--PUBLIC VERSION--

Does size matter?

Queuing theory to determine bed capacities in the Erasmus MC

R. te Poele

Does size matter?

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Queuing theory to determine bed capacities in the Erasmus MC:

a trade-off between availability and efficiency

Rotterdam, June 16, 2009

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Management Summary

In 2015, the Erasmus MC in Rotterdam will open her new constructed building. In this setting, the organization of care will also change into a more patient-centered configuration.

Motivation
Simultaneous with this reorganization, the Erasmus Medical Center plans to downsize her bed capacity to reduce costs. Although many other hospitals also reduce bed capacity, this decision requires a better-founded quantitative approach than currently used. To be precise, target efficiency levels instead of service level standards primarily drive current capacity allocation. Additionally, advantages of merging departments are not fully acknowledged.

Objective
The objective of this project is to determine the consequences in terms of efficiency and service level of the provisional capacity configuration with current and future patient arrival rates and length of stay (LOS) and study the effects of establishing one or multiple day care center(s).

Based on the objective the following main question needs to be answered:
Should the Erasmus MC change the intended allocation of clinical beds over the themes and/or introduce day care centers to improve bed availability and efficiency in her new building?

Methodology
First, theories relevant to the capacity allocation in hospitals are explored. A mathematical queuing model (the Erlang loss model) turns out to be most appropriate for the research objective. Using availability (the probability of an arrival being admitted) as the service level, the Erlang loss model can determine the number of required operational beds and the corresponding efficiency. This model is especially suitable in situations where variation in demand is an important characteristic (which is the case for of hospital wards) and requires only two parameters: the average arrival rate and the mean length of stay. Subsequently, the model is validated with data of the Erasmus MC of the year 2007.

Results
For clinical patients, the model turned out to be a valid representative of bed occupancy and the total number of refusals. It became clear that larger departments are able to operate at higher efficiency while attaining the same availability. These effects are called economies of scale, which mean hospitals should not use the same target efficiency levels for departments of different sizes.
Deciding on the appropriate capacity level (number of beds) is a trade-off between availability and efficiency. Currently, norms for neither availability nor efficiency are formulated yet. That is why we designed a method to support making this trade-off. The method maximizes the weighted sum of availability and efficiency per theme. The recommended clinical bed capacities using this method (with equal weights assigned to availability and efficiency) are as follows:

Theme	Capacity	Availability	Efficiency
1	76	95.5%	87.9%
2	107	95.9%	90.0%
3	149	96.5%	91.5%
4	57	95.0%	86.0%
5	96	95.9%	89.3%
6 adult	62	94.8%	87.0%
6 child	134	96.4%	91.0%
Total	**681**		

However, as total capacity is limited, it might not be advantageous for the entire hospital to maintain the same availability level for each theme. When the goal is to minimize the total number of refusals, themes with a relatively high load (the average arrival rate times the mean length of stay) should have a relatively high availability level.
Therefore, we developed a tool to determine how the hospital should allocate a given total number of beds over the themes.

For day care patients, the Erlang loss model turned out to be a valid representative of bed occupancy as well. We calculated required bed capacity when all themes would have both their own separate surgical day care department and a non-surgical day care department, as well as merging day care departments like in the following scenarios:

1. Establishing a center for surgical day care for all themes
2. Establishing a center for non-surgical day care for all themes
3. Establishing a collective day care center for all themes together
4. Hospitalizing day care patients in the clinical wards

If the Erasmus MC merges day care departments (scenarios 1 to 3) without adjusting capacity, availability of the merged department exceeds the availability of the separate department. This effect is similar to the economies of scale mentioned above and can be understood by the concept called variability pooling, also known as the portfolio effect. This concept states combined processes' variability is less than the sum of the variability of the individual processes. Scenario 4 however decreases the availabilities of the merged departments compared to the separate departments, unless the weights assigned to availability and efficiency meet certain requirements. We therefore discourage to introduce scenario 4.
Because of the increased availability for the scenarios 1 to 3, day care centers require fewer beds to achieve a certain availability level. The reduction in bed capacity differs per scenario:

	Capacity (in beds)		
Scenario	**Reduction**	**Average**	**Peak**
1	6-12	13	23
2	11-17	38	84
3	19-34	46	105

Because arrivals of day care patients do not occur during the entire day, the results from the Erlang loss model (displayed in the Average column) are a slight underestimation of the required bed capacity. Therefore the Peak column also provides the required bed capacity that assumes all daily patients arrive at once. The latter is therefore an overestimation.

