. (1999). Application of discrete-event simulation in health care clinics: A survey. *Journal of the Operational Research Society, 50*, 109–123.

Kelton, W.D., Sadowski, R.P. and Swets, N.B. (2010). *Simulation with Arena*. McGraw-Hill, New York.

Kumar, A.P. and Kapur, R. (1989). Discrete simulation application- scheduling staff for the emergency room. In: MacNair, E.A., Musselman, J.K. and Heidelberger, P. (eds). *Proceedings of the 1989 Winter Simulation Conference*. Institute of Electrical and Electronics Engineers, Washington DC, USA, 4–6 December, 1112–1120.

Lowery, J.C. (1993). Multi-hospital validation of critical care simulation model. In: Evans, G.W., Mollaghasemi, M., Russell, E.C. and Biles, W.E. (eds). *Proceedings of the 1993 Winter Simulation Conference*. Institute of Electrical and Electronics Engineers, Los Angeles, California, USA, 12–15 December, 1207–1215.

Mukherjee, A.K. (1991). A simulation model for management of operations in the pharmacy of a hospital. *Simulation, 56*, 91–103.

Pegden, C.D., Shannon, R.E. & Sadowski, R.P. (1995). *Introduction to Simulation Using SIMAN*. McGraw-Hill, New York.

Rising, E.J., Baron, R. and Averill, B. (1973). A systems analysis of a university-health-service outpatient clinic. *Operations Research, 21*, 1030–1047.

Ross, S.M. (2002). *Simulation*. Academic Press, Amsterdam.

Ross, S.M. (2003). *Introduction to Probability Models*. Academic Press, Amsterdam.

Smith, E.A. and Warner, H.R. (1971). Simulation of a multiphasic screening procedure for hospital admissions. *Simulation, 17*, 57–64.

Smith, S.R., Schroer, B.J. and Shannon, R.E. (1979). Scheduling of patients and resources for ambulatory health care. In: Highland, H.J., Spiegel, M.G. and Shannon, R. (eds). *Proceedings of the 1979 Winter Simulation Conference.* Institute of Electrical and Electronics Engineers, San Diego, California, USA, 3–5 December, 553–562.

Swisher, J.R., Jun, J.B., Jacobson, S.H. and Balci, O. (1997). Simulation of the Queston physician network. In: Andradottir, S., Healy, K.J., Withers, D.E. and Nelson, B.L. (eds). *Proceedings of the 1997 Winter Simulation Conference.* Institute of Electrical and Electronics Engineers, Atlanta, Georgia, USA, 7–10 December, 1146–1154.

Takács, L. (1955). Investigation of waiting time problems by reduction to Markov processes. *Acta Mathematica Hungarica, 6*, 101–129.

Appendix

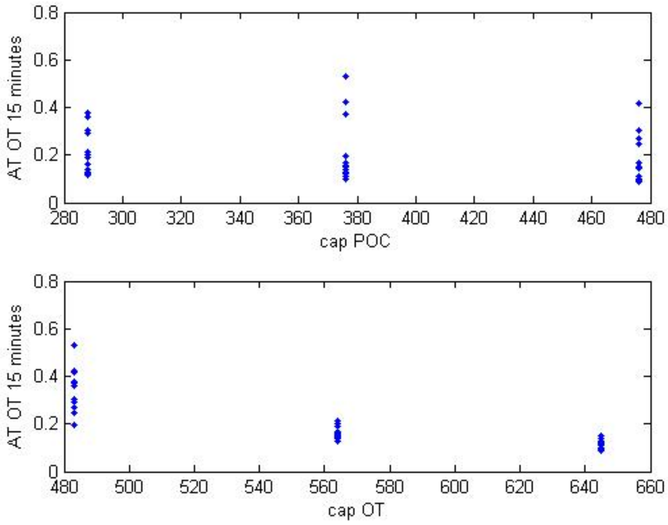

Figure A1: Access times of the orthoptic visits with duration 15 minutes vs. capacity levels of the pediatric outpatient clinic and the orthoptic department.

