Maintaining service level at reduced capacity in hospitals

a discrete event simulation

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Abstract

Hospital management is challenged to deal with conflicting objectives of low costs and high quality of care. Erasmus MC is the largest hospital in the Netherlands and will move to another building in a few years time. The hospital aims to keep the service level, consisting of the percentage of waiting patients and average waiting time, constant while reducing the capacity with 30%. In order to determine the service level, we need to model the patient flow at Erasmus MC. We first provide a thorough data analysis and visualize patient flow using transition probability matrices and diagrams. Discrete event simulation is then used to determine the current service level of the hospital.

Simulation results reveal that the capacity reduction will lead to a drastic decrease in the service level. We therefore propose several options that might lead to an increase in the service level. These options include increasing the capacity during the weekend, combining several medical departments and reducing the length of stay. We again use simulation to determine the effectiveness of these measures concerning the service level. All options turn out to increase the service level and we therefore advice the management to implement these solutions.

Keywords: *healthcare, patient flow, service level, discrete event simulation*

Preface

This thesis is my final assignment for the study Econometrics and Management Science with specialization in Operations Research and Quantative Logistics at the Erasmus University Rotterdam.

Last year, Erasmus Medical Center was looking for an intern to do research on the influence of organisational changes on their service level. I offered Erasmus MC to investigate whether its service could be improved while reducing the capacity. I would like to thank Erasmus MC for giving me the opportunity to do an internship with a practical scope.

Erasmus MC warned me that it would be difficult to obtain the correct data. Obtaining information was harder than expected and took a lot of time. The hospital could not provide many details on the different aspects of patient flow. However, I managed to cope with the shortcomings in the data and used alternatives to include all important characteristics of patient flow. It was very useful to learn how to deal with incomplete data.

I would like to thank my academic supervisor Taoying Farenhorst from the Erasmus University. Her critical inputs during my research were often eye-openers and helped me to gain a better insight in the different aspects of the research. I especially want to thank her for her willingness to continue supervising me in her free time.

Last, but not least, I would like to thank my family for their understanding during the past months. I have enjoyed lots of support while you might not have fully understood what I was actually doing.

Marit Souverijn
Rijnsburg, January 2013

Contents

1 Introduction

Rising costs in healthcare are a worldwide problem and the pressure to contain costs increase (OECD, 2011). On the other hand, quality of care also becomes more important due to high standards. Hospital management is thus challenged to deal with the conflicting objectives of low costs and high quality of care. It is therefore critical for hospitals to provide the best possible patient care within allocated resources. Health care logistics can make a major contribution to maintain high level care at affordable costs.

There are many different options to improve the efficiency of hospitals, such as surgical facility scheduling and inpatient admission scheduling. However, many medical departments are dependent on scarce resources and also impose constraints on other medical departments. Most of these resources are related to patient flow and it is therefore essential to gain an insight into the patient flow.

1.1 Problem description

Erasmus University Medical Center is the largest university hospital in the Netherlands. In order to increase patient care, the hospital recently introduced divisions which brings certain types of care together. The main reason for the introduction of divisions is to increase efficiency, quality and safety. In a few years time, the hospital also moves to a new building which is currently being built. Due to cost limits, the movement leads to a reduction in the capacity of approximately 30%. However, the management of Erasmus MC does not want this capacity reduction to result in a lower service level. The service level consists of the capacity utilization rate, percentage of waiting patients and average waiting time. They therefore asked us to investigate whether it is possible to reduce the capacity while keeping the service level constant. We thus formulate the main research question as follows.

> *How can we maintain service level at Erasmus MC while reducing the capacity?*

Erasmus MC currently does not have any information about their service level due to a recent reorganization. To be able to determine the current service level it is necessary to understand the patient flow. By analysing and simulating the patient flow, the performance measures used to indicate the service level can be determined. Simulation can also be used to determine the impact of changes in the capacity on the service level.

In order to answer the main research question, the following sub-questions will be addressed.

1. *How is service level defined at Erasmus MC?*
   The service level at Erasmus MC is defined using several performance measures. We first provide the definitions of these performance measures and explain how they are related to patient care.

2. *How can patient flow be characterized at Erasmus MC?*
   We need to model patient flow to be able to determine the service level of the hospital. In order to model patient flow, we first need to investigate the specific characteristics of patient flow at Erasmus MC. We therefore perform a detailed analysis on the data provided by Erasmus MC.

3. *How can we model patient flow?*
   Modelling patient flow will enable us to measure the service level of the hospital. We use discrete event simulation to model patient flow through the hospital.

4. *Which methods to model patient flow exist in the current literature?*
   Health care logistics have already contributed to the efficiency of hospitals in many different ways. We perform a literature overview on potential modeling techniques regarding the patient flow in hospitals. We will discuss both analytical and simulation methods.

5. *What is the current service level of the hospital?*
   The management of the hospital aims to keep the service level constant while reducing the capacity. Since they do not have any information regarding their current performance, we first need to determine the current service level. The simulation model can be used to determine the performance measures which are used to indicate the service level.

6. *How is the service level effected by a capacity reduction?*
   Since we want to maintain the service level while reducing capacity, we have to determine how much the service level is effected by the capacity reduction. The future service level can be determined using our simulation model.

7. *What measures can be taken to maintain the current service level?*
   Since the capacity of the hospital reduces with 30% we expect the service level to decline. We therefore investigate several options that might help to increase the service level. We again use simulation to test whether the proposed measures lead to the desired service level.

1.2 Thesis outline

The remainder of this thesis is structured as follows.

In the next section we provide more information about Erasmus MC. This includes information on the organisational structure and the performance measures that will be used. We furthermore provide a comprehensive definition of patient flow and present the global characteristics of patient flow at Erasmus MC.

Health care logistics has already been used to model patient flow using different techniques. In Section 3 we discuss some of the existing methods. It shows how this research is related to the existing literature and why the current knowledge is insufficient.

Data analysis is one of the key steps in modelling and analysing patient flow. Erasmus MC provided patient data of all patients who visited the hospital during 2011. In Section 4 we give a general description of the data and provide some general statistics. We also give a more detailed analysis of some specific parts of the patient flow that are needed for our simulation model. In this section, we also construct the transition rates and a transition diagram. This will give insight in the sequence of treatments and shows the relationship between the different medical departments.

Discrete event simulation will be used to model patient flow and to measure the service level. In Section 5 we explain the different aspects of the simulation model and discuss the assumptions that are made.

The results of the simulation will be discussed in Section 6. We first determine the current service level and the future service level. After that, we investigate several options that might help to maintain the current service level.

We will end this thesis with a discussion, conclusion and recommendation to the hospital.

2 Erasmus MC

In this section we provide more information about Erasmus MC. We first describe the organisational structure at the hospital followed by a definition of the service level. After that, we give a definition of patient flow and present some of the characteristics of patient flow at Erasmus MC. In Section 2.3 we discuss some important definitions that are commonly used. In the last section we suggest several options that might help to increase the service level.

2.1 Organisational structure

This thesis is done for and in cooperation with Erasmus University Medical Center. Erasmus MC is the largest university hospital in the Netherlands and combines the services of a hospital with providing education and medical research.

In order to increase the quality of patient care, Erasmus MC recently introduced divisions which bring certain types of care together and assemble them within one hierarchical point. A division can therefore be explained as a partnership between different medical departments. Those medical departments act independently as well as structurally cooperate. The main reason for the introduction of divisions is to increase efficiency, quality and safety. The hospital is divided into nine divisions and each division consists of several medical departments. Figure 1 shows a tree diagram of the organisational structure at Erasmus MC. We will refer to the different medical departments (MD) using the numbers given in brackets in Figure 1.

This research will only focus on division Dijkzigt, which is the largest division. However, the methods would also be applicable to other divisions and must therefore be easy to adapt.

Erasmus MC uses three performance measures to determine their service level. Firstly, we look at the capacity utilization rate of the hospital, called S_1. This utilization rate provides a relationship between the potential capacity and the capacity currently being used. The output is displayed as a percentage and is calculated using formula (1). The hospital aims at a capacity utilization rate of at least 80%.

$$\mathrm{S}_1 = \left(\frac{\text{Used capacity}}{\text{Potential capacity}}\right) \cdot 100 \tag{1}$$

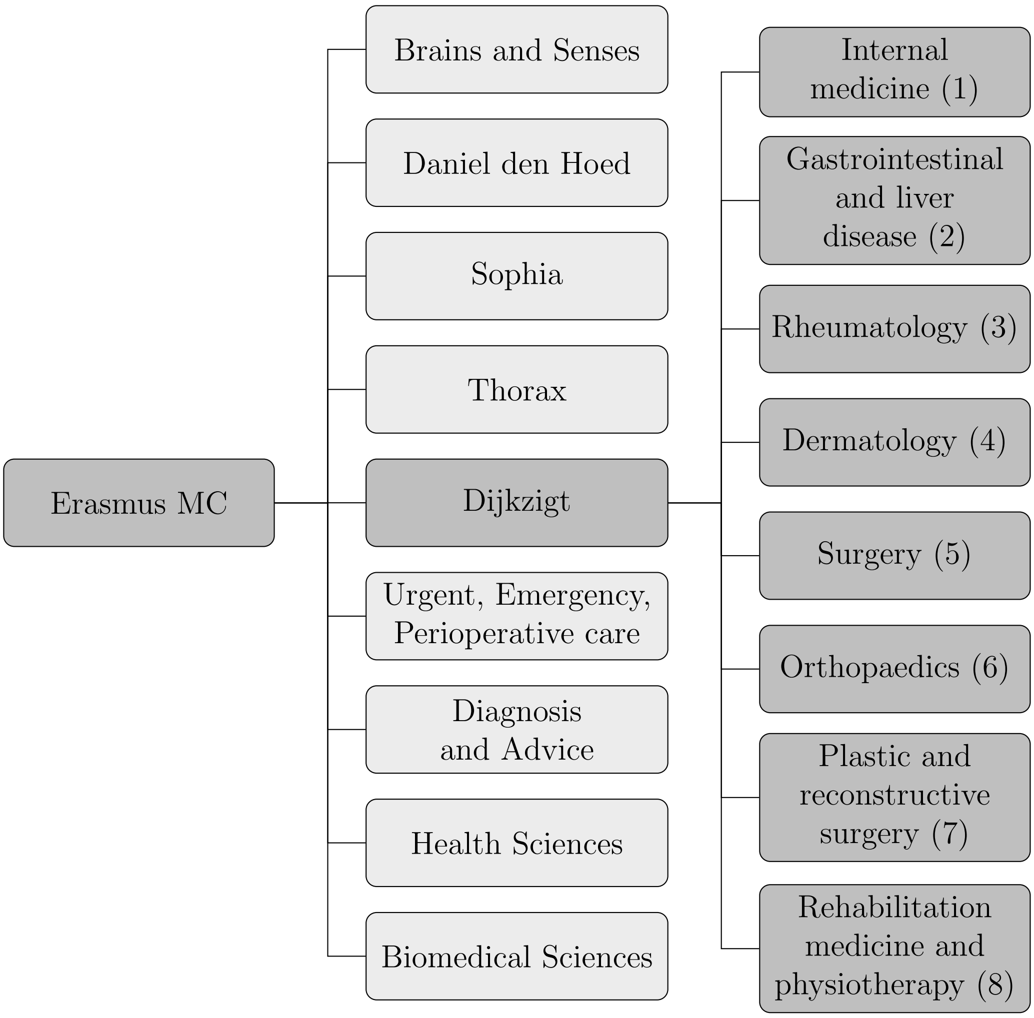

Figure 1: Organisational structure at Erasmus MC

The second performance measure, called S_2, is the percentage of patients who have to wait for their next appointment. Patients usually have to revisit the hospital after several days or weeks. If there is not enough capacity on the day at which a patient should revisit the hospital, the appointment will be scheduled later resulting in a waiting time for the patient. The following formula is used to calculate this percentage:

$$S_2 = \left(\frac{\text{Total \# of waiting patients}}{\text{Total \# of patients}} \right) \cdot 100 \tag{2}$$

The last performance measure is the average waiting time of patients in days. We make a distinction between the unconditional and the conditional waiting time. The unconditional waiting time, called S_3, is equal to the average number of days a patient has to wait. The conditional waiting time, called S_4, is equal to the average number of days a patient has to wait, given that this patient has to wait. The conditional waiting time will thus be higher than the unconditional waiting time. Both statistics provide useful information on the service level of the hospital. Formula (3) and (4) are used to calculate both measures.

$$S_3 = \left(\frac{\text{Total waiting time all patients}}{\text{Total \# of patients}} \right) \tag{3}$$

$$S_3 = \left(\frac{\text{Total waiting time all patients}}{\text{Total \# of waiting patients}} \right) \tag{4}$$

2.2 Patient flow

In literature, patient flow is described from two perspectives, the clinical and the operational (Côté, 2000).

From a clinical perspective, patient flow represents the progression of a patient's health status. Accordingly, an understanding of the patient flow offers knowledge and insight into the health care needs associated with disease progression or recovery status. This is useful information for healthcare providers, hospital administration and patients.

From an operational point of view, patient flow can be seen as the movement of patients through a set of locations in a health care facility. Now, patient flow is equivalent to the demand for health care services. Information on the demand can be used for effective resource allocation and capacity planning.

In this thesis, we only consider patient flow from an operational point of view. In the remainder of this thesis, we refer to patient flow from an operational perspective when we talk about patient flow.

Flow patterns of patients are defined from the point where patients are first admitted to the hospital and ends at the point of discharge (Konrad et al, 2012). Within these points, patients may encounter activities and services and require a variety of health care resources. These activities and services are called treatments. Another characteristic of patient flow is the random nature of the health care elements: not all of the elements in a patient flow network are applicable to all patients. Patient flow furthermore encompasses the following elements:

- The set of treatments during a patients stay
- The sequence of treatments
- The duration of treatments
- The resources required to perform these “treatments”

Usually, patient flow is analysed during a visit to the hospital. The sequence of events then starts at the registration desk and waiting room and ends with an exit. In this case, we look at the sequence of individual visits to the hospital instead of the sequence within a visit. At Erasmus MC, patients can visit three kind of clinics. The following clinics and corresponding types of treatments are defined at Erasmus MC:

- Polyclinic: a medical department that treats outpatients. Outpatients are patients who are not hospitalized but treated and released at the same day. Appointments at the polyclinic are used for medical consultations and minor treatments. We refer to this kind of treatment as a **polyclinical treatment**.
- Outpatient clinic: a medical department where patients are ‘hospitalized’ for observation or treatment, without the need for an overnight stay. When patients have an appointment at an outpatient clinic, we refer to this as a **day treatment**.
- Inpatient clinic: a medical department where patients are hospitalized for observation or treatment. Patients who are admitted to the inpatient clinic stay overnight or for an indeterminate time. We refer to this as a **clinical admission**.

2.3 Terminology

In this secion we discuss some terms and definitions which are commonly used in health care literature and which are relevant for this thesis.

- Capacity: the capacity in the hospital depends on many different factors. These factors include the number of beds and examination rooms, medical equipments and qualified personnel. There will thus be fluctuations in the capacity due to illness and holidays of personnel. This can also lead to a lower capacity than you would expect based on the available number of beds and examination rooms. In this research, we only work with the actual capacity which is based on all factors. For each medical department, the capacity per day is denoted as the total number of appointments that can be handled at that day.

- Waiting time: in healthcare literature, the waiting time usually denotes the time between an appointment and the actual starting time of that appointment. In this research, the waiting time refers to the number of workdays between the moment an appointment is needed, which is known, and the moment of the appointment itself. Weekenddays are thus not included in the waiting time. Example: a patient needs a follow-up appointment at day 10. Due to capacity shortage, the actual appointment takes place on day 14. If there is no weekend between day 10 and 14, the waiting time of the patient is 4 days. If there is a weekend between day 10 and 14, the waiting time of the patient is 2 days.

- Length of stay: length of stay (LOS) is commonly used in healthcare and denotes the number of days a patient spends in an inpatient clinic. After this time, a patient can either be discharged or transferred to another inpatient clinic. We also refer to this as the duration of a clinical admission.

2.4 Measures to increase service level

We propose three different options that might help to increase the service level. We first investigate whether it is useful to increase the capacity during the weekend. Secondly, we look at the effect of combining two medical departments. At last, we measure the effect of reducing the length of stay of clinical admissions.