Conclusion and recommendations

First, we advise the Erasmus MC to abandon the norm efficiency of 85% for all departments and incorporate a way to measure availability in their business activity monitoring system. The tools explained above can be helpful in making the trade-off between efficiency and availability and formulating appropriate norms for each department. Second, … -- confidential section --

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Preface

This thesis concludes my study in Industrial Engineering and Management at the University of Twente in Enschede, the Netherlands. Within this education I chose for the Master specialization in Health Care Technology & Management. This Master track studies –among other things- the application of operations research and management sciences (OR/MS) in hospitals.

The research project I accomplished was executed in the Erasmus Medical Center and illustrates how a mathematical model and optimization techniques can help hospitals to improve their performance. This application of mathematics in a health care environment was exactly what attracted me in the HCT&M track.
That is why I would like to thank Naomi Nathan for bringing this assignment to my attention and for bringing me into contact with a broad spectrum of Erasmus MC's people involved in the project. Among these people are the managers of the future themes of the Erasmus MC. Thanks to them, I was able to identify the research topics most relevant for the Erasmus MC and check my findings with practical consequences. All people I interviewed were interested and enthusiastic to share their ideas with me. I experienced this very inspiring and motivating, but sometimes a bit confusing as well. Fortunately, Naomi and also Corina Schols were always willing to listen to me and guided me to focus my research.
I also would like to thank Lenny van Moorsel and Bart van Acker of the Erasmus MC's Business Intelligence department, who were very helpful when collecting the data I needed to perform the research.

I worked at cluster bureau 17 of the Erasmus MC and had a pleasant stay, especially because of the nice atmosphere at this department. That is why I would like to thank all colleagues of the cluster bureau for the amusing lunch and coffee breaks, the nice social talk, interest and helpfulness.

Tom Coenen and Koos Krabbendam were my supervisors from the University of Twente. I would like to thank Tom for sharing his knowledge on queuing and mathematical theory, his constructive comments on my writing, supervising my progressions and his flexibility in scheduling our meetings. Koos was very helpful in sharing his knowledge on operations management and thinking of organizational consequences.

And last but not least, I would like to thank my parents, friends, family and housemates for their support and when necessary instructing me to take some time off.

Rotterdam, 16 June 2009

Renée te Poele

1. Introduction

In developed countries the health care sector accounts for a high and still increasing share of the national product. However, spending more money on health care does not automatically mean better health. In the Netherlands, the expenses on health care equal 13.1% of the gross domestic product, of which the majority is spent on hospitals (CBS, 2008a). This has put cost reductions in health care expenses high on the agenda.

Many researchers (e.g. Carter, 2002. Koole, 2008. Merode, 2002. Bakker, 2004) have argued the potential of Operations Research to decrease hospitals' expenses without reducing or while even improving the quality of care.

The rising pressure on expenses becomes also visible in the largest academic hospital in the Netherlands, the Erasmus Medical Center. Simultaneous with a large new building and reorganization project, the Erasmus MC's management plans to decrease their capacity to a great extent. Capacity is expressed in the number of beds. This and other definitions can be found in the list at the end of this report. However, the decision of capacity reduction is primarily driven by standard norm efficiency instead of service level standards like the percentage of refused admissions. Besides, the Erasmus MC sees opportunities to improve efficiency and attract more day care patients by separating the more simple and planned day care from the more complex and profound clinical care. Managers are however uncertain whether the introduction of day care centers improves or deteriorates efficiency and/or service level.

Inspired by former OR research, we show how a queuing model (the Erlang loss model) can contribute to the discussion of strategic capacity planning, bed distribution over the wards and separating or merging departments. The objective of this project is to determine the consequences of the capacity configuration provisionally decided upon with current patient arrival rates and LOS of the Erasmus MC and what effects of establishing one (or multiple) day care center(s) can be.