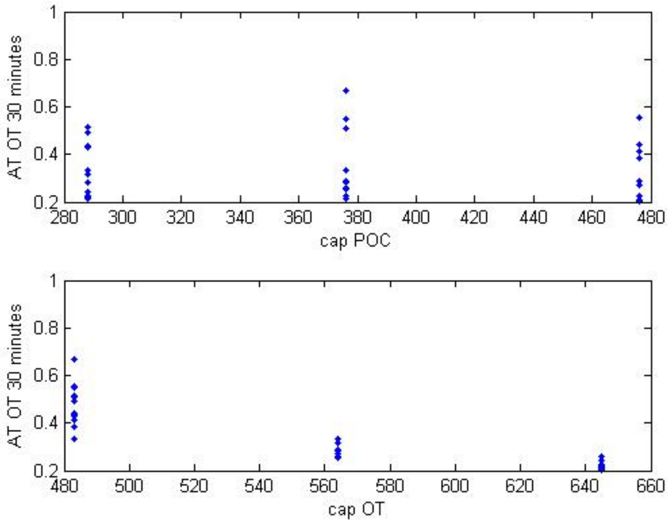

Figure A2: Access times of the orthoptic visits with duration 30 minutes vs. capacity levels of the pediatric outpatient clinic and the orthoptic department.

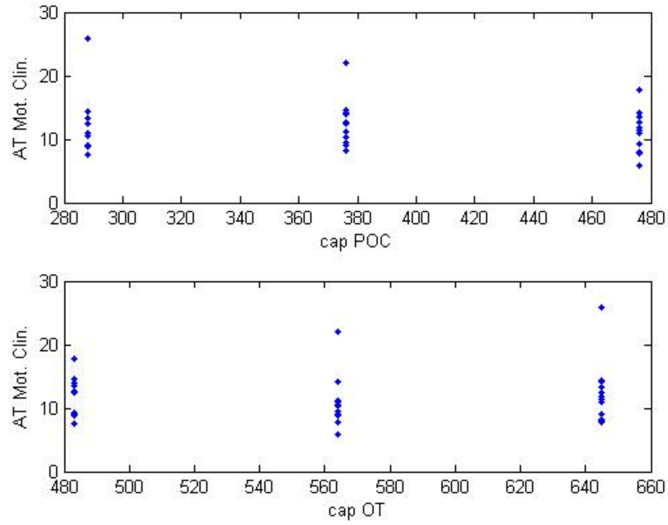

Figure A3: Access times of the motility clinic vs. capacity levels of the pediatric outpatient clinic and the orthoptic department.

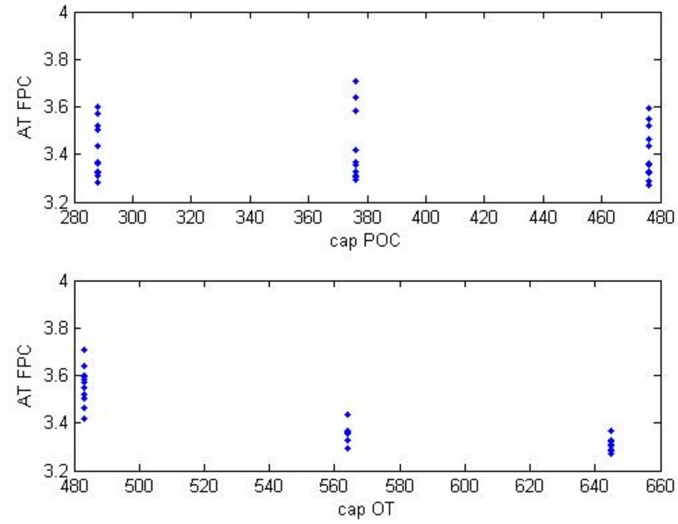

Figure A4: Access times of the first post-operative checkups vs. capacity levels of the pediatric outpatient clinic and the orthoptic department.

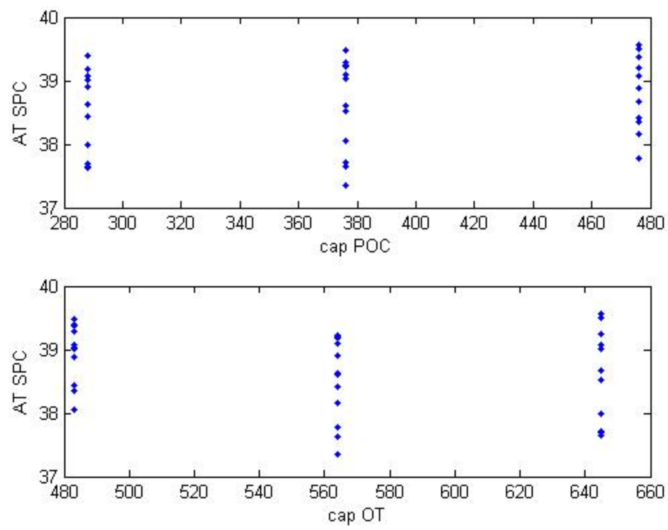

Figure A5: Access times of the second post-operative checkups vs. capacity levels of the pediatric outpatient clinic and the orthoptic department.