2.4.1 Increase capacity during the weekend

The upcoming reduction in capacity is quite large and cannot be easily overcome by small changes in the system. The best option to increase the service level is to recapture the loss of capacity. This can be done by increasing the capacity during the weekend. There are currently no polyclinical appointments or day treatments during the weekend, so this is a fair option to reduce the loss in the service level. This method is already used at some medical departments who use very expensive equipment. In that case, the equipment is too valuable to remain unused during the weekend. We will investigate the influence on the service level when we increase the capacity on Saturday or during the entire weekend.

2.4.2 Combine medical departments

An optimal use of the available capacity leads to shorter waiting times and thus results in a higher service level. We expect that there will be some medical departments with capacity problems while there is ample capacity at other medical departments. Merging medical departments might thus lead to an increase in the capacity utilization rate. We will investigate the effect of combining a medical department with a high service level with a department with a low service level.

In Section 2.3 we already mentioned that the capacity depends on the number of beds and examination rooms, medical equipments and qualified personnel. Combining medical departments thus does not necessarily lead to a higher service level because personnel might not be able to conduct different types of treatments. However, we assume that the capacity shortfall is only caused by a reduction in the number of beds and examination rooms. Combining the beds and rooms of two medical departments can thus lead to a higher service level as appointments can be scheduled more efficiently.

2.4.3 Reduce LOS

The length of stay of clinical patients has a large impact on the capacity of the inpatient clinic. The waiting times of clinical patients can thus be reduced by reducing the length of stay. The hospital aims at a length of stay of approximate 5 days, but we expect that there is a substantial group of patients who exceed this five-day limit. The hospital actively tries to reduce the length of stay by improving the scheduling of treatments during the hospitalization of a patient. Therefore, we will investigate the influence of a reduction in the lenght of stay on the service level.

3 Literature Overview

3.1 General

The operations research community is active in a relatively small field of healthcare management, although health care systems can benefit from operations research in many different ways (Carter, 2002). Modeling patient flow is considered to be vital in understanding the operation of a hospital and is therefore proved to be useful in improving the efficiency. Hence, literature in healthcare simulation and modeling is vast and is expanding at a rapid rate. This literature covers a diverse range of applications with many interacting and overlapping areas (Brailsford et al, 2009).

Over the past years, several review articles have been written on health care modeling. These articles tend to focus on a specific modeling methodology or on the use of modeling for a specific department. Modeling has especially been used for discrete parts of the hospital, such as clinics, emergency departments and operating theatres. Although there is a lot of literature on the modeling of separate medical departments, attempts to model the whole hospital are rare (Günal and Pidd, 2010). This can be explained by the fact that it is difficult to represent the complexity of hospitals in a simulation model. Appropriate simplifications of hospital activities and the appropriate level of details are the key to success. In this thesis we attempt to model a whole division of the hospital, which has not been done very often. It is therefore difficult to find literature which adresses this type of problem, so we have to adapt exisiting methods to this specific case.

3.2 Patient flow

In the current literature, many different techniques are used to model patient flow. There are mainly two type of methods, namely analytical and simulation methods. The most common theoretical methods are queueing and markov models. In our case, it is very difficult to use theoretical models because patients have to wait several days or weeks before revisiting the hospital. The existing methods are based on patient flow within one visit instead of the patient flow of several separate visits. Discrete event simulation and system dynamics are the most commonly used simulation methods. These methods are more appropriate for our problem, because it is easier to adapt those methods to specific problems. These four methods are discussed in more detail below.

3.2.1 Queueing models

Healthcare processes can be seen as queueing systems in which patients arrive, wait for service, obtain service and then depart (Fomundam and Herrmann, 2007). These processes differ in complexity and scope, but they all consist of a set of activities and procedures that patients must undergo to reveice the needed treatment. The resources in this queueing systems are the personnel and equipment required for the activities and procedures.

The advantages of queueing models is that they are simpler and require less data compared to simulation models (Green, 2006). One of the major limitations is the assumption of Poisson arrival rates. This leads to significant different outcomes compared to methods that do not assume that arrivals are equally likely throughout the day (Young, 1962). Another disadvantage is that they cannot capture all characteristics of an actual operational setting and that they provide more generic results.

3.2.2 Markov chain models

Markov and semi-Markov models can also be used to model patient flow. These models assume that sub-groups of patients are homogenous and that events occur at equally spaced intervals of time (Weiss et al, 1982). Markov models furthermore capture two types of randomness: the next destination of a patient and the length of stay in any facility are treated as random variables.

These models are especially useful for large population groups where Markov assumptions hold. For example, length of stay is assumed to be dependent on the current location and next destination. Besides that, it permits a detailed analysis of resource utilization and provides a thorough portrayal of patient flow. Limitations arise when analytic results are desired (Côté and Stein, 1999).

3.2.3 Discrete event simulation

Discrete event simulation (DES) is one of the most widely used techniques in operations research (Brailsford and Hilton, 2001) and can be used to model systems that can be viewed as a queueing network. It models the system as networks of queues and activities and changes in the state occure at discrete points of time.

Simulation has multiple advantages compared to other techniques (Brailsford and Hilton, 2001). These are its flexibility, ability to deal with variability and uncertainty and its use of graphical interfaces which facilitates comprehension by health care specialists. The disadvantage of discrete event simulation is that it can be time consuming due to large execution times. Another disadvantage is that the simulation jumps from event to event and thus skips the intervening time between events.

In this thesis, we will use discrete event simulation to model the patient flow at Erasmus MC. We choose to use DES because of its flexibility to capture all specific characteristics of the hospital.

3.2.4 System dynamics

System dynamics models a system as a series of stocks and flows (Brailsford and Hilton, 2001). In contrast to queueing models, state changes are contineous. It models the system like a contineous quantity, rather like a fluid, flowing through a system of reservoirs and tanks connected by pipes. Rates of flow are controlled by valves and fixing the rates of inflow and outflow thus determines the time spent at each reservoir.

The main difference between system dynamics and discrete event simulation is that the first is essentially deterministic while the latter is stochastic. Furthermore, system dynamics is usually used at a higher, more strategic level to get insight in the interrelations between different parts of a system.

3.3 Patient types

Creating patient types is an important aspect of simulation models. Patient types are groups of patients with similar characteristics and a similar consumption of hospital resources. This consumption is based on the length of stay and the sequence of hospital units visited. In literature, this is referred to as the patient classification problem (Isken and Rajagopalan, 2002).

Too many patient types are undesirable from a modeling perspective as it becomes unmanageable. On the other hand, too few classes makes it difficult to obtain a valid simulation which reflects the huge variation in patient flow. A balance should thus be found between modeling capability and modeling burden. In practice, expert opinions are gathered from clinicians and those patient types which are believed to provide sufficient modeling are selected. This approach might work well, but it is time consuming and cannot be used for standardization across hospital departments. Therefore, datamining techniques like clustering can be used to create patient groups with similar characteristics.

3.3.1 Diagnosis Related Groups

Diagnosis Related Groups (DRGs) are well known in healthcare literature and were created in the late 1970s to provide a method for defining the output of hospitals (Fetter, 1991)

The main objective of DRGs is to make a definition of patient types, each of which represents a relatively homogenous patient population with respect to the 'bundle' of hospital resources consumed. The set of patient definitions should be meaningful to both medical and nonmedical users as well as easy to implement in a wide range of settings. It should therefore have the following properties (Fetter et al, 1980):

- Patient groups must be medically interpretable and should thus consist of patients with homogeneous diagnostic categories.
- Groups should be defined on commonly available variables which are relevant to either the condition of the patient or the treatment process.
- There must be a manageable number of groups which are mutually exclusive and exhaustive.
- The groups must contain patients with a similar expected consumption of hospital resources.

DRGs do not make a distinction between scheduled and unscheduled patients or between the type of arrival: either through the emergency department or an elective admission. DRGs are therefore not very useful for patient flow modelling because it misses some distinctions which are important for patient flow. On the other hand, the classification is too fine for a simulation model (Isken and Rajagopalan, 2002).

3.3.2 Clustering analysis

Clustering analysis is a classification technique which assigns cases, data or objects into groups such that the items in a cluster are similar to one another and different from the items in other clusters. Clustering is a main task of explorative data mining and reveals associations, relationships, structures and patterns in masses of data.

Homogeneous groups are created based on selected characteristics. Since these characteristics are chosen by the owner, it is a convenient method to use for the creation of patient types. K-means cluster analysis is a specific clustering technique and can be used to create patient types for the purpose of patient flow simulation modeling (Isken and Rajagopalan, 2002).

The main advantage of cluster analysis relative to DRGs is that extra relevant characteristics can be added which are missing in the latter.

Since we are modeling an entire division of the hospital, it is important to keep the simulation as simple as possible. Using different patient types will lead to too much diversification and makes it harder to analyse the results. Therefore, we only make a distinction between patients who are treated at different medical departments. In this way, we have eight different patient types. Besides that, it also makes it easier to analyse the differences between the medical departments.

4 Data analysis

In this section we provide information on the data provided by Erasmus MC for the purpose of this research. First of all, we give a general description of the data and provide some general statistics. After that, we provide a more detailed analysis on the data and present the different aspects and characteristics of patient flow. At last, we construct a transition diagram to visualize patient flow and to get a clear insight in the sequence of treatments.

4.1 General information

Erasmus MC provided data of all patients from division Dijkzigt who visited the hospital during 2011. Data collection from a hospital is a sensitive process due to the personal nature of patient's treatment and medical history (Côté, 1999). For that reason, patient data is anonymised by assigning a random numeric id and by removing all personal information.

Data is provided on the three types of treatments previously determined. The hospital provided lists of all the appointments made at division Dijkzigt during 2011. For each appointment information is included about the date of the appointment, an anonymised patient number, the kind of treatment and a code for the medical department where the appointment took place.

For the polyclinical appointments, extra information is provided on the time and type of the appointment. In order to reduce the complexity of the hospital, the time and type of the appointment are not considered in this research. This does not lead to any limitations because we are only interested in the total number of appointments that can be scheduled during each day. The time and type of appointments does not add extra value to the data analysis but only leads to an unnecessary increase in the complexity of appointment scheduling.

For clinical admissions, information is provided on both the date of admission and discharge. It furthermore provides information about different parts of the hospitalization and the length of stay.

In total, this results in data of 73,336 patients. These patients made 419,857 visits to the polyclinic, 11,583 visits to the outpatient clinic and 15,115 clininal admissions during one year. These are all appointments of the eight different medical departments. By using the patient numbers and date of all the appointments, we can connect all the treatments of one patient. This information can be used to analyse the patient flow in the hospital. In the next sections we provide more details about the data per medical department.

4.2 Medical departments

In this section, we provide more information on the number of patients per medical department. Table 1 shows the number of patients for each medical department for the three types of treatments. The numbers at the top row correspond to the different medical departments as explained in Section 2.1.

The first thing that we notice is that department 8, rehabilitation medicine and physiotherapy, only works with polyclinical appointments. We furthermore notice that all departments have much more polyclinical appointments than day treatments and clinical admissions. This is rather logical because patients usually have several polyclinical appointments prior to and after a day treatment or clinical admission.

Table 1 also shows that medical department 1, internal medicine, is the largest division followed by departments 4 and 2. Department 8 also has a lot of polyclinical appointments but the number of patients of this department is much lower. This can be explained by the fact that patients usually need multiple appointments in a rather short time period.

We should also notice that clinical admissions might consist of several parts. Patients can be transferred to another department after a few days. It could also happen that patients are transferred to a department of another division. Since patients might move to another division and return to division Dijkzigt within the same clinical admission, this can be useful information. We therefore add another medical department for the clinical admissions. We will refer to this as medical department 9.

MD	1	2	3	4	5	6	7	8
Poli	147,340	44,869	10,844	60,053	38,867	21,668	13,304	82,912
Day	1,940	5,373	300	3,251	270	80	339	0
Clinic	4,672	1,527	90	242	4,583	1,220	927	0

Table 1: Number of patients per medical department

4.3 Capacity

Now that we have looked at the number of patients per medical department, it is also interesting to look at the number of patients per day. Figure 2 shows different graphs of the number of polyclinical appointments.

Sub-figure (A) in Figure 2 shows the number of appointments per day. This figure clearly shows that there is some kind of weekly pattern in the number of appointments. In order to investigate this weekly pattern we make two other graphs. Sub-figure (B) shows the number of appointments per day without weekenddays and holidays. This graph shows a much more stable line, indicating that the number of appointments is much lower during the weekend. However, there is still some variation in the number of appointments. Therefore, we also look at the number of appointments per day for each day of the week. This graph is shown in sub-figure (C). When we look at this figure, we notice that there is indeed a difference in the number of appointments at each day of the week. It shows that the number of appointments is higher on Mondays and Tuesdays and lower on Fridays.

The average number of appointments per weekday also confirm these findings. These results also hold for the number of day treatments and the number of clinical admissions. The only difference is that the number of clinical admissions is somewhat higher during the weekend compared to the number of day treatments and appointments. At the inpatient clinic, patients are usually hospitalized for several days. Therefore, many patients are still hospitalized during the weekend resulting in a higher number of patients at the inpatient clinic compared to the polyclinic and outpatient clinic.

In our simulation, the capacity of the three types of treatments for each day of the week is based on the average number of appointments during 2011. However, the average number of appointments will be lower than the actual capacity because the capacity utilization rate is currently lower than 100%. We therefore increase the average number of appointments with 25%. This percentage is based on the experience of the hospital regarding the capacity utilization rate. Tables 13, 14 and 15 in Appendix A provide information about the capacity that we use in our simulation.

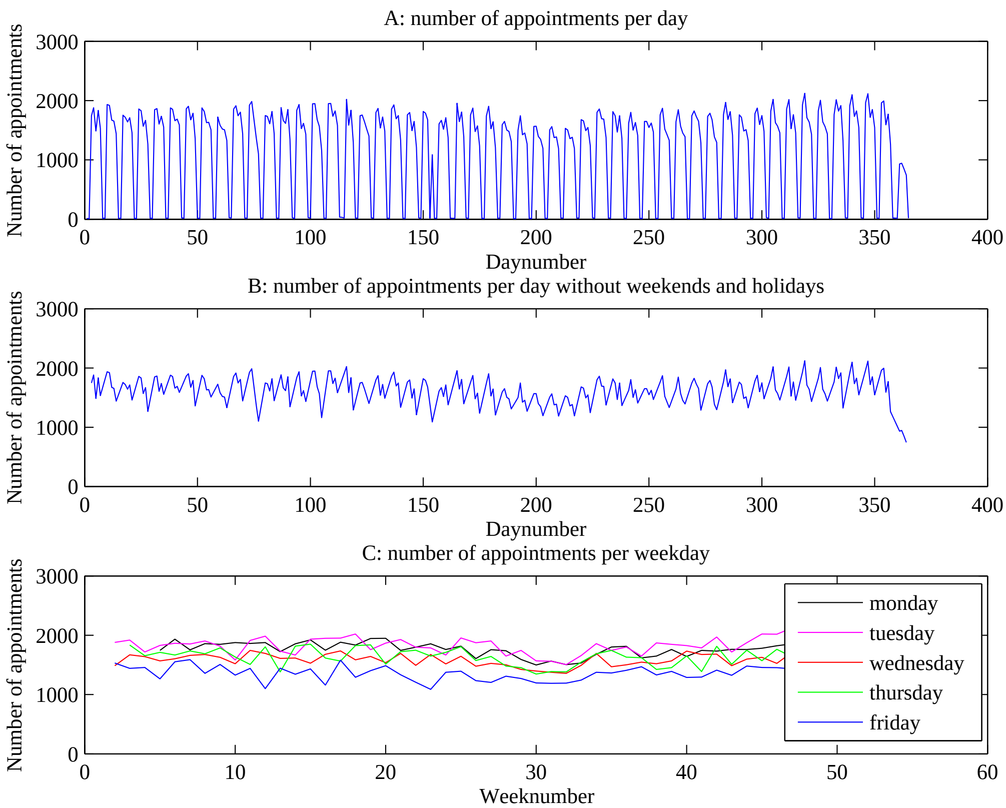

Figure 2: Number of polyclinical appointments

4.4 New Patients

In the previous section we looked at the number of appointments per day. Patients usually return to the hospital several times during the year. In order to analyse the patient flow, it is important to investigate the number of new arriving patients per day. Figure 3 shows the number of new arriving patients per day at the polyclinic. The graph shows a large number of new patients at the beginning of the year. The number of new arriving patients rapidly declines and stabilizes after a few months.