In Chapter 2, the project framework will be explained. Subsequently, relevant developments, former research, the research objective and questions, the methodology and report structure will pass. Chapter 3 describes the organizational context of the project, which consists of the Erasmus MC and its reorganization and discussion regarding day care. Chapter 4 discusses theories relevant to capacity allocation in the hospital and the performance measures of interest (efficiency and service level). Chapter 5 subsequently describes how data to measure these variables were collected and other methodological assumptions. Chapter 6 puts the data collection into use and determines patient characteristics like arrival rate and length of stay. Chapter 7 summarizes the model that predicts efficiency and service level using the figures presented in Chapter 6. Chapter 8 applies this model to compute the efficiency and service levels in case the Erasmus MC maintains the provisional organization. This chapter also extends former OR research with some useful instruments. Chapter 9 also applies the model described in Chapter 7 to calculate the effects of alternative organizational configurations. Chapter 10 carries out sensitivity analyses. Chapter 11 describes organizational considerations that also should be involved in capacity planning decisions of the Erasmus MC. Finally, Chapter 12 concludes the report and gives a brief discussion on the result of this research project.

2. Project framework

This chapter subsequently discusses the background of this research project (2.1), the research problem (2.2), the methodology to solve the problem (2.3) and the structure of this report (2.4).

2.1 Background

The pressure on the health care sector to lower costs is rising. This pressure calls for major efficiency interferences in hospitals processes. This section first describes the most important developments in the hospital sector in general and the Erasmus MC more specificly. Subsequently, former research performed in the area of hospital's capacity planning is examined.

2.1.1 Developments

Many hospitals' first response to the call for efficiency is to decrease the number of operational beds. This response is supported by reduction of patients' length of stay (LOS). Nationally, mean LOS –day care patients excluded– decreased from 9.5 days in 1998 to 7.3 days in 2005 (CBS, 2008b). This trend is expected to continue in the future: in 2015, the mean LOS would then be decreased to 6.3 days. An additional development of more patients receiving treatment in day care instead of clinical care reinforces this trend. Besides, mean LOS is below 6 days in other western countries, even nowadays. This difference is mainly caused by a high degree of so-called incorrect bed days, due to increased LOS in the hospital because of lacking capacity at nursing homes. The latter indicates even more LOS reduction is possible in the Netherlands (College Bouw Zorgvoorzieningen, 2003a and b). Chapter 3 will evaluate whether this LOS reduction also applies for academic centers like the Erasmus MC.

Because of the developments mentioned above, the Erasmus MC plans to decrease their bed capacity to a great extent: from 1200 to 800 beds. Starting 2010, the financial structure of the health care system will change: hospitals will no longer receive an extra budget for new buildings, but have to include this in their cost of goods sold (COGS). To be able to offer competitive prices to health care insurance companies, the hospital wants to keep COGS as low as possible. Therefore, costs of a new building should be limited and expanding space is under pressure. As a consequence, the total number of 800 beds is more-or-less given; changes in allocation over the themes and between day care and clinical beds however can be made. However, there are some indications that the new bed capacity will not suffice. The total bed capacity however will only be increased in case there is solid quantitative support.

The Erasmus MC's capacity reduction will come into force at the time of the new constructed building opening in 2015. Simultaneously, the organization of care will change. Medical specialties will be bundled into six themes, based upon centralizing the patient and the care process he/she walks through (Erasmus MC, 2002). This reorganization is mainly inspired by the major change of the financial structure of the Dutch healthcare system: the DBC system. This financial system is comparable with a diagnosis related group (DRG) classification system and was introduced in 2005 in the Netherlands. Where the hospital was formerly compensated for every action separately, the DBC system presumes a multidisciplinary process around the patient and compensates for the entire treatment at once. The current organization based on medical specialties does not fit with this financial system, so there is a call for change. The intended theme based structure should meet the call for more patient-centered processes.