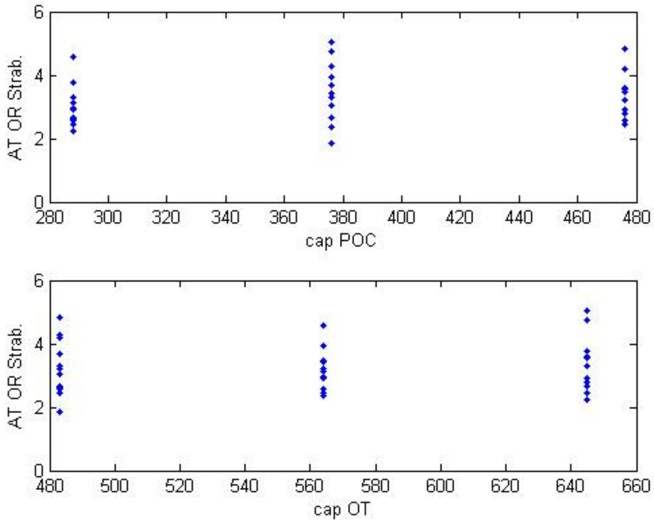

Figure A6: Access times of the strabismus surgeries vs. capacity levels of the pediatric outpatient clinic and the orthoptic department.

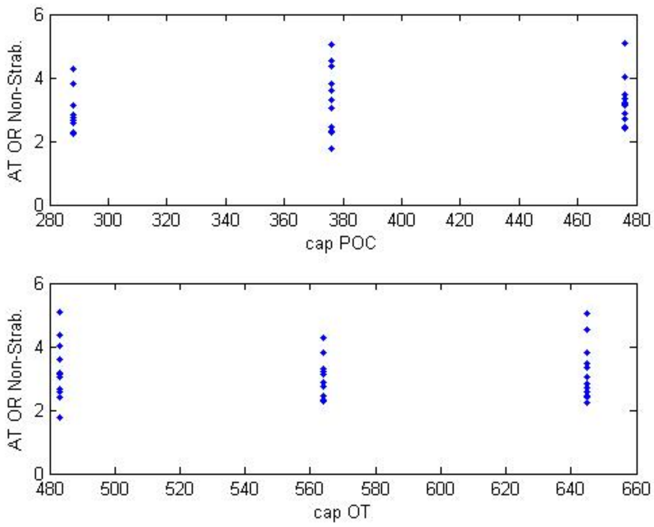

Figure A7: Access times of the non-strabismus surgeries vs. capacity levels of the pediatric outpatient clinic and the orthoptic department.

Table A1: The transition matrix of the strabismus care pathway.