This trend can be explained by the fact that we only have data of one year. All patients visiting the hospital at the beginning of the year are thus labeled as new arriving patients. However, many of these patients are actually revisiting the hospital instead of visiting for the first time. After some months the number of new arriving patients thus stabilizes because all patiens revisiting the hospital are correctly labeled. In our simulation model we therefore use a warm-up period of 200 days.

The number of new arriving patients at the day treatment and at the outpatient clinic show a similar trend.

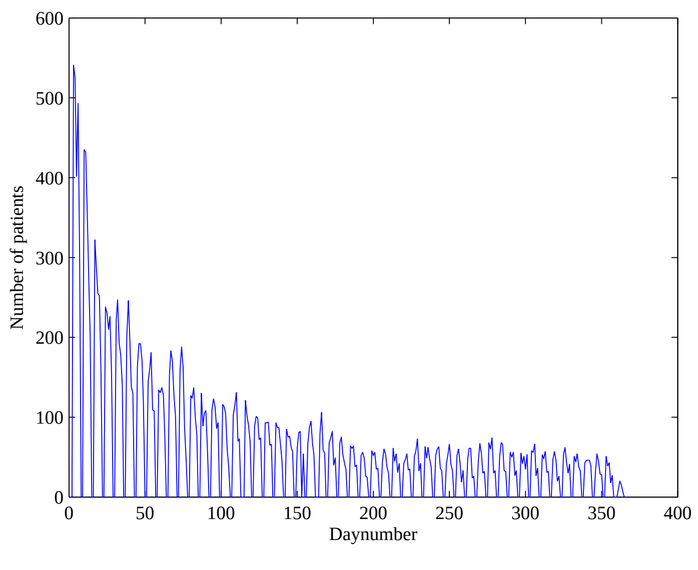

Figure 3: Number of new arriving patients

4.4.1 Distribution new patients

For the simulation, we need to determine the distribution of the number of new arriving patients per day for each treatment of the medical departments. We use the truncated normal distribution to determine the number of new arriving patient per day at the polyclinic. Figure 4 shows the fitted normal distribution. The estimate parameters of the normal distribution are given in appendix C.

The number of new patients at the outpatient and inpatient clinic are quite low. For each possible number of new patients, we therefore calculate the probability that these number of new patients arrive at one day. We then use those probabilities to determine the number of new patients per day.

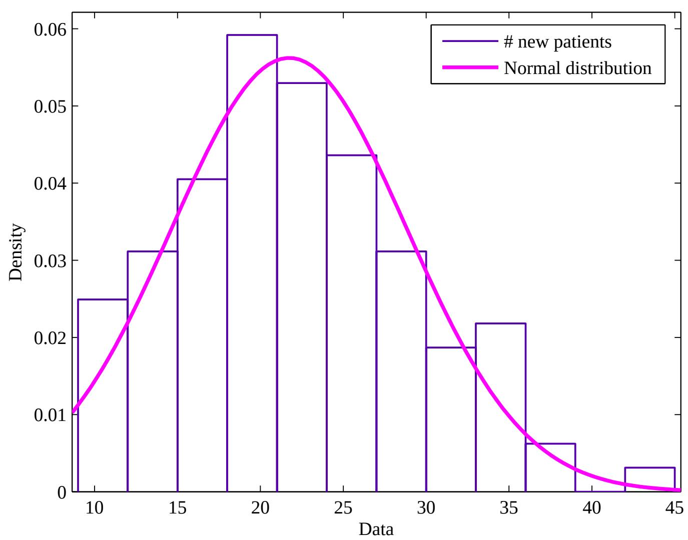

Figure 4: Distribution new arriving patients polyclinic

4.5 Length of stay

Length of stay of clinical admissions is an important issue when analysing patient flow. Reducing the length of stay of patients can lead to a large reduction in the required capacity. The hospital therefore wants to reduce the length of stay to approximate five days.

Table 2 shows the average, median and variation of the length of stay in days for the different medical departments. When we look at the average length of stay, we notice that in general it is somewhat higher than five days. Medical departments 3 and 5 have a somewhat higher average length of stay and medical department 7 has a somewhat lower average length of stay.

When we look at the variation we notice that all departments have a rather large variation in the length of stay. The medical departments 3 and 5 show by far the largest variation whereas department 7 has the smallest varation. It is thus clear that there is a lot of variation in the length of stay. The median length of stay of all medical departments is lower than 5. This is confirmed when we look at the distribution of the length of stay. Most of the patients have a relatively short stay, while some other patients stay much longer. We can thus conclude that most of the patients satisfy the five-day limit, but we must note that there are also a lot of patients who exceed this limit.

MD	1	2	3	4	5	6	7
average	5.44	5.55	6.68	5.11	6.35	5.60	4.06
variance	44.95	42.45	70.78	49.71	69.79	36.07	15.00
median	3	3	3.5	2	4	4	3

Table 2: Average length of stay in days and variance

Although we stated above that the average length of stay is approximate five or six days, this does not mean that all patients stay in the hospital for only six days. Clinical admissions might consist of different parts because patients can be transmitted to other departments. The length of stay as described above is thus the length of stay of one part of an admission. The total length of stay can therefore be much longer than five days. Almost 20 % of all clinical admissions consist of several parts with a maximum of 16 sub-admissions.

4.5.1 Distribution LOS

We also look at the distribution of the length of stay of clinical admissions. Figure 5 shows a histogram of the length of stay in days. The figure shows that most of the patients have a relatively small length of stay. However, it also shows that there are some patients who have a much longer length of stay. It thus confirms that there is a large variation in the length of stay.

The length of stay has a large impact on the required capacity. It is therefore rather important to use the right distribution for the length of stay. We use the lognormal distribution to determine the length of stay of clinical admissions. We haven chosen the lognormal distribution because this model is widely used for describing the distribution of length of stay (Marazza et al, 1998). Figure 6 shows the fitted lognormal distribution of the length of stay. The maximum likelihood estimates of the parameters are given in appendix C.

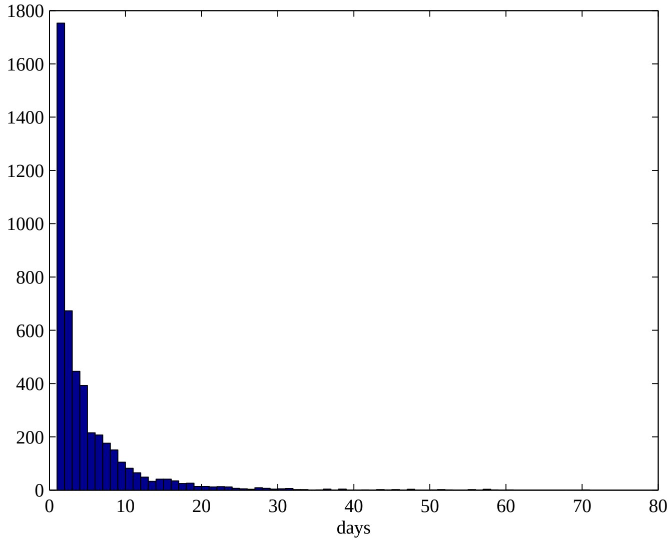

Figure 5: Histogram of the length of stay department 1

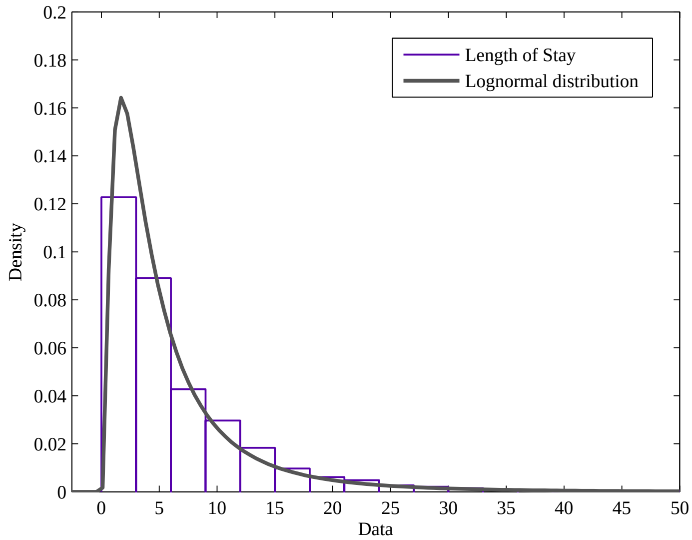

Figure 6: Distribution of the length of stay

4.6 Interarrival times

When patients visit the hospital, they usually need a follow-up appointment after a few days or weeks. The time between two appointments is an important aspect of patient flow. We refer to the time between two appointments as interarrival time.

Table 3 shows the interarrival times between the different types of treatments. We notice a few things when we look at the interarrival times between treatments. First of all, we see that the time between a polyclinical admission and the next treatment deviates between 27 and 31 days. Secondly, we notice that the time between two day treatments is somewhat longer with an average of 38 days. The time between a day treatment and a clinical admission and the time between two clinical admissions is relatively small. The average interarrival time between those treatments lies between 8 and 10 days. There is thus a small variation in the average interarrival times between the different types of treatments.

	Poli	Day	Clinic
Poli	31	30	27
Day	19	38	8
Clinic	21	17	10

Table 3: Average interarrival time in days

To get a better insight in the variation of the interarrival times, Figure 7 shows the interarrival times in days between the different appointments. Sub-figure (A) shows the interarrival times of polyclinical appointments. It shows a kind of exponential distribution with several peaks. Those peaks are located at the time intervals corresponding to a multiple of 7 days. This is a rather logical perception because patients usually have to revisit the hospital after one or multiple weeks.

A histogram of the interarrival times of the day treatments are shown in sub-figure (B). This figure does not reveal a very clear distribution, but it does show the same sort of peaks as in the top figure. Those peaks are again located at time intervals corresponding to a multiple of 7 days and especially at intervals of 14 days.

At last we look at the interarrival times of the clinical admissions in sub-figure (C). This histogram again shows an exponential distribution but the peaks are less clear. The interarrival times between the different medical departments show similar kind of distributions.

We can thus conclude that the distributions of the interarrival times cannot be easily captured in a known distribution. Since there is a lot of data on the interarrival times, we use bootstrapping to determine the interarrival times in the simulation. This will lead to a representative distribution of the simulated interarrival times.

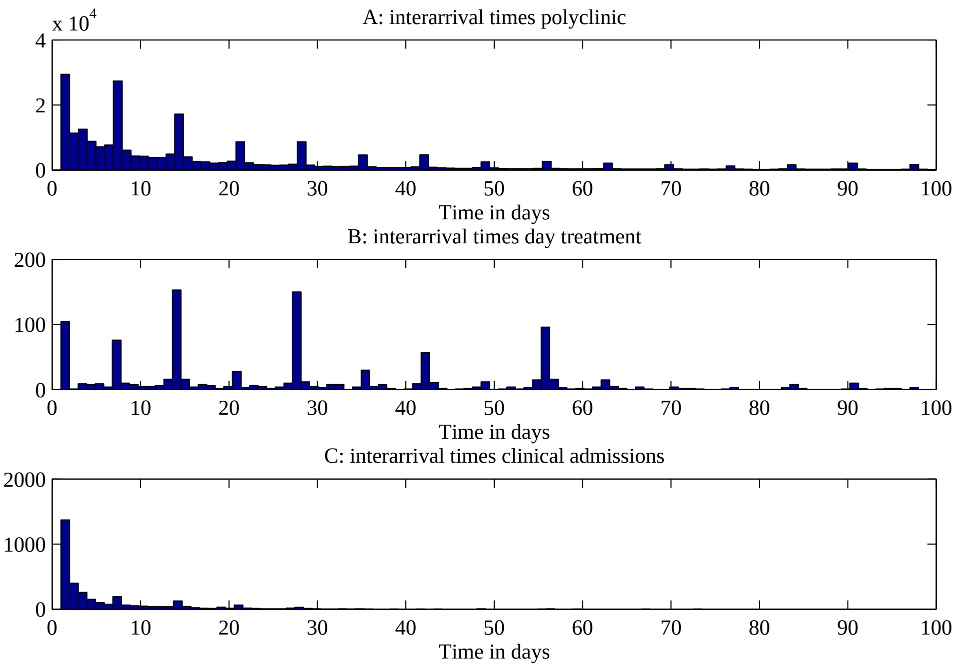

Figure 7: Histogram of the interarrival times between appointments

4.7 Transition rates

In this section we determine the transition rates between the different types of treatments and medical departments of division Dijkzigt. In the first part we construct the transition rates between the three different types of treatments. In the second part we also look at the transition rates between the different medical departments to get more information about the relationship between the medical departments.

4.7.1 Division Dijkzigt

In this section we construct a transition diagram that gives insight in the patient flow between the three different types of treatments of division Dijkzigt. We assume that patient flow can be seen as a Markov chain where patients move from one state to another. Markov chains are memoryless which means that the next state only depends on the current state and not on the sequence of events that preceded it. The next treatment of a patient therefore only depends on the current treatment of a patient. The transition rates between the three types of treatments are equal to the probability that a patient moves from one treatment to another treatment. We use the data of 2011 to determine the probability that a patient moves from one state to another state.

When a patient currently has a polyclinical appointment, the next event of the patient can either be a polyclinical appointment, day treatment, clinical admission or end of treatment. We must take into account that we only have data of one year. We thus do not know whether patients finish their treatment or need a follow-up apointment due to the lack of information about future visits. However, we need this information to determine the probability that a patient finishes its treatment after the current treatment. We therefore assume that patients finish their treatment when their last treatment was more than 2 months ago and they do not yet have a follow-up appointment.

Figure 8 shows the transition diagram of division Dijkzigt with the corresponding transition rates. These transition rates are equal to the probability that you move from one state to another. The arrows entering the three different types of treatments correspond to the probability that new patients arrive at the particular type of treatment. The arrows leaving the three treatments correspond to the probability that patients have finished their entire treatment. The other arrows show the transition rates between the different types of treatments.

Firstly, we look at the arrival rate of new patients. Almost all new patients enter the hospital through the polyclinic. This is not very surprising because patients are usually referred to the polyclinic by their general practitioner. After a consult at the polyclinic, patients can be referred to the inpatient or outpatient clinic.

Secondly, we see that patients almost never move from a day treatment to a clinical admission and vice versa. This is again rather logical because patients normally have a polyclinical appointment inbetween. The high transition rates to the polyclinic were also expected because there are much more polyclinical treatments than other treatments. Most of the patients only have appointments at the polyclinic and never visit the other clinics at all.

At last we notice a surprisingly high transition rate from a clinical admission to a clinical admission. This can be explained by the fact that clinical admissions sometimes consist of several parts. These parts are all seen as different clinical admissions resulting in a relatively high transition rate. Analysing the transition diagram of the three different types of treatments thus does not lead to new insights.