The effects of the bed reduction and the new organization on the availability of a bed for arriving patients are currently unknown. Therefore, the Erasmus MC would like to obtain more insight in these effects and called for advice about the division of beds over the themes.

Besides, the Erasmus MC searches for other initiatives that might optimize the usage of the hospital's beds. Specifically, there is some internal discussion about day care: while some say these patients can be admitted at the regular clinical wards, others argue it is better to establish special center(s) and hospitalize such patient groups at separate wards. Because both options are arguable, there is a call for quantitative insight to support decision-making.

2.1.2 Former research

The essence of capacity planning is to get the balance between capacity and demand right. Currently, capacity decisions in hospitals are to a great extent based on historically obtained rights and driven by available budgets and target efficiency levels (Green, 2002). From Operations Research perspective, this approach neglects some important logistic aspects and fails to provide good insight in the actual availability of capacity. Below we shortly explain the most important aspects. Chapter 4 will go more deeply into these theoretical concepts.

First, performance does not only involve efficiency, but also quality of the service provided. This holds for all industries, but even more for health care because it is often a matter of life and death. Quality of the care involves both effectiveness and availability of the service. In this report, we focus on availability and leave medical effectiveness out of scope. Bad hospital bed availability means extensive waiting times and numerous refusals. These are partially caused by the characteristics of health care: it is a typical service, in which the customer (patient) is part of the process. Services are intangible and therefore cannot be stored. (Slack, Chambers & Johnston, 2007) Therefore, it is not possible to produce services before demand for them has occurred. A cumulative representation of capacity plans would only show when demand could not be met. And although waiting times and refusals cannot be completely prevented, both should be within acceptable limits.

Second, the current approach is a deterministic model. This means it assumes there is no randomness in patient arrival rates and LOS. In reality however, these numbers are often very uncertain. Uncertainty appears in service requirements (including the length of stay) of patients, arrival moments of emergency admissions, unpredictability of complications, etc. Although there is control over the moment non-emergency patients (the so-called elective patients) arrive by making appointments, their lengths of stay are often also hard to predict. (Green & Hguyen, 2001 & Koole, 2008) Carter (2005) even states that health care has to deal with more variability than any other industry. A mathematical modeling study (Gallivan, Utley, Treasure & Valencia, 2002) shows the tremendous impact of variability on capacity requirements. If this variability is disregarded during modeling an unrealistic and static representation of reality will emerge, which is also referred to as the flaw of averages (see Figure 1).

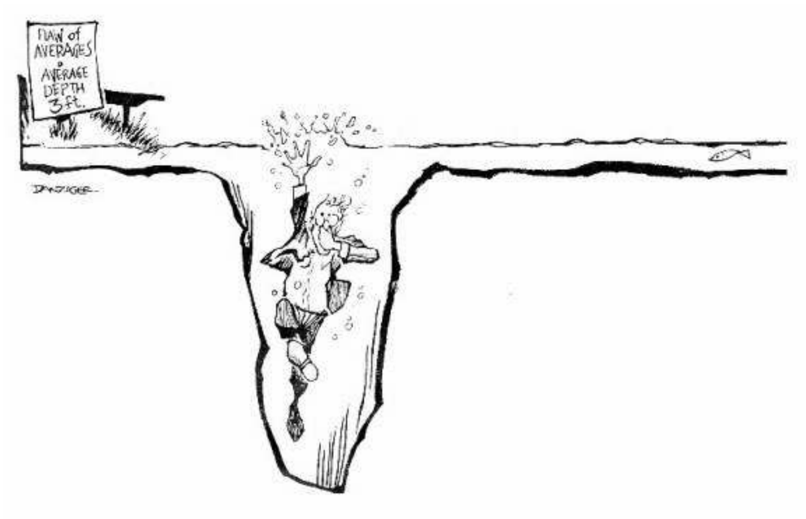

Figure 1: Example of the flaw of averages: the statistician who drowned while crossing an (on average) three feet deep river (by Jeff Danziger, published in the San Jose Mercury News, Sunday October 8 2000)

Therefore, we searched for a stochastic model that incorporates both efficiency and availability of the system.