From	Via\To	POC	OT 15 min.	OT 30 min.	Mot. Clin,	FPC	SPC	OR Strab.	OR Non-Strab.	Non-Str. Depts.	Exit	Abs. Sum
None	None	55.80	8.62	3.93	0.98	0.05	0.38	0.30	0.36	29.57	0.00	23950
	POC	54.32	2.51	6.85	0.22	0.00	0.01	0.00	0.46	7.29	28.34	13364
	OT 15 min.	35.56	50.44	0.48	2.86	0.00	0.00	0.05	0.00	6.64	3.97	2064
	OT 30 min.	10.63	9.88	16.26	11.69	0.00	0.11	0.53	0.00	34.33	16.58	941
	Mot. Clin.	0.85	11.06	62.13	0.00	0.00	0.00	1.28	0.00	22.13	2.55	235
	FPC	0.00	0.00	0.00	0.00	0.00	84.62	7.69	0.00	7.69	0.00	13
	SPC	18.48	25.00	8.70	7.61	0.00	1.09	0.00	0.00	17.39	21.74	92
	OR Strab.	6.85	0.00	0.00	0.00	82.19	0.00	0.00	0.00	8.22	2.74	73
	OR Non-Strab.	27.91	0.00	0.00	1.16	0.00	0.00	0.00	2.33	65.12	3.49	86
	Non-Str. Depts.	19.84	1.37	53.40	3.28	0.06	0.13	0.95	20.98	0.00	0.00	7082
POC	POC	54.84	2.54	8.53	0.09	0.01	0.08	0.03	0.52	4.52	28.83	21104
	OT 15 min.	16.62	59.90	0.45	3.75	0.01	0.03	0.42	0.12	3.49	15.21	6936
	OT 30 min.	12.58	52.46	3.33	8.67	0.10	0.06	0.45	0.06	3.82	18.47	3092
	Mot. Clin.	3.37	48.31	29.21	0.00	0.00	1.12	1.69	0.56	13.48	2.25	178
	FPC	16.00	4.00	2.67	0.00	0.00	60.00	0.00	0.00	14.67	2.67	75
	SPC	14.20	37.50	5.11	4.55	0.00	0.57	0.00	0.57	10.80	26.70	176
	OR Strab.	3.41	2.27	1.14	0.00	86.36	1.14	0.00	0.00	4.55	1.14	88
	OR Non-Strab.	78.16	1.37	0.34	0.00	0.34	0.00	0.00	1.71	13.65	4.44	293
	Non-Str. Depts.	38.12	4.55	4.34	0.36	0.15	0.27	2.21	9.78	0.00	40.22	3342
OT 15 min.	POC	9.53	71.49	0.67	1.03	0.03	0.11	0.36	0.16	2.60	14.02	7282
	OT 15 min.	35.85	46.58	0.23	2.85	0.00	0.02	0.12	0.00	2.10	12.25	12992
	OT 30 min.	23.85	10.09	15.60	5.50	0.00	0.00	0.92	0.00	8.26	35.78	109
	Mot. Clin.	10.48	42.64	0.91	0.50	0.20	0.00	15.83	0.00	23.59	5.85	992
	FPC	0.00	0.00	0.00	0.00	0.00	0.00	50.00	0.00	50.00	0.00	2
	SPC	23.21	17.86	0.00	1.79	0.00	0.00	0.00	0.00	5.36	51.79	56
	OR Strab.	0.00	6.08	0.00	0.00	84.53	1.10	0.00	0.00	5.52	2.76	181
	OR Non-Strab.	50.00	10.00	0.00	0.00	30.00	0.00	0.00	0.00	0.00	10.00	10
	Non-Str. Depts.	11.75	29.92	2.25	0.83	0.08	0.17	43.00	0.75	0.00	11.25	1200
OT 30 min.	POC	15.52	34.54	15.04	3.61	0.00	0.12	1.68	0.12	9.03	20.34	831
	OT 15 min.	15.65	54.27	1.01	11.83	0.00	0.05	0.16	0.00	3.08	13.95	1885
	OT 30 min.	1.90	1.10	29.31	6.91	0.00	0.00	1.18	0.00	38.50	21.11	2634
	Mot. Clin.	3.24	13.61	10.18	0.38	0.00	0.10	9.61	0.00	50.62	12.27	1051
	FPC	20.00	40.00	20.00	0.00	0.00	0.00	20.00	0.00	0.00	0.00	5
	SPC	20.00	26.67	6.67	13.33	0.00	0.00	0.00	0.00	6.67	26.67	15
	OR Strab.	1.62	2.97	0.00	0.00	82.16	0.27	0.00	0.00	12.16	0.81	370
	OR Non-Strab.	12.50	25.00	12.50	0.00	12.50	0.00	0.00	0.00	37.50	0.00	8
	Non-Str. Depts.	1.50	1.28	49.63	7.49	0.04	0.20	6.04	0.68	0.00	33.14	5410
Mot. Clin.	POC	3.64	56.36	6.67	0.00	0.61	0.00	7.88	0.00	15.15	9.70	165
	OT 15 min.	10.00	22.39	0.00	1.55	0.00	0.14	13.52	0.00	47.89	4.51	710
	OT 30 min.	8.10	4.60	10.48	1.75	0.00	0.00	19.21	0.16	40.63	15.08	630
	Mot. Clin.	9.09	54.55	18.18	0.00	0.00	0.00	0.00	0.00	9.09	9.09	11
	FPC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00	50.00	2
	SPC	0.00	0.00	0.00	0.00	0.00	0.00	50.00	0.00	25.00	25.00	8
	OR Strab.	2.01	3.79	0.45	0.00	79.46	0.67	0.00	0.00	9.60	4.02	448
	OR Non-Strab.	50.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00	0.00	2
	Non-Str. Depts.	2.47	2.84	23.26	0.55	0.18	0.09	60.53	0.37	0.00	9.71	1092