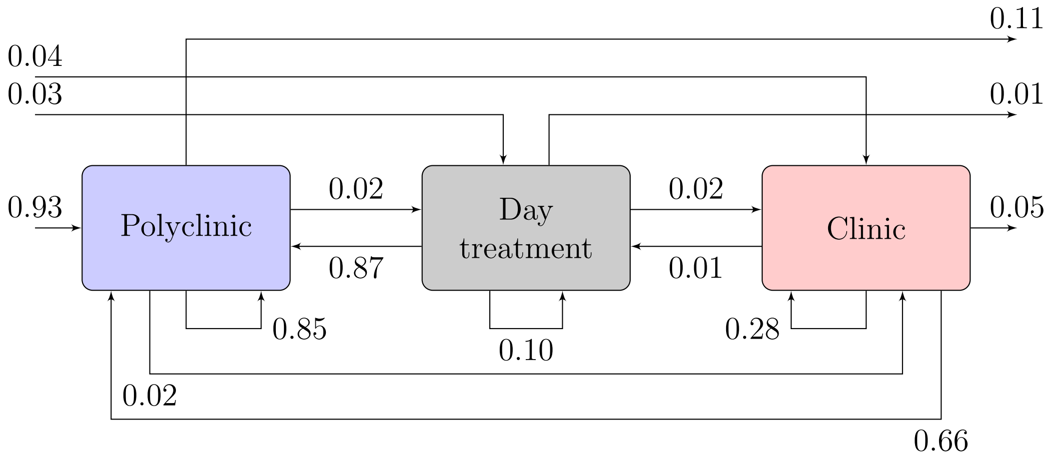

Figure 8: Example of transition diagram division Dijkzigt

4.7.2 Medical departments

In the previous section we looked at the transition diagram of division Dijkzigt. However, this division consists of multiple medical departments. We therefore look at the transition rates between the different medical departments to get a better insight in the relationship between those departments. In the last section, we assumed that patients finish their treatment when the last visit was more than two months ago and they do not yet have a follow-up appointment. We refer to this as the exit threshold. An exit threshold of 60 days thus means that a patient finishes its treatment when the last treatment was more than 60 days ago and the patient does not yet have a follow-up appointment. However, the exit threshold is actually different for the different types of treatments at each medical department. This exit threshold influences the total number of appointments during one year and also influences the division of appointments across the medical departments. We use trial and error to determine the exact exit thresholds of the different medical departments. For all types of treatments of all medical departments, we started with a threshold value of 30 days. We then increase the threshold values and compare the number of appointments in the data with the number of appointments in the simulation. If the number of appointments in the simulation is lower than the actual number of appointments, we further increase the threshold value. When the simulated number of appointments cannot get closer to the actual number of appointments, we have found the right threshold value. The exit threshold are given in Table 4

MD	1	2	3	4	5	6	7	8
Poli	101	75	55	105	77	70	95	15
Day	78	75	77	75	76	70	75	-
Clinic	78	75	80	75	72	73	74	-

Table 4: Exit thresholds in days of the treatments at each department

In contrast to the knowledge about the relationship between the different types of treatments, the management does not have any information about the relationship between the different medical departments. Figure 9 shows the transition diagram of division Dijkzigt. This is a simplified version of the transition diagram because it does not show all the arcs. Arcs actually exist between all types of treatments of all medical departments. The corresponding transition rates are given in the transition probability matrices in appendix B. We consider the following transition rates:

R_{ij} - polyclinic i to polyclinic j
S_{ij} - polyclinic i to day treatment j
T_{ij} - polyclinic i to clinic j

U_{ij} - day treatment i to polyclinic j
V_{ij} - day treatment i to day treatment j
W_{ij} - day treatment i to clinic j

X_{ij} - clinic i to polyclinic j
Y_{ij} - clinic i to day treatment j
Z_{ij} - clinic i to clinic j

The transition rates clearly show that patients are mostly treated at only one medical department. This can be concluded from the fact that the transition rates between treatments of the same medical department are relatively high while transition rates between different medical departments are almost negligible. It thus does not happen very often that a patient moves from one medical department to another medical department, although it is possible.

We already mentioned that the transition rates between most of the medical departments are almost negligible. There is one exception because the transition rate from medical department 3 to department 1 is relatively high compared to the other transitions rates. Therefore, we assume that there might be some connection between rheumatology and internal medicine. Overall, the small transition rates between different medical departments thus confirm that it is a good choice to use various departments.

Furthermore, the same conclusions can be drawn as in the previous section.

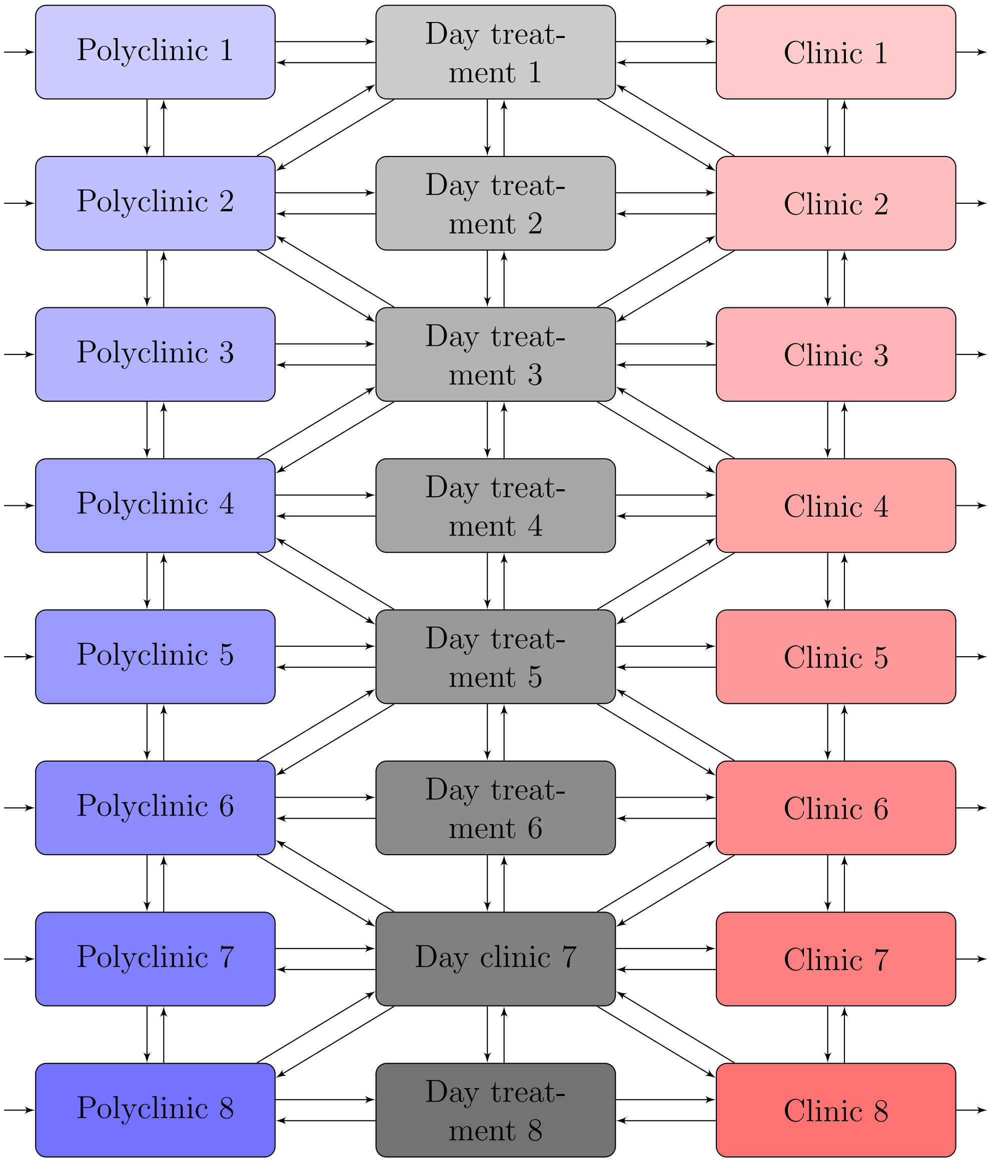

Figure 9: Transition diagram division Dijkzigt

5 Simulation

In this section, we introduce the simulation model that is used to analyse the patient flow at Erasmus MC. Firstly, the general aspects of the simulation model are explained. After that, more details on the simulation are given as well as the assumptions that are made. At last, we give a validation of our simulation model.

5.1 Simulation model

5.1.1 General idea

Patient flow in the Erasmus MC is modelled using discrete event simulation. This means that the hospital is represented as a chronical sequence of treatments and each treatment changes the state of the hospital. In this section we discuss the main aspects of the simulation model.

The simulation model simulates the patient flow in the hospital day by day. Since patients are able to move from one medical department to another medical department, patients of all eight departments are included in the same simulation model. We distinguish two types of patients, namely patients who are revisiting the hospital and newly admitted patients.

At the beginning of each day, we first look at the patients who are revisiting the hospital. We will look at the patients of all medical departments. For each patient revisiting the hospital, we determine whether this patient has finished the treatment or whether the patient requires another follow-up appointment. If the patient finished the treatment, we move on to the next patient. Otherwise, the next type of treatment and date is determined. The next treatment might take place at another medical department than the department where the patient is currently treated. Now that the date and place of the next treatment is determined, we schedule the follow-up appointment.

If all revisiting patients are either discharged or provided with a new appointment, we move on to the new patients. Each day, patients are referred to the different medical departments of the hospital by their general practitioner. These new patients need an appointment at the hospital and thus need to be scheduled on the first available day.

If all patients (re)visiting the hospital are processed, we move on to the next day. Since patient flow in a hospital is an infinite process, the simulation is stopped after a predetermined number of days. In our case, we run the simulation for 565 days. We have seen in Figure 3 in Section 4.4 that the number of new arriving patients stabilizes after 200 days. We therefore use the first 200 days as warm-up period and the next 365 days to analyse the patient flow. At the end of the year, there will be patients who need a follow-up appointment which cannot be scheduled during the current year. There will also be patients who need a follow-up appointment during the next year. It is important to decide how to cope with these patients because this decision will have influence on the performance measure. Since we only have received data of one year, these appointments are not included in the data. We therffake place in the current year. In this way, we are able to compare the simulation results with the data. The waiting time of these patients is thus ignored which means that the waiting time in our simulation might be slightly shorter than the actual waiting time.

A schematic overview of the simulation is shown in Figure 10. In this section, only the general idea behind the simulation is explained. More details on the seperate parts of the simulation are given in the following subsections.

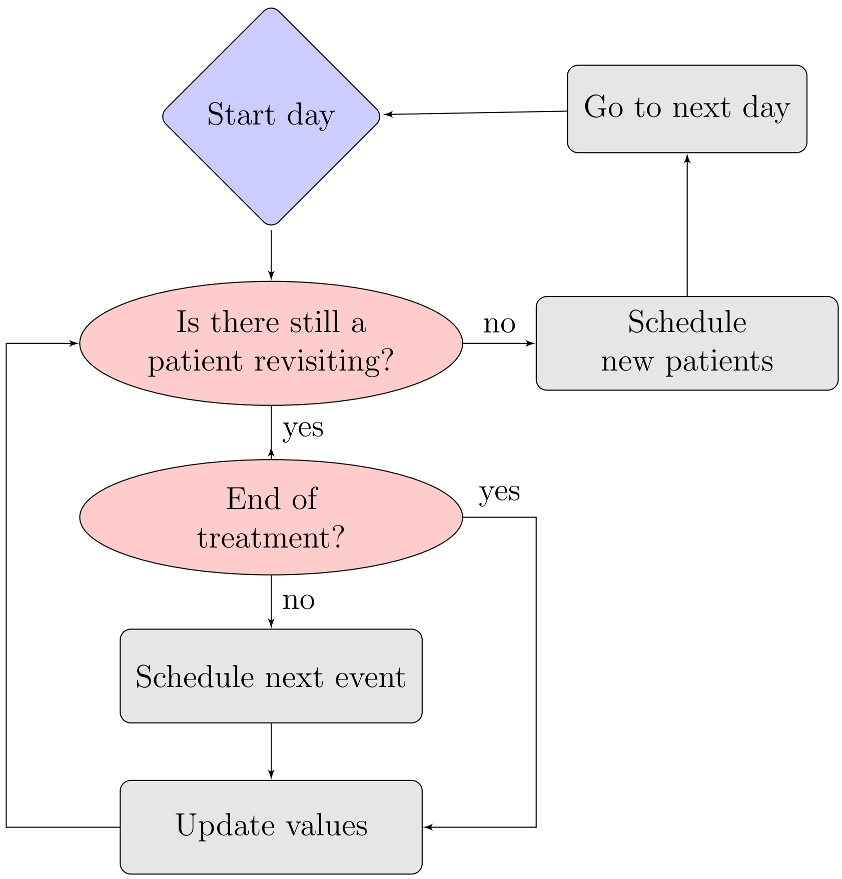

Figure 10: Schematic overview of the simulation

5.1.2 New patients

As explained before, the simulation model checks each day whether there are new patients admitted to the hospital. In reality, new patients are usually sent to the hospital by their general practitioner. This practitioner contacts the hospital which then schedules an appointment for the patient.

The number of new patients per day is predetermined for each type of treatment of each medical department. If possible, these patients are immediately scheduled on the same day of their reference. If this is not possible due to limited capacity, an appointment will be scheduled on the first available day.

5.1.3 Scheduling treatments

When patients visit the hospital, they either finish their treatment or need a follow-up appointment. If the patient finishes his treatment, he will not return to the hospital anymore and no further actions are taken. If the patient does not finish his treatment, the next treatment of this patient will be determined. The next treatment of a patient is determined based on the current department and treatment of this patient and the flowchart made in Section 4. We consider the transition diagram with the different medical departments as shown in Figure 9. Patients can thus be transferred from one medical department to another department.

After determining the next treatment of a patient, we need to schedule this appointment. The time of the next appointment depends on both the current and next type of treatment as well as the medical departments where both treatments take place. We need this information because we have seen in Table 3 in Section 4.6 that the interarrival time between different types of treatments and departments fluctuates. We then use bootstrapping to determine the time between both treatments, resulting in the date of the next appointment. Now that we know the date of the next treatment, we start scheduling this treatment. We need to take a few things into account when scheduling appointments.

First of all, we assume that appointments are generally not scheduled during the weekend. This is a reasonable assumption because the data shows that there are only a few appointments during the weekend. When scheduling the next treatment of a patient, we thus need to check whether the treatment takes place during the weekend. If the treatment takes place on a Sunday, we move this treatment to Monday. If a polyclinic treatment or a day treatment is set on a Saturday, the treatment is moved to Friday. We choose to move those patients to Friday because this will spread the patients over two days. Otherwise, all patients are rescheduled to only one day resulting in a high peak on Mondays. If the patient is currently treated on Friday and the next appointment is set on the following day, it is not possible to move the appointment to Friday. In that case, the next appointment of the patient would be on the same day. If this happens, we move the appointment to Monday. Clinical appointments are moved to Monday because those appointments last for more than one day. In our simulation, less than 3% of the appointments were rescheduled because they were originally planned during the weekend. This assumption thus does not lead to a very high increase in the number of appointments on Friday and Monday.

Secondly, we need to check whether there is enough capacity on the day of the next appointment. If there is enough capacity, the appointment is scheduled on that day. If there is not enough capacity, the appointment is rescheduled on the first available day. This is in line with the way in which appointments are made at Erasmus MC. A new appointment is scheduled when the patient is visiting the hospital. When rescheduling an appointment, we again take into account that appointments do not take place during the weekend.
A schematic overview of scheduling appointments is shown in Figure 11.

5.1.4 Updating values

The last part of the simulation that needs more explanation is the part where the values are updated. Since we use discrete event simulation there are some event lists that need to be updated. Besides that, we also have to keep track of several other statistics in order to calculate some measurement values.

Firstly, we look at the event lists that are used in the simulation. The event lists used are lists of patients who are revisiting the different departments at each day and lists of the new arriving patients per day. For the inpatient clinics, there are also event lists of the departing patients per day per medical department. There are no departure event lists for the polyclinics and outpatient clinics because patients who visit these clinics always leave within one day. With these event lists we can keep track of the patients.

Secondly, we update several statistics which can be used to calculate some measurement values. Those statistics include the total number of patients per department, the total nuber of patients who have to wait per department and the waiting time of patients per department. With those statistics we can calculate the performance measurements used to determine the service level.