Capacity planning and control for service operations is best considered using queuing theory (Slack et al, 2007). This means while sometimes demand may be satisfied instantly, at other times customers (patients) have to wait. There are several queuing models available, each with their own system characteristics. Following de Bruin et al (2006 & 2008) and McManus (2004), the Erlang loss model is an adequate representation of a hospital's in-patient flow. The former research projects, which were executed in other hospitals than the Erasmus MC, show us the relation between capacity, availability and efficiency for clinical patients. Also, the efficiency of merging departments is demonstrated.

Unfortunately, these former research projects do not provide us with a methodology to actually make the trade-off between availability and efficiency. Besides, they disregard the fact that total bed capacity might be restricted, so do not present a way hospitals should allocate beds over their departments in this case. Finally, they were applied to clinical patients only. As far as we know, it was never evaluated whether this model is also applicable to day care patients.

2.2 Research problem

This project links the hospital-wide question whether the provisional allocation of 800 beds over the themes results in desirable availability and efficiency with the question what separate day care ward(s) can do to optimize bed exploitation.

2.2.1 Objective

The aim of this project is to determine the consequences (bed availability and efficiency) of the provisional capacity configuration with current patient arrival rates and LOS and what effects of establishing one or multiple day care center(s) can be. The research project has the following objective:

To determine required ward capacity for current patient characteristics and study the effects on availability and/or efficiency of introducing day care centers in the new Erasmus MC.

2.2.2 Central research question

As mentioned in Section 2.1, the Erasmus MC plans to implement bed reduction and reorganization. However, the effects of this bed reduction and the new organization on the bed availability for arriving patients are yet unknown. Besides, one is uncertain whether the introduction of day care centers improves or deteriorates availability and efficiency. The following central research question results from the research objective stated above:

Should the Erasmus MC change the intended allocation of clinical beds over the themes and/or introduce day care centers to improve bed availability and efficiency in her new building?

As described in Section 2.1 we expect that the Erlang loss model is an adequate representation of a hospital's in-patient flow. Until now, this model has not been used in the Erasmus MC. So before we can answer the central research question, we should evaluate whether the Erlang loss model is also applicable for clinical patients and day care of the Erasmus MC. To do so, the hospital's admission process and her new organization will be analyzed and data of patient arrivals and LOS are collected.
At the same time, we further investigate the theoretical background of variability, the Erlang loss model and other possible methods to analyze availability and efficiency.
For this part of the project, the following sub questions should be regarded:

1. How do wards currently manage admissions of elective and (semi-)emergency patients?
2. What methods can be used to analyze bed availability and efficiency based on capacity, arrival rates and LOS?
3. Which assumptions should be made for the methodology?
4. How will patients be distributed over the 6 themes?
5. What are patient arrival numbers and LOS to the wards (based on the 6 themes)?
    - Using current patient arrival numbers and LOS in combination with the way patients are distributed over the themes.
6. What is the provisional bed allocation over the 6 themes, assuming 800 beds?
7. Which model will be used to determine availability and efficiency in the provisional situation and to assess the effects of a day care center?

Hereafter, we can use the model that is formulated and validated to support the Erasmus MC to decide upon the appropriate capacity and bed allocation over the departments. The following three sub questions should be answered for this part of the research project:

8. What would be ward availability and efficiency with the provisional ward capacities and current patient arrival rates and LOS?
9. Which method should be used to make the trade-off between availability and efficiency?
10. What instrument is best to allocate beds over the departments in case total bed capacity is limited?

The same model can be used to determine whether the Erasmus MC should introduce day care centers to improve bed availability and efficiency in her new building. This part of the research question is investigated using the following sub questions:

11. What are arguments for and against separate day care centers?
12. Which scenarios (organizational configurations) regarding day care center(s) should be tested?
13. What would be the effects of hospitalizing day care patients in the clinical wards versus in day care center(s)?