Table A1: The transition matrix of the strabismus care pathway. *(Continued)*

From	Via\To	POC	OT 15 min.	OT 30 min.	Mot. Clin,	FPC	SPC	OR Strab.	OR Non-Strab.	Non-Str. Depts.	Exit	Abs. Sum
FPC	POC	9.33	3.63	2.07	0.00	1.04	68.91	0.00	0.00	7.77	7.25	193
	OT 15 min.	40.43	31.91	2.13	6.38	0.00	10.64	0.00	0.00	4.26	4.26	47
	OT 30 min.	10.00	15.56	13.33	3.33	0.00	5.56	0.00	0.00	28.89	23.33	90
	Mot. Clin.	0.00	0.00	20.00	0.00	0.00	60.00	0.00	0.00	20.00	0.00	5
	FPC	33.33	0.00	0.00	0.00	0.00	50.00	0.00	0.00	16.67	0.00	6
	SPC	18.51	23.42	8.58	5.17	0.05	0.35	0.00	0.00	12.54	31.39	1994
	OR Strab.	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	6
	OR Non-Strab.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	Non-Str. Depts.	4.53	0.38	10.19	0.38	0.38	74.34	1.89	1.13	0.00	6.79	265
SPC	POC	4.46	69.87	2.68	4.24	0.00	0.67	0.00	0.22	3.79	14.06	448
	OT 15 min.	32.31	43.08	0.17	8.38	0.00	0.17	0.00	0.00	2.39	13.50	585
	OT 30 min.	3.96	0.88	22.91	11.01	0.00	0.44	0.00	0.00	26.87	33.92	227
	Mot. Clin.	8.03	13.14	16.06	0.00	0.00	0.00	2.92	0.00	48.18	11.68	137
	FPC	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1
	SPC	8.33	25.00	0.00	33.33	0.00	0.00	0.00	0.00	8.33	25.00	12
	OR Strab.	20.00	0.00	0.00	0.00	80.00	0.00	0.00	0.00	0.00	0.00	5
	OR Non-Strab.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	1
	Non-Str. Depts.	5.38	3.08	26.92	10.26	0.00	0.51	3.33	1.79	0.00	48.72	390
OR Strab.	POC	2.74	1.37	2.74	0.00	82.19	4.11	0.00	0.00	4.11	2.74	73
	OT 15 min.	9.84	1.64	11.48	0.00	0.00	70.49	0.00	0.00	3.28	3.28	61
	OT 30 min.	0.00	0.00	12.50	0.00	0.00	62.50	0.00	0.00	12.50	12.50	8
	Mot. Clin.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	FPC	6.78	1.62	3.33	0.21	0.21	74.23	0.00	0.00	8.32	5.29	2344
	SPC	25.00	25.00	18.75	0.00	0.00	6.25	0.00	0.00	0.00	25.00	16
	OR Strab.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	OR Non-Strab.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	Non-Str. Depts.	3.77	0.34	0.00	0.00	93.15	1.37	0.00	0.00	0.00	1.37	292
OR Non-Strab.	POC	46.18	1.45	0.48	0.00	0.00	0.12	0.00	2.67	42.91	6.18	825
	OT 15 min.	80.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.00	10
	OT 30 min.	42.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	57.14	0.00	7
	Mot. Clin.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	1
	FPC	22.22	11.11	11.11	0.00	0.00	33.33	0.00	0.00	22.22	0.00	9
	SPC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	OR Strab.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	OR Non-Strab.	47.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	47.06	5.88	17
	Non-Str. Depts.	6.79	0.29	1.55	0.06	0.00	0.06	0.06	25.30	0.00	65.90	1739
Non-Str. Depts.	POC	33.07	4.66	5.47	0.16	0.26	0.29	0.94	2.78	23.82	28.54	3090
	OT 15 min.	20.50	40.30	1.38	2.34	0.14	0.14	5.09	0.28	18.16	11.69	727
	OT 30 min.	2.75	1.21	20.67	6.32	0.03	0.01	2.81	0.07	51.02	15.10	7052
	Mot. Clin.	0.99	1.13	41.16	0.28	0.00	0.28	25.46	0.14	25.60	4.95	707
	FPC	5.92	0.70	2.79	0.00	0.35	66.90	1.05	0.00	18.47	3.83	287
	SPC	6.78	3.39	14.83	5.08	0.00	0.85	0.42	0.00	41.53	27.12	236
	OR Strab.	2.94	1.20	0.30	0.00	83.23	0.54	0.00	0.00	11.06	0.72	1664
	OR Non-Strab.	24.08	0.13	0.22	0.00	0.17	0.00	0.00	0.43	70.51	4.45	2313
	Non-Str. Depts.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0

Table A2: The mean access times of the simulation runs with middle failure level.