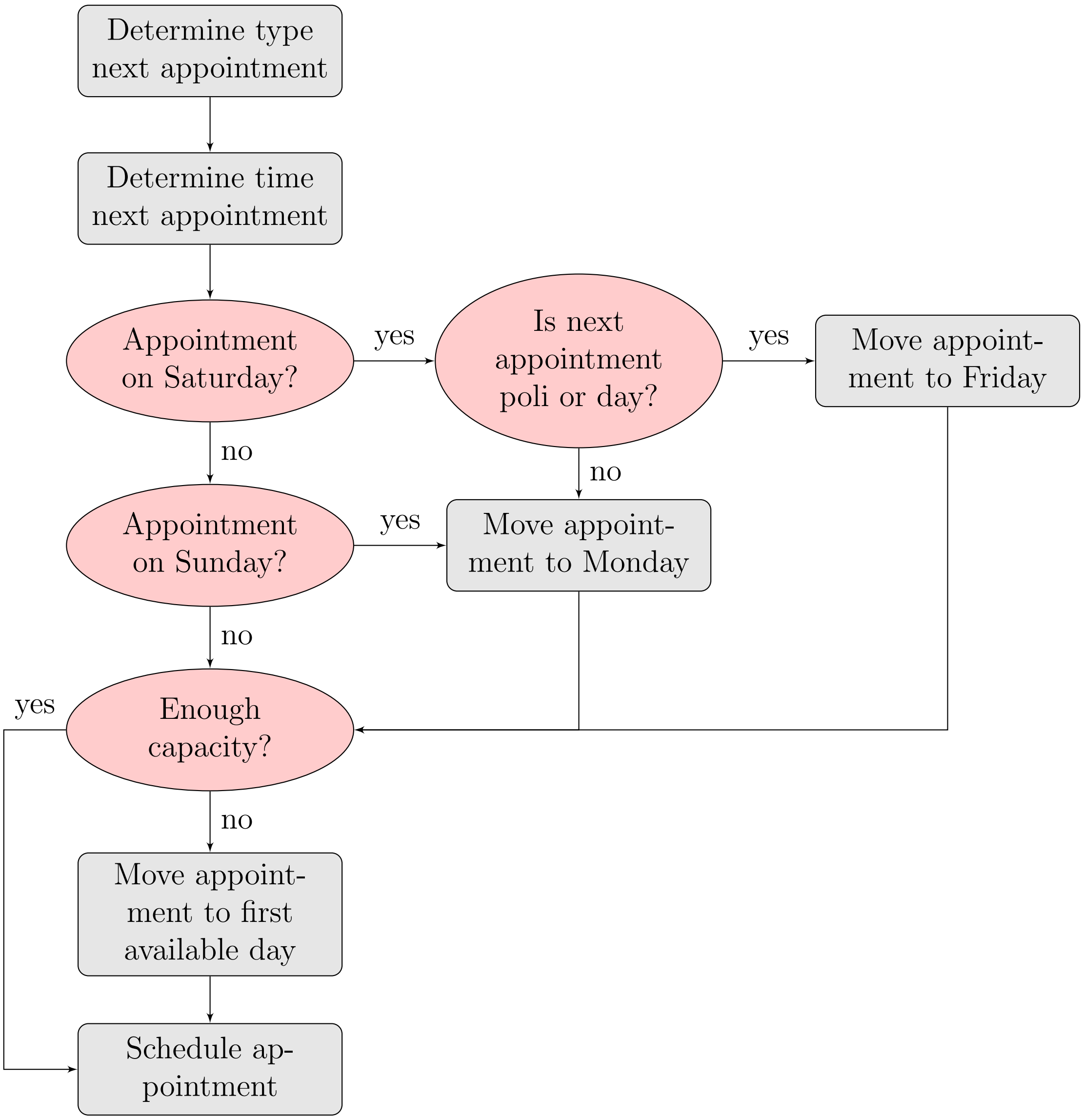

Figure 11: Schematic overview of appointment scheduling

5.2 Assumptions

Representing the complexity of a hospital in a simulation model is rather difficult. It is therefore essential to use appropriate simplifications of the different hospital activities and to use the appropriate level of detail. In order to reach these simplifications, many assumptions have to be made. We have made assumptions regarding the capacity of the treatments, the scheduling of patients and the determination of follow-up appointments. In this section we provide more information about these assumptions.

5.2.1 Capacity

The capacity of the different types of treatments of the different departments in the hospital remains quiet uncertain. Therefore, we make some assumptions regarding the capacity of the different types of treatments. First of all, the capacity of the three treatments for each day of the week is based on the average utility during 2011. Since this utility will be lower than the actual capacity, we increase these values with 25% as explained in Secion 4.3. We also assume that the capacity at each day of the week remains constant throughout the year. In reality, there are small fluctuations of the capacity due to illness and holidays of personnel. However, it is reasonable to assume a constant capacity since these are only small fluctuations.

Data of 2011, given in Figure 2, shows that the capacity is lower during the weekends for all types of treatments. There will be no capacity at the polyclinics and outpatient clinics during the weekend. The only exception is the polyclinic at medical department 8, rehabilitation medicine and physiotherapy, which has a small capacity during the weekend. This department regularly treats patients who need to be seen every day, resulting in a low capacity during the weekend. For the inpatient clinic, this works rather different as patients are usually hospitalized for multiple days. Therefore, there is a large probability that patients are still hospitalized during the weekend. The capacity of the inpatient clinic during the weekend will thus be higher than the other clinics, but still lower than the capacity during weekdays.

Tables 13, 14 and 15 in Appendix A provide information about the capacity that we use in our simulation.

5.2.2 Follow-up appointments

In order to determine the next type of treatment of a patient, the flow chart made in Section 4.7.2 will be used. A random number is drawn from the uniform distribution and the next treatment is then determined based on the probabilities of the flow chart and the current treatment. The medical department at which the treatment takes place is thus determined at the same time. This flow chart is based on the data of 2011.

5.2.3 Scheduling

For the scheduling of patients, many assumptions are made. Firstly, we explain some general assumptions regarding the scheduling of appointments. After that, we consider the scheduling of new patients who visit the hospital and the scheduling of follow-up appointments.

First of all, we assume that appointments are generally not scheduled during the weekend. Secondly, we assume that the length of stay of clinical patients is predetermined. A clinical admission is scheduled when there is enough capacity during each day of the stay. If there is not enough capacity, the appointment is scheduled on the first available date at which there is enough capacity for each day of the stay. A patient thus needs to wait for his appointment until there is enough capacity during his entire stay. We assume that patients have unlimited patience and thus wait until there is enough capacity. This might not be a very realistic assumptions, but there is no information on the number of refused or leaving patients.

5.3 Validation

In order to validate our simulation model, we compare the results of our simulation with the data. We run our simulation ten times and compare the average number of patients in the simulation with the actual number of patients during 2011.

First of all, we look at the 95% confidence interval of the total number of appointments of the different types of treatments of all medical departments. The 95% confidence interval of the total number of polyclinical appointments in one year is between the lower endpoint 415,165 and the upper endpoint 421,983 appointments. The 95% confidence interval of the total number of day treatments is (11,320;11,771) and of clinical admissions is (14,942;15,513). In 2011, there were 419,857 visits to the polyclinic, 11,583 visits to the outpatient clinic and 15,115 clininal admissions. We can thus conclude that the total number of treatments in the simulation are similar to the number of treatments during 2011.

We can also split the total number of appointments into the different medical departments. Table 5 shows the number of patients for each medical department of the different types of treatments. The number of appointments per medical department in 2011 are given in Table 1 in Section 4.2. On first sight, the number of appointments in the simulation seem to be similar to the number of appointments in the data.

We therefore also look at the percentual difference between the number of appointments in the simulation and in the data. Table 6 shows the absolute percentual difference between the number of appointments. Many of the departments actually have an absolute difference in the number of appointments of less than 1%. Almost all departments have an absolute difference below 5% except for the polyclinic and inpatient clinic of medical department 3. Those clinics have an absolute difference of respectively 5.68 and 11%. A difference in the number of appointments of 11% might seem rather high. However, it can be explained by the fact that this clinic treats less than 100 patients during a year. A small reduction in the number of patients thus leads to a high percentual change.

Overall, we can conclude that the number of appointments in the simulation are similar to the number of appointments in 2011. There are some minor changes in the number of appointments but this is limited to less than 5% for most medical departments. It is actually likely that there is a slight fluctuation in the number of appointments per year. If we would compare the number of appointments in 2010 with the number of appointments in 2011 we would find similar deviations.

Based on the validation described in this section, we conclude that the simulation results will be similar to the real world situation in 2011.

MD	1	2	3	4	5	6	7	8
Poli	146,076	44,941	11,460	60,551	39,208	22,182	13,317	82,694
Day	1,879	5,206	312	3,332	265	83	324	0
Clinic	4,673	1,525	80	251	4,643	1,260	959	0

Table 5: Number of appointments per medical department

MD	1	2	3	4	5	6	7	8
Poli	0.86	0.17	5.68	0.83	0.88	2.38	0.10	0.26
Day	3.15	3.11	4.03	2.51	1.78	4.00	4.51	-
Clinic	0.03	0.11	11.00	3.93	1.32	3.30	3.47	-

Table 6: Absolute percentual difference between the number of appointments in the simulation and the number of appointments in the data

6 Results

In this section we present the results of the simulation. We first show the results when using the current capacity and determine the current service level. Secondly, we investigate the service level in the future situation with reduced capacity. At last, we propose several options that might help to increase the service level and investigate the effectiveness of these solutions.

6.1 Current service level

In this section we discuss the results of the simulation of division Dijkzigt with the current capacity. We look at the results of the simulation of one year and repeat this simulation ten times. When analysing the results, the average value of the different parameters are considered. We determine the current service level using the three performance measures.

6.1.1 S_1: Capacity utilization rate

In this section we look at S_1 given in formula (1) in Section 2.1. The capacity utilization rate gives information about the relationship between the available capacity and the capacity currently being used.

Figure 12 shows the utilization rate of the different types of treatments. Department 8 is not included because this department only has a polyclinic. When we look at this figure, we notice that the utilization rate of polyclinical treatments lies around 80%. Only medical department 3 has a somewhat higher utilization rate whereas the other departments have slightly lower capacity utilization rate. The capacity utilization rate of day treatments also lies around 80%. The only exception is medical department 6, which has a lower utilization rate of 65%. At last, we look at the utilization rate of clinical admissions. The figure shows a generally higher utilization rate between 80% and 90%. Only medical department 3 has a lower utilization rate of 75%.

We already mentioned in Section 2.1 that the hospital aims at a capacity utilization rate of at least 80%. Generally, the medical departments meet this requirement set by the hospital. There are only a few clinics that do not meet this 80% limit.

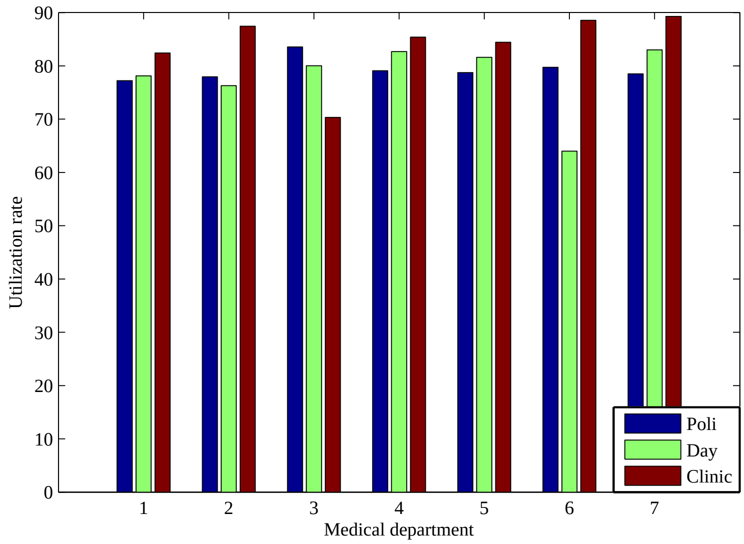

Figure 12: Utilization rate of the different medical departments

6.1.2 S_2: Percentage of waiting patients

In this section we look at S_2 given in formula (2) in Section 2.1. This performance measure provides information about the percentage of patients who need to wait for their next appointment. Tables 7 to 9 show the percentage of patients that have to wait at least 1 to 5 days.

We first look at the waiting times of the polyclinical treatments. The first thing that we notice is that there is a small percentage of patients who have to wait at least 1 day. This holds for all medical departments and the percentage of waiting patients deviates between 3% and 17%. This might seem contradictory becasue we already concluded that the capacity utilization rate lies below 100%. Normally, we would expect almost no waiting times with such a low capacity utilization rate. In this case, it works rather different because patients have to revisit the hospital after a certain amount of days. It might thus happen that there is ample capacity between the two visits, while there is no capacity at the moment an appointment is needed. This results in a relatively high percentage of patients who have to wait one day for their appointment. However, for most of the patients an one-day delay in their next appointment does not lead to a decrease in the quality of care.

We furthermore notice that the waiting times are relatively short. There are no patients at medical departments 1, 2, 5 and 8 who have to wait more than one day. The other medical departments only have a small percentage of patients who have a waiting time of at most four days. Less than 10% of the patients has to wait more than one day at these medical departments.

Secondly, Table 8 shows the percentage of patients who have to wait for a day treatment. We immediately notice that the percentage of patients who have to wait one or several days for their appointment are much higher compared to the waiting times at polyclinics. At medical departments 5, 6 and 7 almost 70% of the patients have to wait at least one day. Departments 1, 2 and 4 perform rather good, less than 15% of the patients have to wait more than 2 days. The percentage of patients who have to wait several days is much higher at the other medical departments. Up to 40% of the patients has to wait more than 5 days for a treatment at department 7.

The impact of waiting times on patients are rather difficult to interpret due to the variety in the progress of patients diseases. Chronical patients who visit the hospital several times a year are generally not affected by a few days waiting time. Those patients usually have to revisit the hospital after several months, so a delay of several days is negligible. For patients who have more acute diseases and who have to revisit the hospital after several days, a small delay can already be rather worrisome.

However, we do not have any information about the acuteness of patients diseases. In reality, only the treating pysician knows which patients can or can not wait for their next appointment due to the nature of their illness. Patients who can not wait will be treated at the required date, even if there is no capacity available. However, the number of patients who can not wait for their next appointment are negligible. We therefore assume that the current waiting times are reasonable and do not lead to a detoriation of the patient's disease.

Table 9 shows the waiting times for clinical admissions. Medical department 1 and 5 perform very good, less than 10% of the patients have to wait more than one day. The other departments have much more waiting patients with percentages ranging between 29 and 77 for a waiting time of at least one day. There are also much more patients who have to wait several days for their next appointment at these departments. Up to 45% of the patients have to wait more than 5 days for a treatment at department 3. This seems rather contradictory because the utilization rate of this department is rather low. This can be explained by the fact that the length of stay of clinical admissions at department 3 is relatively high compared to the other departments. Scheduling patients is then harder because capacity is required during each day. This leads to higher waiting times and a lower utilization rate.

MD	1	2	3	4	5	6	7	8
1 day	4	6	15	3	3	11	17	9
2 days	0	0	1	1	0	3	6	0
3 days	0	0	0	1	0	2	4	0
4 days	0	0	0	0	0	0	2	0
5 days	0	0	0	0	0	0	0	0

Table 7: Percentage of patients who have to wait at least 1 to 5 days for a policlinical treatment at each medical department (MD)

MD	1	2	3	4	5	6	7
1 day	12	6	48	32	68	64	60
2 days	5	2	32	12	58	48	51
3 days	3	1	23	5	49	39	46
4 days	1	0	18	3	38	32	42
5 days	1	0	15	2	25	9	39

Table 8: Percentage of patients who have to wait at least 1 to 5 days for a day treatment at medical department (MD)

MD	1	2	3	4	5	6	7
1 day	5	29	77	58	7	30	43
2 days	2	24	63	53	4	25	38
3 days	1	20	55	49	2	20	33
4 days	0	16	49	46	2	15	29
5 days	0	13	45	44	1	12	24

Table 9: Percentage of patients who have to wait at least 1 to 5 days for a clinical admission at each medical department (MD)

6.1.3 S_3: Average waiting time

Now, we look at performance measure S_3 given in formula (3) in Section 2.1. The waiting time refers to the number of workdays between the moment an appointment is needed and the moment of the appointment itself as explained in Section 2.3. Weekenddays are not included in the waiting time, so a waiting time of five days corresponds to an one week delay of the appointment. The average waiting time in weekdays of all medical departments are shown in Figure 13.

The average waiting time of polyclinical appointments is less than one day for every medical department and is thus negligible. This is in line with our expectation, because we already noticed that only a small percentage of patients have a waiting time of more than one day.

The average waiting times of day treatments and clinical admissions are also relatively low for most of the medical departments. The average waiting time is less than 4 days, except for day treatments at medical department 5 and 7 and clinical admissions at department 3 and 4. The waiting times of day treatments at department 5 and 7 are respectively 4.9 and 7.3 days.

The waiting time for clinical admissions of department 3 and 4 are much higher with an average of 18.8 and 8.4 weekdays. However, this is in line with the previous results because those departments also have a high percentage of patients who have to wait more than 5 days for their next clinical admission. Although we did expect a higher waiting time for those departments, we did not expect an average waiting time of almost 19 days. This high waiting time can be explained by the fact that there are several patients who have to wait much longer than one week, thus resulting in a large increase in the average waiting time.

6.1.4 Conclusion

Since we have determined all the performance measures using discrete event simulation, we now have information about the current service level. The capacity utilization rate lies around 80% for most medical departments of both polyclinics and outpatient clinics. The utilization rate of inpatient clinics is somewhat higher and lies between 80% and 90%. The actual capacity utilization rate during the past years was approximately 80%. We can thus conclude that the simulation leads to similar results.

The percentage of patients who have to wait for their next polyclinical appointment is rather low. Less than 20% of the patients have to wait one day and less than 10% of the patients have to wait several days. The percentage of patients who have to wait for a day treatment is much higher. Especially departments 5, 6 and 7 have a high percentage of waiting patients of up to 68%. Less than 10% of the patients have to wait for a clinical admission at the inpatient clinic of departments 1 and 5. The percentage of waiting patients at the other medical departments are much higher with percentages ranging between 12 and 77%.

The last performance measures is the average waiting time of patients. The waiting time for a polyclinical appointment is negligible at all medical departments. The average waiting time of day treatments and clinical admissions is less than 10 days for all medical departments. The only exception is the waiting time for a clinical admission at department 3. On average, patients have to wait almost 19 days for an appointment at this clinic because there are many patients who are hospitalized for a relatively long period.

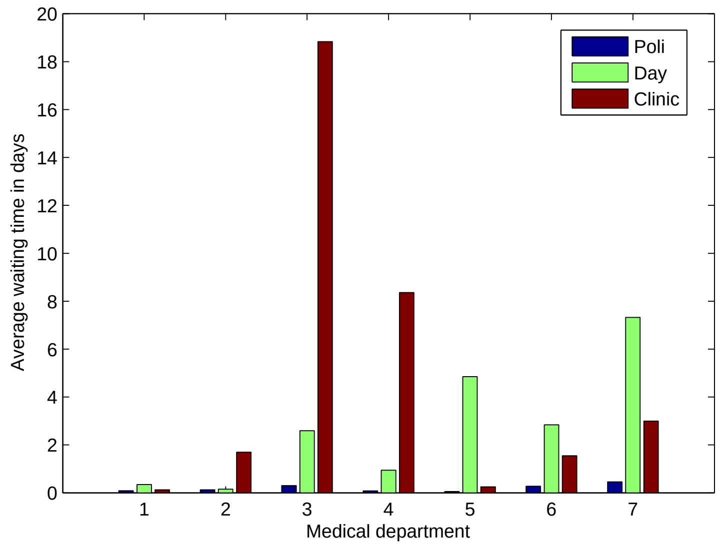

Figure 13: Average waiting times of patients

6.2 Future service level

In a few years time, the hospital moves to another building with a lower capacity. In this section we analyse the impact of this capacity reduction on the service level of the hospital. In order to determine the future service level, we decrease the capacity of all typs of treatments at all medical departments with 30% in the simulation settings. The other settings remain unchanged.

Before determining the performance measures, we look at the total number of appointments in the future situation with reduced capacity. In one year there are on average 374,558 policlinical treatments, 10,148 day treatments and 12,331 clinical admissions. When we compare the number of appointments in the future situation with the number of appointments in the current situation given in Section 5.3, we conclude that the total number of appointments decreases. This can be explained by the fact that the waiting times will increase due to limited capacity. Therefore, appointments cannot be scheduled during the current year but will be scheduled during the next year, resulting in a lower number of appointments. The number of appointments at the polyclinic and outpatient clinic decrease with 11% whereas the number of appointments at the inpatient clinic decrease with 20%. A 30% capacity reduction thus leads to a lower reduction in the number of appointments. This is in line with the previous results, because we already noticed in Section 6.1.1 that the capacity utilization rate was below 100%.

6.2.1 S_1: Capacity utilization rate

We now look at performance measure S_1, the capacity utilization rate. Since the capacity of the medical departments is reduced, we expect the utilization rate to increase. Figure 14 shows the capacity utilization rate in the future situation.

We indeed notice a large increase in the utilization rate. The capacity utilization rate of polyclinics lies between 98 and 100%. The utilization rate of inpatients clinics also lies between 98 and 100%, except for medical departments 5 and 6. These departments have a capacity utilization rate of respectively 91% and 84%. The utilization rate of inpatient clinics lies between 89 and 97%. In Section 6.1.1 we noticed that the current capacity utilization rate lies between 80 and 90%. The utilization rate of inpatient clinics thus shows the smallest increase. Compared to the utilization rate of polyclinics and outpatient clinics, the inpatient clinic has a relatively low utilization rate. At the inpatient clinic, patients are hospitalized for several days. Patients are therefore only hospitalized if there is enough capacity during each day of the stay. It can therefore happen that there are patients who need to be hospitalized for three days while there is capacity during only two days. In that case, the patient can not be hospitalized and the capacity remains unused. This discrepancy between the available and required capacity thus leads to a lower capacity utilization rate.

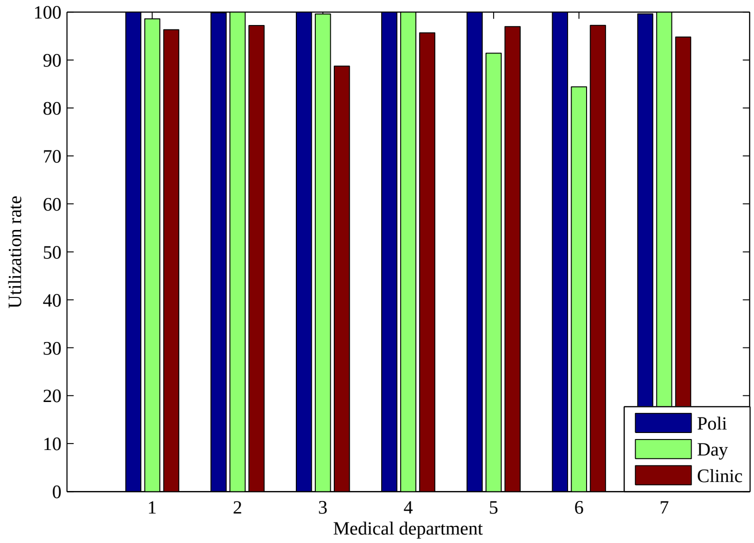

Figure 14: Utilization rate of the different medical departments

6.2.2 S_2: Percentage of waiting patients

We also look at performance measure S_2, the percentage of patients who have to wait at least a certain amount of days for their next appointment. These percentages are given in Tables 10, 11 and 12. We immediately notice a large increase in the percentage of patients who have to wait for a polyclinical appointment. In the current situation less than 20% of the patients have to wait one day and less than 10% of the patients have to wait several days. Table 10 shows that the percentage of patients who have to wait one day lies around 70% in the future situation. This is a large increase in the percentage of waiting patients and thus leads to a decrease in the quality of care.

The same conclusions can be drawn for the outpatient and inpatient clinics. The percentage of patients who have to wait at least one day are all higher than 50%. Besides that, the percentage of waiting patients at all medical departments are increased compared to the current situation. The percentage of patients who have to wait more than one week for a day treatment or clinical admission is higher than 50% for most medical departments. These are seriously high percentages and might result in a lower quality of care. We can thus conclude that the service level declines when the capacity is reduced because the number of waiting patients increases with approximately 50%.

MD	1	2	3	4	5	6	7	8
1 day	67	73	75	72	72	69	66	75
2 days	64	70	72	70	70	67	64	70
3 days	60	66	69	68	67	64	61	63
4 days	57	63	66	66	65	62	59	56
5 days	54	60	63	64	62	60	57	46

Table 10: Percentage of patients who have to wait at least 1 to 5 days for a day treatment for each medical department

MD	1	2	3	4	5	6	7
1 day	72	58	51	84	91	70	70
2 days	69	55	37	80	87	58	64
3 days	67	52	29	79	84	51	61
4 days	65	49	25	77	81	46	58
5 days	63	46	22	75	78	27	56

Table 11: Percentage of patients who have to wait at least 1 to 5 days for a day treatment for each medical department

MD	1	2	3	4	5	6	7
1 day	77	82	79	74	79	79	82
2 days	75	80	71	70	78	77	81
3 days	72	79	66	67	76	75	79
4 days	70	77	61	65	74	73	77
5 days	67	74	57	62	72	71	75

Table 12: Percentage of patients who have to wait at least 1 to 5 days for a clinical admission for each medical department

6.2.3 S_3: Average waiting time

At last, we also look at the average waiting time of patients who have to wait for their next appointment. Figure 15 clearly shows that the waiting times drastically increase when the capacity is reduced.

In Section 6.1.3 we saw that the average waiting time of polyclinics was negligible. Figure 15 shows that the average waiting time of polyclinics in the future situation lies between 7 and 12 days. This is a rather large increase in the average waiting time.

The waiting time of day treatments at medical departments 3 and 6 remains below 5 days. The waiting time of the other medical departments are all below 20 days, except for department 5 which has an average waiting time of almost 34 days. This is an extremely high waiting time, resulting in a large decrease in the service level.

At the inpatient clinic, waiting times also increase compared to the current situation. The average waiting time now lies between 13 and 22 days. Since these are average waiting times, this means that there is also a group of patients who have to wait several months for their next appointment.

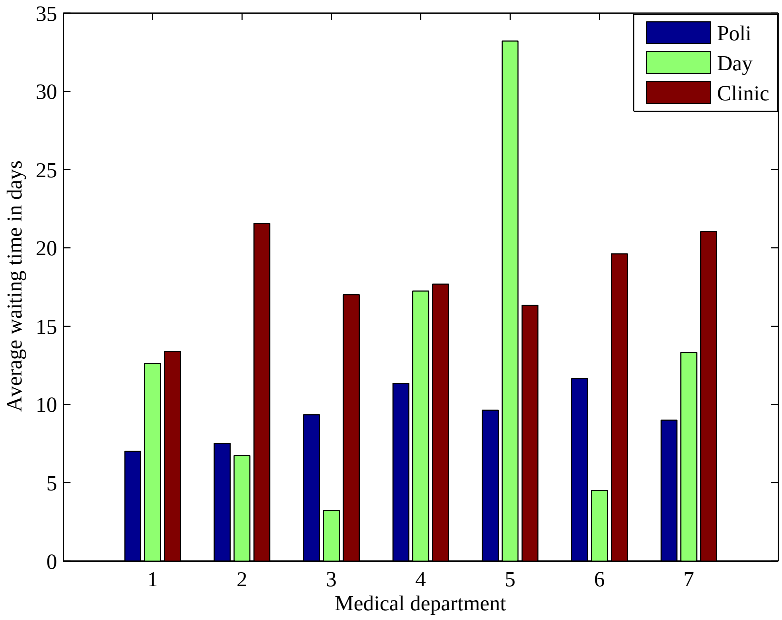

Figure 15: Average waiting time of patients

6.2.4 Conclusion

In the future situation the capacity utilization rate increases to values between 80% and 100%. The capacity utilization rate of polyclinics is especially high with more than 98% at all medical departments. The available capacity will thus be used more efficiently resulting in lower average costs.

The percentage of waiting patients drastically increases when the capacity is reduced. More than 50% of the patients have to wait at least 1 day at all medical departments. The average waiting time of patients also increases, especially at the inpatient and outpatient clinics. At some departments, patients even have an average waiting time of more than 20 days.

We can thus conclude that the service level declines in the future situation. The inpatient and outpatient clinics are the main bottlenecks when the capacity is reduced.

6.3 Maintaining service level

In the last section we have seen that the service level decreases when the capacity is reduced. However, the management of the hospital aims to keep performance measures S_2 and S_3 equal to the current service level. We therefore investigate several options that might help to increase the service level. These options were already discussed in Section 2.4.

6.3.1 Increase capacity during the weekend

In this section we investigate the influence on the service level when we increase the capacity on Saturday or during the entire weekend. The capacity fluctuates during the week due to differences in the available personnel. It would therefore also be possible to increase the capacity at each weekday to the maximum capacity during the week. However, we believe that this increase in the capacity is not enough to maintain the current service level. We therefore increase the capacity during the weekend, although that might be more expensive than increasing the capacity during weekdays. The capacity during the weekend will be equated with the lowest capacity during the weekdays. If the capacity is lowest on Mondays, the capacity during the weekend will thus be equal to the capacity on Mondays.

Figures 16 and 17 show the average waiting time of patients at polyclinics and oupatient clinics.

Firstly, we look at the average waiting time for polyclinical appointments. The average waiting time reduces with at most 7 days when the capacity is increased on Saturdays. When the capacity is increased during the entire weekend, the average waiting time is less than 2 days for all medical departments.

Figure 17 shows the average waiting time for day treatments. We notice that the average waiting time of departments 5 and 6 stays approximately the same. This can be explained by the fact that the capacity at these departments is not changed. The capacity during one or more weekdays is equal to zero and we therefore do not change the capacity during the weekend. The other medical departments show a small decrease in the average waiting time of patients

We do not show the average waiting time of clinical admissions because inpatient clinics already treat patients during the weekend. The increase in the capacity will thus be rather small, resulting in a small increase in the service level.

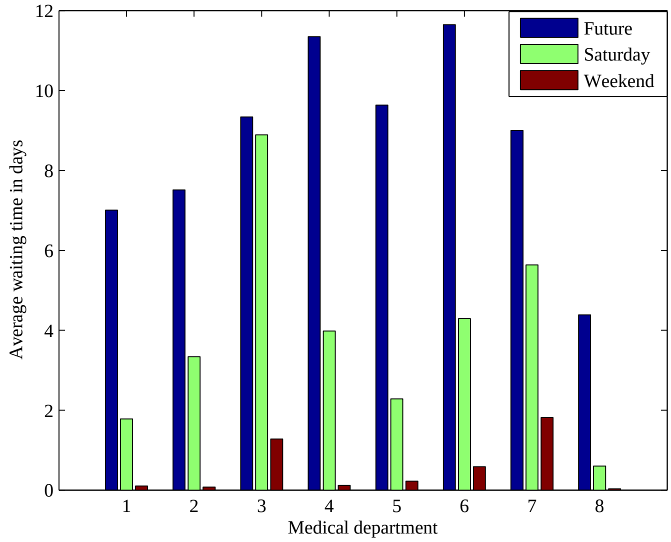

Figure 16: Average waiting time of patients for polyclinical appointments

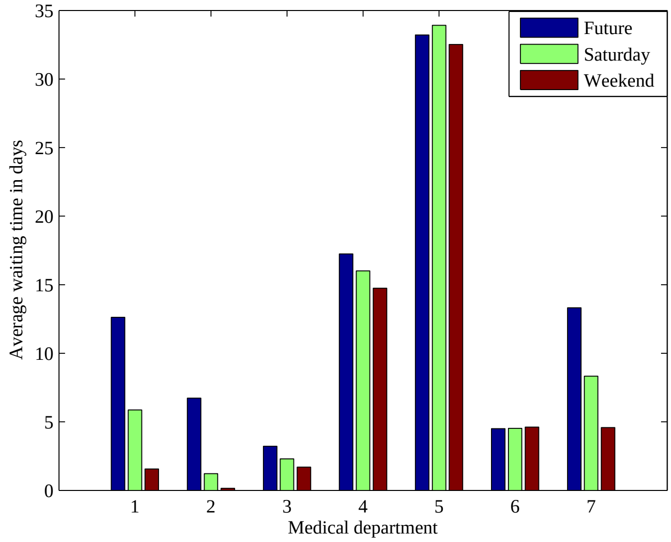

Figure 17: Average waiting time of patients for day treatments

Now that we have seen that the average waiting time decreases when the capacity increases during the weekend, we look at the percentage of patients who have to wait for their next treatment. This is shown in Figure 18 for the polyclinical appointments and day treatments of department 1.

Sub-figure (A) shows the percentage of patients who have to wait for a polyclinical appointment. When we increase the capacity on Saturday, the percentage of patients who have to wait is almost halved. When the capacity is increased during the entire weekend, the percentage of patients who have to wait is almost equal to the current percentage of waiting patients.

The percentage of waiting patients at the outpatient clinic also decreases when the capacity is increased. If we increase the capacity on Saturdays, the percentage of waiting patients is approximately 20% lower. The percentage of patients who have to wait is more than 40% lower if we increase the capacity during the entire weekend.

We did not include the figures of the other medical departments, but these show similar graphs as the ones shown in Figure18.

As expected, we can conclude that the service level increases when the capacity during the weekend is increased. This especially leads to a large reduction in the average waiting time of polyclinical appointments. If we increase the capacity during the entire weekend, the waiting time is approximately equal to the waiting time in the current situation. The average waiting time at the outpatient clinic shows a small decrease whereas the percentage of patients who have to wait decreases with 40%.