			Department							
Scenario	cap POC	cap OT	POC	OT 15 minutes	OT 30 minutes	Mot. Clin.	FPC	SPC	OR Strab.	OR Non-Strab.
l/l/m (base case)	288	483	0.78	0.36	0.49	12.39	3.60	39.39	3.31	3.13
l/l/m (base case)	288	483	0.76	0.29	0.43	8.76	3.51	39.01	2.61	2.55
l/l/m (base case)	288	483	0.79	0.38	0.51	7.57	3.57	39.08	2.66	2.67
l/l/m (base case)	288	483	0.91	0.30	0.44	9.07	3.52	38.43	2.59	2.57
l/m/m	288	564	0.78	0.21	0.33	10.61	3.37	37.62	2.43	2.29
l/m/m	288	564	0.74	0.16	0.29	8.73	3.37	38.91	3.14	3.13
l/m/m	288	564	0.88	0.20	0.32	10.43	3.36	39.18	2.95	2.76
l/m/m	288	564	0.57	0.19	0.31	9.14	3.44	38.63	4.59	4.29
l/h/m	288	645	1.01	0.12	0.23	25.78	3.33	39.00	2.67	2.59
l/h/m	288	645	1.57	0.12	0.22	13.28	3.31	37.70	3.76	3.79
l/h/m	288	645	0.94	0.12	0.22	10.95	3.28	37.99	2.93	2.84
l/h/m	288	645	0.90	0.14	0.24	14.32	3.32	37.65	2.24	2.23
m/l/m	376	483	0.14	0.37	0.51	12.66	3.58	38.04	3.68	3.60
m/l/m	376	483	0.13	0.20	0.33	14.01	3.42	39.29	1.87	1.77
m/l/m	376	483	0.12	0.42	0.55	14.56	3.64	39.03	4.29	4.38
m/l/m	376	483	0.13	0.53	0.67	9.06	3.71	39.49	3.03	3.04
m/m/m	376	564	0.12	0.13	0.26	9.57	3.30	38.61	2.35	2.30
m/m/m	376	564	0.12	0.14	0.26	11.14	3.36	39.23	3.41	3.28
m/m/m	376	564	0.12	0.17	0.29	22.05	3.37	39.09	2.38	2.33
m/m/m	376	564	0.17	0.15	0.28	10.35	3.33	37.35	3.93	3.81
m/h/m	376	645	0.14	0.12	0.23	9.14	3.31	37.65	4.75	4.53
m/h/m	376	645	0.14	0.15	0.26	8.29	3.37	38.53	5.06	5.03
m/h/m	376	645	0.15	0.10	0.22	14.13	3.30	39.24	3.29	3.06
m/h/m	376	645	0.12	0.11	0.22	12.41	3.31	37.71	2.65	2.45
h/l/m	476	483	0.09	0.27	0.41	12.69	3.52	39.38	4.82	5.09
h/l/m	476	483	0.08	0.25	0.38	9.23	3.47	38.88	3.21	3.17
h/l/m	476	483	0.08	0.42	0.55	13.43	3.59	39.08	4.21	4.02
h/l/m	476	483	0.10	0.31	0.44	17.81	3.55	38.35	2.44	2.41
h/m/m	476	564	0.07	0.15	0.27	10.86	3.44	38.15	3.46	3.21
h/m/m	476	564	0.08	0.15	0.27	5.87	3.36	39.20	2.92	2.86
h/m/m	476	564	0.07	0.17	0.29	7.73	3.36	38.42	2.57	2.44
h/m/m	476	564	0.09	0.14	0.27	14.19	3.36	37.79	3.19	3.15
h/h/m	476	645	0.08	0.11	0.22	11.89	3.33	39.08	3.58	3.46
h/h/m	476	645	0.08	0.10	0.20	11.47	3.32	39.49	3.54	3.35
h/h/m	476	645	0.08	0.09	0.20	7.85	3.27	39.56	2.46	2.40
h/h/m	476	645	0.09	0.10	0.21	7.94	3.29	38.67	2.78	2.71