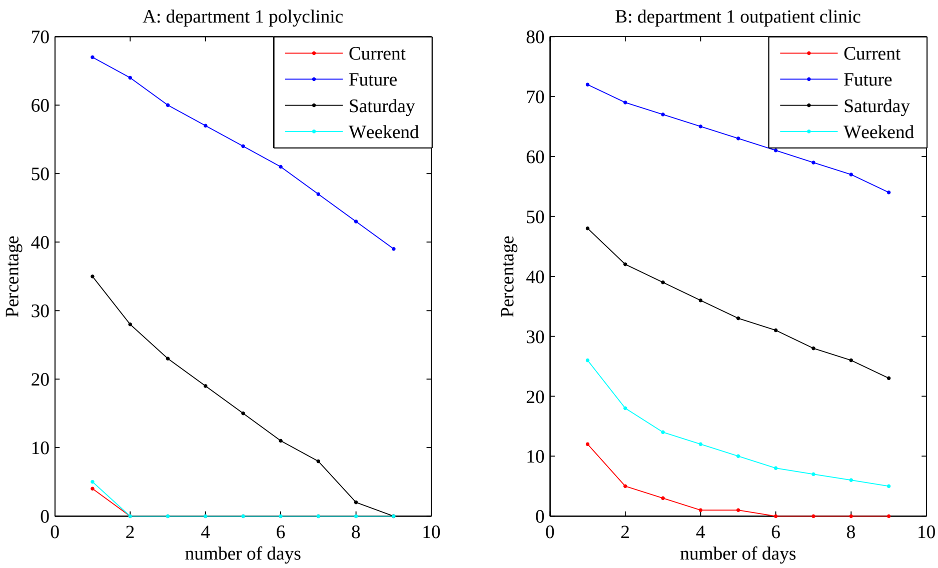

Figure 18: Percentage of patients who have to wait at least 1 to 10 days for either a polyclinical appointment or a day treatment at department 1

6.3.2 Combining medical departments

In this section we investigate whether the service level can be improved by combining two medical departments. The average waiting time of inpatient clinics is lowest at department 1 and the average waiting time of outpatient clinics is lowest at department 3. This can be seen in Figure 15 in Section 6.2.3. We therefore investigate the effectiveness of combining medical departments 1 and 3. In this way, both departments are able to gain benefit from the collaboration. In our simulation model, we use one new medical department and remove departments 1 and 3. The capacity of this new department consists of the capacity of both medical department 1 and 3. Patients who have an appointment at either department 1 or 3 will be treated at the new medical department.

Figure 19 shows the average waiting time of department 1 and 3 for the different types of treatments. Sub-figure (A) in Figure 19 shows the average waiting time at the polyclinic. To our surprise, the average waiting time of both medical departments decreases to approximately 4 days. It will probabaly be easier to schedule patients at the required date due to the larger combined capacity. However, the average waiting time will still be higher than in the current situation.

Sub-figure (B) shows the average waiting time at the outpatient clinic. The average waiting time at department 1 decreases from 13 days to 9 days. On the other hand, the waiting time at department 3 increases from 3 days to 7 days. The waiting time of patients is thus spread more evenly across both medical departments. This is a desirable result, because the management of the hospital prefers a large number of patients with a small waiting time rather than a small number of patients with a large waiting time.

The same holds for the inpatient clinic, shown in sub-figure (C) in Figure 15. Medical department 1 shows a small increase in the waiting time whereas department 3 shows a small decrease in the waiting time.

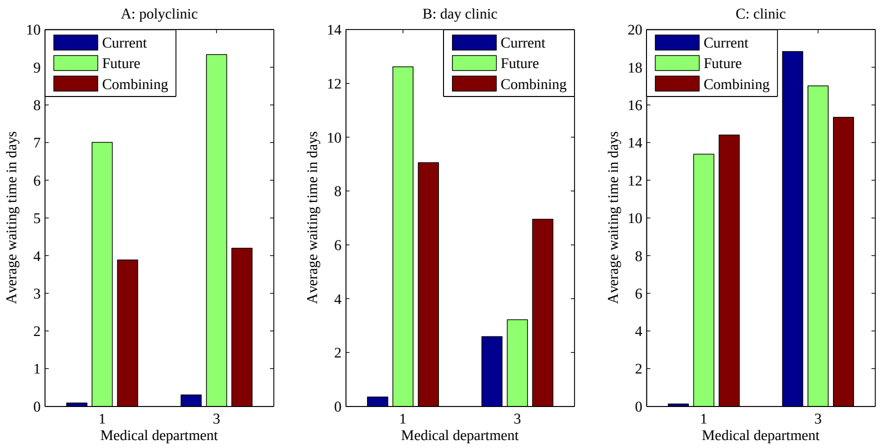

Figure 19: Average waiting time of patients for polyclinic, day treatments and clinical admissions of medical departments 1 and 3

We also look at the percentage of patients who have to wait for their next appointment. The graphs are shown in Figure 20 for the first medical department and in Figure 21 for the third medical department.

When we look at department one, we notice a relatively large decrease in the number of waiting patients for polyclinical appointments and day treatments. The percentage of patients who have to wait for a polyclinical appointment decreases with almost 20%. The outpatient clinic shows a decrease of approximately 10%. Combining the medical departments thus leads to decrease in the average waiting time as well as the percentage of waiting patients. Sub-figure (C) in Figure 20 shows a small increase in the percentage of waiting patients of less than 2%.

Sub-figure (A) in Figure 21 again shows a large decrease in the percentage of waiting patients at the polyclinic. Combining medical departments 1 and

3 thus has a positive effect on both departments. However, when we look at sub-figures (B) and (C) we notice an increase in the percentage of waiting patients at both the outpatient and inpatient clinic. Combining both departments thus has a negative effect on the outpatient clinic of medical department 3. It leads to a higher average waiting time and a higher percentage of waiting patients. The percentage of patients who have to wait for a clinical admission also increases, while the average waiting time only shows a small decrease.

Overall, we can conclude that combining medical departments one and three has a positive effect on both departments of the polyclinic. For the day treatments, the service level of department 1 increases while the service level of department 3 decreases. This can be useful to spread the waiting time more evenly across the different medical departments. Both outpatient clinics actually perform worse regarding the percentage of patients who have to wait. The average waiting time of clinical admissions at department 1 and 3 only show small changes. We thus recommend the hospital to combine the polyclinics and outpatient clinics of department 1 and 3. We furthermore advice the hospital to investigate whether other combinations lead to better results.

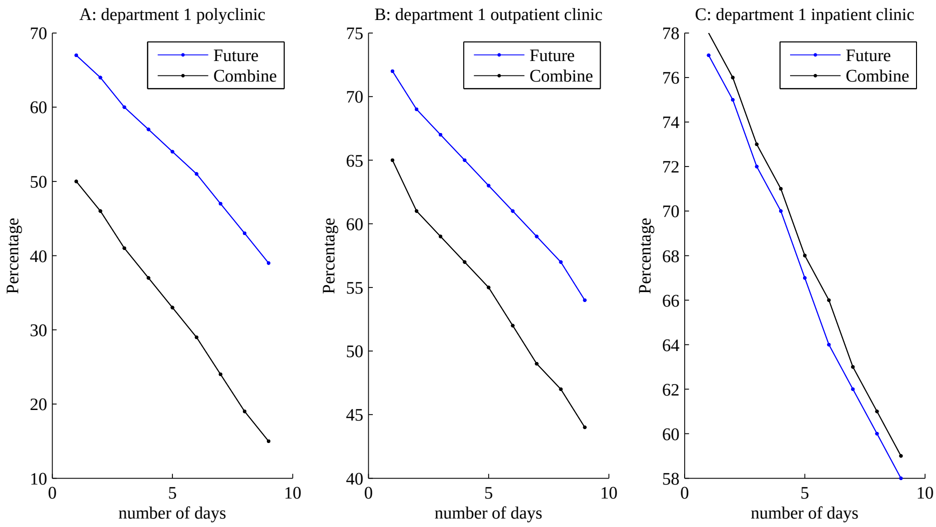

Figure 20: Percentage of patients who have to wait at least 1 to 10 days for either a polyclinical appointment, day treatment or clinical admission at medical department 1

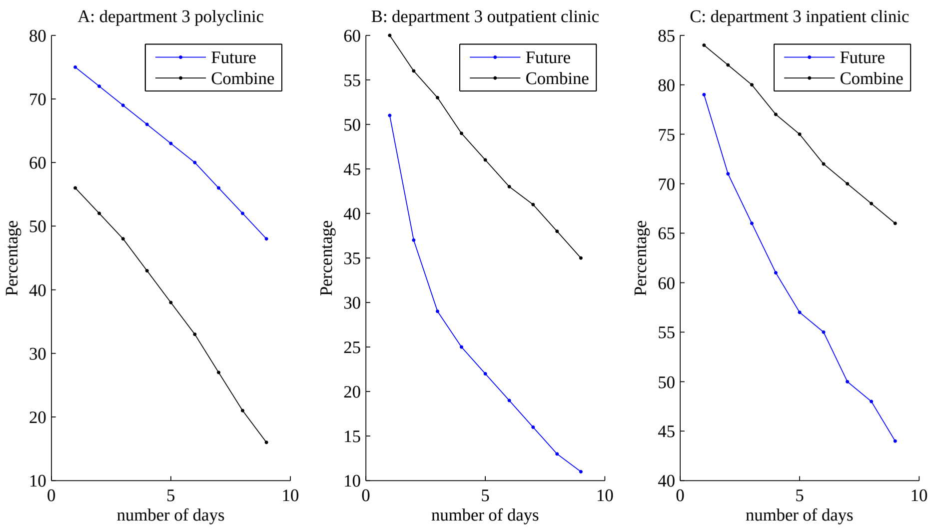

Figure 21: Percentage of patients who have to wait at least 1 to 10 days for either a polyclinical appointment, day treatment or clinical admission at medical department 3

6.3.3 Reduce the length of stay

We now investigate the influence of a reduction in the length of stay on the service level. We investigate this by reducing the length of stay with one day if the duration is longer than five days. If the duration is shorter than five days, we expect that it is not possible to reduce the length of stay with a more efficient scheduling of treatments. We therefore do not decrease the length of stay if the duration is shorter than five days. On the other hand, we believe that it will not be possible to decrease the length of stay with more than one day, even if the duration is much longer than 5 days. Improving the scheduling of treatments during the hospitalization will not lead to a larger decrease in the length of stay than 1 day.

Figure 22 shows the average waiting time of patients. This figure shows a rather large decrease in the waiting time of all medical departments when the length of stay is reduced. All medical departments show a decrease of 4 to 10 days in the waiting time. This is a very good result if we consider that the length of stay is reduced with only one day. We can thus conclude that reducing the length of stay has a rather large positive effect on the average waiting time.

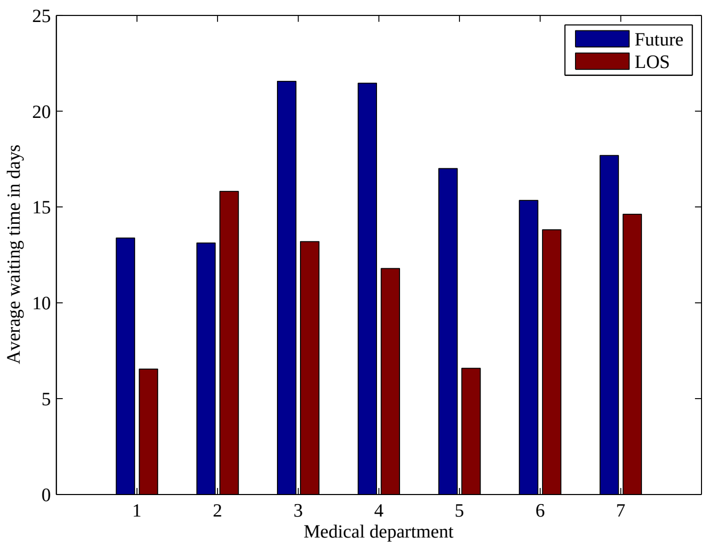

Figure 22: Average waiting time of patients

At last, we also look at the percentage of patients who have to wait at least 1 to 10 days. Figure 23 shows the percentages of medical department one. The percentage of waiting patients at medical department 1 decreases with more than 5%. We did not include the figures of the other medical departments because those show similar results.

We can thus conclude that trying to reduce the length of stay indeed leads to an increase in the service level. The average waiting time as well as the percentage of waiting patients reduces. We therefore advice the management to keep stimulating the personnel to actively try to decrease the length of stay. This can be done by scheduling the treatments more efficiently during a hospitalization.

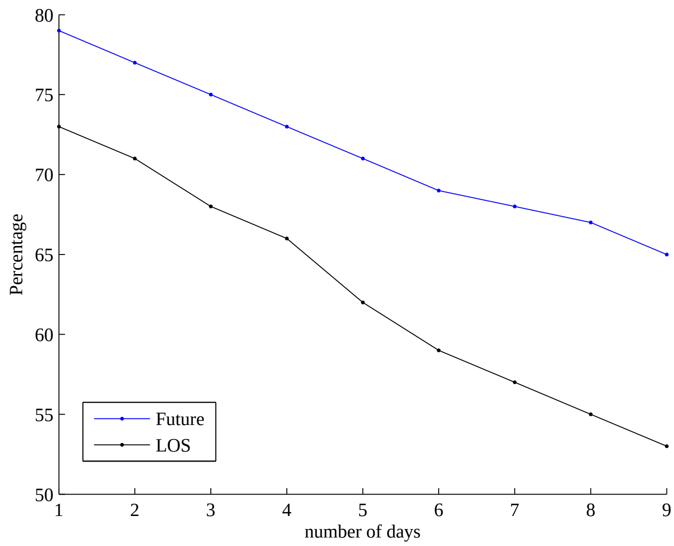

Figure 23: Percentage of patients who have to wait at least 1 to 10 days for a clinical admission at medical department 1

7 Conclusion

The main goal of this paper was to find a way to maintain the service level at Erasmus MC while reducing the capacity. We used discrete event simulation to model patient flow at division Dijkzigt. This model can be used to determine the current service level of the hospital, including the capacity utilization rate and average waiting time. It can also be used to analyse the impact of a capacity reduction and to investigate several options to increase the service level.

We first analysed the data and constructed a transition diagram to gain insight in the patient flow between the different medical departments. This analysis did not lead to any surprising results. It confirmed that patients have polyclinical appointments before and after day treatments and clinical admissions. It also confirmed that patients are usually treated at only one medical department and are rarely transferred to other medical departments.

Secondly, we used our simulation model to investigate the current service level of the hospital. The capacity utilization lies around 80%, which is in line with the actual utilization rate. The percentage of patients who have to wait for their next polyclinical appointment is rather low, less than 20% of the patients have to wait one or multiple days. For the outpatient and inpatient clinic these percentage are higher. The average waiting time of patients is also quite low. The waiting time for a polyclinical appointment is negligible and the other waiting times are all less than 10 days. Only the waiting time of clinical admissions at department 3 is higher with an average of almost 19 days.

Within a few years time, the hospital moves to a new building resulting in a capacity reduction of 30%. With our simulation model, we were able to determine the impact of this reduction on the service level of the hospital. The capacity utilization rate increases to values between 80% and 100%. However, the percentage of patients who have to wait and the average waiting time also increases. The average waiting time of patients especially increases at the inpatient and outpatient clinics. The percentage of patients who have to wait increases to more than 50% at all medical departments of all types of treatments. Reducing the capacity will thus lead to lower costs, but this comes at the expense of a much lower service level.

Of course, the hospital aims to keep the service level equal while reducing the capacity. We therefore investigated several options to increase the service level. Firstly we increased the capacity on Saturday and during the entire weekend. This leads to a large decrease in the average waiting time, which becomes approximately equal to the average waiting time in the current situation. The percentage of waiting patients also decreases with 40%. Secondly, we combined two medical departments to be able to share the capacity of both departments. This leads to an increase in the service level of both departments for polyclinical appointments. The average waiting time as well as the percentage of waiting patients decreases with at least 20%. For the outpatient clinic, the waiting time is spread more evenly across both medical departments. However, combining medical departments 1 and 3 leads to a decrease in the service level of the inpatient clinic. Both the average waiting time and percentage of waiting patients increase. At last, we investigated whether reducing the length of stay leads to an increase in the service level. This is indeed true, the waiting time and percentage of waiting patients decrease with at least 10%.

We thus advice the management of the hospital to investigate whether it is possible to carry out the solutions mentioned above. This leads to a large increase in the service level and thus helps to nullify the consequences of the capacity reduction.

7.1 Discussion and future research

During this research we encountered a few limitations and shortcomings. In this section we mention them and provide possibilities for improvement and future research.

The data provided by the hospital was very limited. First of all, there was almost no information about the current capacity of the different medical departments. The capacity is actually the most limiting factor when investigating waiting times and other service measurements. Small deviations in the actual capacity can lead to large errors in the service level. However, due to more reliable information about the number of patients per department we do believe that the used capacity is rather accurate.

The hospital furthermore provided us with patient data of one year. We therefore do not know whether a patient visits the hospital for the first time or whether the patient has a follow-up appointment. We also do not know whether patients finished their treatment or need to revisit the hospital. Therefore, we assumed that patients finished their treatment when their last appointment was more than a certain amount of days ago, depending on the medical department where the patient was treated. In reality, this will not be the case because there might be patients who only have to revisit the hospital once or twice a year. On the other hand, there are also patients who do not need to revisit the hospital although their last treatment was only several days or weeks ago. On average, the different exit rates per medical department will thus be appropriate.

More information about the patients could also have led to a more accurate analysis of patient flow. General information such as age, gender and diagnosis are needed to differentiate between patient types. Specific flow diagrams can then be made for different diagnosis, which leads to a more realistic patient flow throughout the hospital. However, we also know that there are thousands of diagnosis and patient types. Since we are analysing an entire division, this would lead to too much diversification.

Overall, we can conclude that more detailed information would have increased the reliablity and accuracy of the simulation model and therefore the results.

We already mentioned in Section 3 that attempts to model a whole hospital are rare. The main contribution of this thesis is that it shows that it can be useful to model an entire division. By using the appropriate simplifications and level of detail, we were able to determine the service level of the hospital. Most of the literature focusses on increasing the efficiency of small parts of the hospital. This thesis shows that it is also useful to look at the whole hospital and to investigate more drastic measures to increase the service level. For example, combining medical departments or increasing the capacity during the weekend can lead to a large increase in the service level. We have thus shown that a broader view can lead to a more efficient hospital.

Our simulation model can be used satisfactorily when analysing global patient flow and service levels of the hospital. It can also be used to determine the impact of changes in the capacity and organisation of the hospital. Our model was able to provide information about the bottlenecks of the hospital. However, when we want to investigate small changes in the organization of medical departments our simulation model cannot be used. For future research, we therefore advice to model specific medical departments instead of an entire dvisision.

Firstly, we think that it would be useful to analyse patient flow during only one visit to the hospital. Information about the patient flow during the visit can be used to increase the efficiency during those visits. This might lead to a higher utilization rate and shorter waiting times. Reducing the waiting time during a visit to the hospital leads to a higher appreciation of patients.

It would also be interesting to consider a redistribution of beds between sites. We have seen in Section 6.3.2 that it can be efficient to combine two medical departments. Sharing capacity can lead to a higher service level of both departments. Investing time in the right allocation of beds between medical departments can thus lead to a higher utilization rate and lower average costs.

Thirdly, we also recommend to use appointment scheduling. In this research we ignored the different appointment types and worked with a total number of appointments per day. In reality, there are different type of appointments which are scheduled at specific time slots during the day. Using the optimal time slots for different appointment types leads to more efficient planning resulting in shorter waiting times and less staff overtime.

Since the hospital will be moving to a new building, we also advice to consider hospital layout planning. Hospital layout planning aims to desing a hospital or medical department in such a way that it minimizes the movement of patients, personnel and equipment. Since the hospital will move to a new building in a few years time, it will be easier to implement the results of hospital layout planning.

References

1. Brailsford, S.C., Harper, P.R., Patel, B. and Pitt, M (2009). An analysis of the academic literature on simulation and modelling in health care, Journal of Simulation (2009) 3, 130-140.

2. Brailsford, S.C. and Hilton, N.A. (2001). A comparison of discrete event simulation and system dynamics for modelling healthcare systems, Proceedings from ORAHS 2000, 18-39.

3. Carter, M. (2002). Diagnosis: Mismanagement of resources. OR/MS Today, 29 (2), 26-32.

4. Côté, M.J. (1999), Patient flow and resource utilization in an outpatient clinic, Socio-Economic Planning Sciences 33 (1999), 231-245

5. Côté, M.J. (2000), Understanding patient flow, Decision line 31, 8-10

6. Côté, M.J. and Stein, W.E. (1999). An erlang-based stochastic model for patient flow, Omega 28 (2000), 347-359.

7. R.B. Fetter (1991). Diagnosis Related Groups: Understanding Hospital Performance, Interfaces Vol. 21, No, 1, Franz Edelman Award Papers (Jan. - Feb., 1991), pp. 6-26.

8. R.B. Fetter, Y. Shin, J.L. Freeman, R.F. Averill and J.D. Thompson (1980). Case Mix Definition by Diagnosis-Related Groups, Medical Care, Vol. 18, No. 2, Supplement: Case Mix Definition by Diagnosis-Related Groups (Geb., 1980), pp. i+iii+v+ix+1-53.

9. Fomundam, S.M. and Herrmann, J.W. (2007). A survey of queueing theory applications in healthcare, the institute for systems research, isr technical report 2007-24.

10. Green, L.V., 2006, Queuing Analysis in Healthcare, Patient Flow: Reducing Delay in Healthcare Delivery. Springer Science Plus Business Media, LLC: 281-307.

11. Günal, M.M. and Pidd, M. (2010). Discrete event simulation for performance modelling in health care: a review of the literature, Journal of Simulation (2010) 4, 42-51.

12. M.W. Isken and B. Rajagopalan (2002). Data mining to support simulation modeling of patient flow in hospitals, Journal of Medical Systems, Vol. 26, No. 2, April 2002.

13. Konrad, R.,Kucukyazici, M. and Lawley, M. (2012). "Using Patient Flow to Examine Hospital Operations." Management Engineering for Effective Healthcare Delivery: Principles and Applications. IGI Global, 2012. 402-417.

14. Law, A.M., Kelton, W.D. (2006). Simulation modeling and analysis, McGraw-Hill education, Europe, 4th edition. OECD, (2012). 'OECD Health Data 2012 - Frequently Requested Data'. In: OECD (ed): OECD.

15. Marazzi, A., Paccaud, F., Ruffieux, C., Beguin, C. (1998). Fitting the Distribution of Length of Stay by Parametric Models, Medical Care, Volume 36, Issue 6, pp 915-927, June 1998.

16. Weiss, E.N., Cohen, M.A., Hershey, J.C. (1982). An iterative estimation and validation procedure for specification of semi-markov models with application to hospital patient flow. Operations Research, Vol. 30, No. 6, 1082-1104.

17. Young, J.P. (1962). A queueing theory approach to the control of hospital inpatient census, industrial engineering department, Johns Hopkins University.

Appendices

A Capacity

In this appendix, we provide information about the available capacity of the three different types of treatments of each medical department. The capacity is denoted as the total number of appointments that can be handled at each day. The capacity remains constant throughout the year for the different days of the week.

MD	1	2	3	4	5	6	7	8
Monday	690	182	26	271	149	88	41	333
Tuesday	671	199	57	208	145	124	93	347
Wednesday	561	184	44	288	108	59	23	326
Thursday	558	182	44	185	201	103	70	306
Friday	430	140	40	226	163	54	34	278
Saturday	0	0	0	0	0	0	0	19
Sunday	0	0	0	0	0	0	0	15

Table 13: Capacity of polyclinics

MD	1	2	3	4	5	6	7	8
Monday	8	23	1	15	0	0	2	0
Tuesday	8	22	1	18	0	0	1	0
Wednesday	7	20	2	12	0	0	1	0
Thursday	8	22	1	14	0	0	1	0
Friday	6	18	1	3	5	2	1	0
Saturday	0	0	0	0	0	0	0	0
Sunday	0	0	0	0	0	0	0	0

Table 14: Capacity of inpatient clinics

MD	1	2	3	4	5	6	7	8
Monday	73	23	1	3	83	19	11	0
Tuesday	79	24	2	4	84	20	13	0
Wednesday	78	25	2	5	83	20	13	0
Thursday	77	25	2	4	84	21	12	0
Friday	75	26	2	3	82	20	10	0
Saturday	56	19	1	2	67	15	7	0
Sunday	56	19	1	2	69	15	8	0

Table 15: Capacity of inpatient clinics

B Transition probability matrices

The transition probability matrices are given in this appendix. State 1 to 8 correspond to the eight medical departments. State 0 corresponds to newly admitted patients whereas state 10 corresponds to the end of treatment, meaning that a patient does not return to the hospital. The clinic also has a ninth department. Clinical admissions can consist of multiple sub-admissions when patients are transferred to other departments. It might also happen that a patient is transferred to a department which does not belong to division Dijkzigt. In the transitation probability matrices this is denoted as state 9.

R_{ij}	1	2	3	4	5	6	7	8	10
0	0.320	0.061	0.011	0.167	0.124	0.089	0.044	0.120	0.000
1	0.724	0.088	0.037	0.018	0.015	0.006	0.002	0.013	0.072
2	0.209	0.465	0.004	0.014	0.036	0.004	0.003	0.037	0.110
3	0.328	0.013	0.436	0.035	0.008	0.019	0.006	0.022	0.108
4	0.050	0.006	0.005	0.727	0.009	0.005	0.005	0.008	0.126
5	0.062	0.029	0.002	0.015	0.623	0.010	0.017	0.033	0.168
6	0.045	0.006	0.006	0.013	0.014	0.625	0.006	0.028	0.215
7	0.023	0.005	0.003	0.020	0.046	0.009	0.498	0.191	0.153
8	0.032	0.015	0.002	0.006	0.019	0.012	0.023	0.800	0.073

Table 16: Transition rates from polyclinic i to polyclinic j

S_{ij}	1	2	3	4	5	6	7	8
0	0.004	0.014	0.001	0.005	0.001	0.001	0.001	0.000
1	0.006	0.003	0.001	0.001	0.001	0.001	0.001	0.000
2	0.001	0.077	0.001	0.001	0.001	0.000	0.001	0.000
3	0.001	0.003	0.012	0.001	0.001	0.000	0.001	0.000
4	0.001	0.001	0.001	0.050	0.001	0.001	0.001	0.000
5	0.001	0.007	0.000	0.001	0.001	0.001	0.001	0.000
6	0.001	0.001	0.001	0.001	0.001	0.004	0.000	0.000
7	0.001	0.001	0.001	0.001	0.001	0.001	0.013	0.000
8	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.000

Table 17: Transition rates from polyclinic i to day treatment j

T_{ij}	1	2	3	4	5	6	7	8	9
0	0.014	0.004	0.001	0.001	0.012	0.003	0.003	0.000	0.003
1	0.011	0.001	0.001	0.001	0.005	0.001	0.001	0.000	0.001
2	0.008	0.021	0.001	0.001	0.009	0.001	0.001	0.000	0.002
3	0.003	0.000	0.004	0.000	0.002	0.001	0.001	0.000	0.001
4	0.002	0.001	0.000	0.003	0.001	0.001	0.001	0.000	0.001
5	0.004	0.001	0.000	0.001	0.025	0.001	0.001	0.000	0.001
6	0.002	0.001	0.001	0.000	0.002	0.031	0.001	0.000	0.001
7	0.001	0.001	0.000	0.001	0.001	0.001	0.032	0.000	0.002
8	0.004	0.001	0.001	0.001	0.005	0.002	0.001	0.000	0.003

Table 18: Transition rates from polyclinic i to clinic j

U_{ij}	1	2	3	4	5	6	7	8
1	0.474	0.017	0.003	0.016	0.006	0.008	0.002	0.083
2	0.064	0.847	0.002	0.003	0.008	0.001	0.000	0.009
3	0.209	0.004	0.285	0.007	0.000	0.007	0.004	0.011
4	0.005	0.001	0.000	0.990	0.000	0.000	0.000	0.000
5	0.000	0.007	0.000	0.000	0.610	0.000	0.000	0.007
6	0.000	0.000	0.000	0.000	0.000	0.025	0.000	0.000
7	0.003	0.009	0.000	0.003	0.003	0.003	0.664	0.120
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 19: Transition rates from day treatment i to polyclinic j

V_{ij}	1	2	3	4	5	6	7	8	10
1	0.334	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.038
2	0.000	0.059	0.000	0.001	0.000	0.000	0.000	0.000	0.005
3	0.004	0.000	0.455	0.000	0.000	0.000	0.000	0.000	0.007
4	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.001
5	0.000	0.000	0.000	0.000	0.030	0.000	0.000	0.000	0.007
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.000	0.003	0.000	0.000	0.000	0.000	0.090	0.000	0.018
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 20: Transition rates from day treatment i to day treatment j

W_{ij}	1	2	3	4	5	6	7	8	9
1	0.014	0.000	0.000	0.001	0.002	0.000	0.000	0.000	0.001
2	0.001	0.002	0.001	0.000	0.001	0.000	0.000	0.000	0.001
3	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.004	0.000	0.000	0.000	0.331	0.000	0.000	0.000	0.004
6	0.000	0.000	0.000	0.000	0.000	0.975	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000	0.000	0.000	0.084	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 21: Transition rates from day treatment i to clinic j

X_{ij}	1	2	3	4	5	6	7	8
1	0.348	0.102	0.003	0.015	0.028	0.005	0.001	0.122
2	0.091	0.677	0.001	0.002	0.015	0.001	0.001	0.071
3	0.386	0.046	0.171	0.000	0.012	0.023	0.000	0.136
4	0.000	0.000	0.000	0.827	0.000	0.000	0.009	0.055
5	0.157	0.071	0.001	0.004	0.245	0.004	0.003	0.212
6	0.009	0.001	0.000	0.003	0.003	0.270	0.003	0.563
7	0.006	0.012	0.000	0.017	0.013	0.014	0.602	0.142
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.015	0.042	0.000	0.006	0.008	0.007	0.003	0.211

Table 22: Transition rates from clinic i to polyclinic j

Y_{ij}	1	2	3	4	5	6	7	8	10
1	0.006	0.004	0.000	0.001	0.001	0.000	0.000	0.000	0.091
2	0.000	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.016
3	0.000	0.000	0.046	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.009	0.000	0.000	0.000	0.000	0.025
5	0.001	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.040
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.013
7	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.020
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.032

Table 23: Transition rates from clinic i to day treatment j

Z_{ij}	1	2	3	4	5	6	7	8	9
1	0.215	0.006	0.001	0.000	0.008	0.001	0.000	0.000	0.046
2	0.007	0.059	0.001	0.000	0.015	0.000	0.000	0.000	0.027
3	0.000	0.000	0.159	0.000	0.000	0.000	0.000	0.000	0.023
4	0.000	0.000	0.000	0.059	0.000	0.000	0.004	0.000	0.013
5	0.007	0.003	0.001	0.000	0.130	0.002	0.001	0.000	0.119
6	0.003	0.003	0.000	0.000	0.003	0.055	0.002	0.000	0.069
7	0.004	0.003	0.000	0.004	0.009	0.002	0.081	0.000	0.068
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.123	0.023	0.001	0.003	0.312	0.054	0.037	0.000	0.124

Table 24: Transition rates from clinic i to clinic j

C Parameter estimates

In this appendix we present the parameter estimates of the length of stay of clinical admissions and the number of new patients .

Parameter estimates length of stay:
Length of stay clinic 1 $\sim$ Lognormal(1.3135, 0.8246)
Length of stay clinic 2 $\sim$ Lognormal(1.2608, 0.9381)
Length of stay clinic 3 $\sim$ Lognormal(1.4547, 0.8811)
Length of stay clinic 4 $\sim$ Lognormal(1.1689, 0.8770)
Length of stay clinic 5 $\sim$ Lognormal(1.3878, 0.9288)
Length of stay clinic 6 $\sim$ Lognormal(1.3895, 0.7949)
Length of stay clinic 7 $\sim$ Lognormal(1.1075, 0.7346)
Length of stay clinic 9 $\sim$ Lognormal(1.1211, 0.8838)

Parameter estimates number of new patients:
New patients polyclinic 1 $\sim$ Normal(43.9907, 14.2620)
New patients polyclinic 2 $\sim$ Normal(9.2243, 4.1330)
New patients polyclinic 3 $\sim$ Normal(1.4112, 1.6250)
New patients polyclinic 4 $\sim$ Normal(28.7196, 9.8697)
New patients polyclinic 5 $\sim$ Normal(22.4579, 8.2568)
New patients polyclinic 6 $\sim$ Normal(19.1869, 9.8929)
New patients polyclinic 7 $\sim$ Normal(8.2617, 5.7974)
New patients polyclinic 8 $\sim$ Normal(21.7383, 7.0955)