To adequately answer the central research question we should be aware of the fact that strategic capacity decisions should be valid now, but also in the future. Therefore, we have to know:

14. How robust are the results of questions 8 and 13 to changing patients' arrival rates and length of stay?
    - Using the model mentioned in question 7

Finally, we will use the results of the sub questions above to give recommendations to the Erasmus MC and explain the consequences of this advice:

15. Which other considerations should be taken into account when deciding upon organizational changes?
16. How should bed capacity and allocation be changed to improve the Erasmus MC's availability and efficiency?

2.3 Methodology

The following figure represents the order in which the questions stated above can be answered. Furthermore, it can be seen that the methodology of our research (enclosed in the frame) cannot be described before some organizational and theoretical concepts are clear. Therefore, we will not elaborate upon the methodology any further in this section, but refer to Chapter 5 for more details.

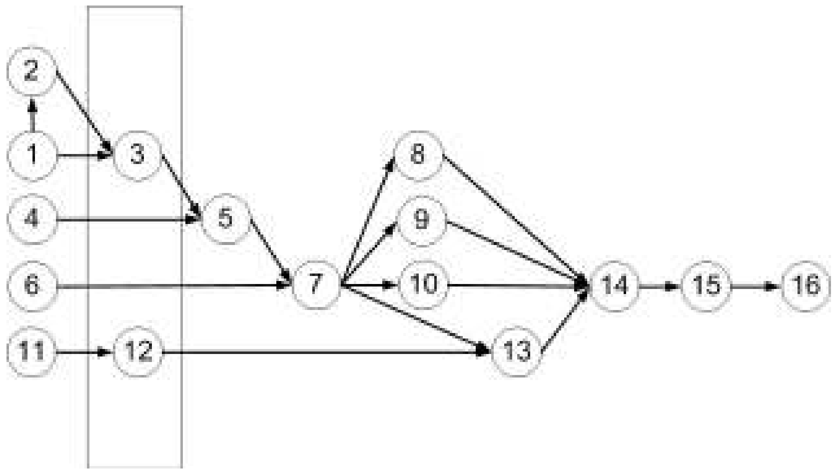

Figure 2: Order of and relations between the research questions

The questions mentioned above help the Erasmus MC in capacity planning. Planning for capacity is usually performed at two levels, each corresponding to either strategic or tactical decisions. This study focuses on the first level decisions, which are strategic and long-term in nature, for example investments in new facilities. The second level of capacity decisions is more tactical in nature, so focusing on short-term issues that include planning of workforce and day-to-day usage of resources. (Reid & Sanders, 2002) For example, it is interesting to see how waiting times preceding elective admission can be reduced. However, this issue concerns the optimization of elective admission scheduling (which depends not only on ward capacity, but also for example on OR-planning) and is thus a study subject viewed apart. Thus –as also indicated in the definition of capacity- this research project focuses on the strategic decisions of determining effective capacity.

2.4 Report structure

Figure 2 illustrates the order of discussion in this report. We first describe which organizational aspects should be considered, regarding research questions 1, 4, 6, and 8, in Chapter 3. This organizational context also influences the methods that can be used to analyze bed availability and efficiency and therefore precede Chapter 4 that describes the theoretical framework. Using these organizational and theoretical frames, we can make assumptions for the methodology and determine how to measure the effects of a separate day care center (Chapter 5). Subsequently, Chapter 6 combines the methodological issues with the way patients will be reorganized into arrival numbers to and LOS at the wards of the six themes. Chapter 7 determines which model represents figures of Chapter 6 best to predict bed availability and efficiency. Chapter 8 uses this model to calculate what availability and efficiency at the wards might be expected with the provisional bed allocation over the six themes. This chapter also provides a methodology to actually make the trade-off between availability and efficiency and a tool to allocate beds over departments in case total bed capacity is limited. Hereafter, Chapter 9 explains the effects of day care center exploitation on the wards. Following, Chapter 10 uses this model to execute sensitivity analyses and estimate the results with future patient arrival rates and LOS. Also, recommendations regarding bed capacity and allocation should not be made without considering their organizational consequences (Chapter 12). Finally, Chapter 11 gives an advice to the Erasmus MC if and how their bed capacity and allocation should be changed to optimize availability and efficiency. Figure 3 gives a graphical overview of the way this report is structured.

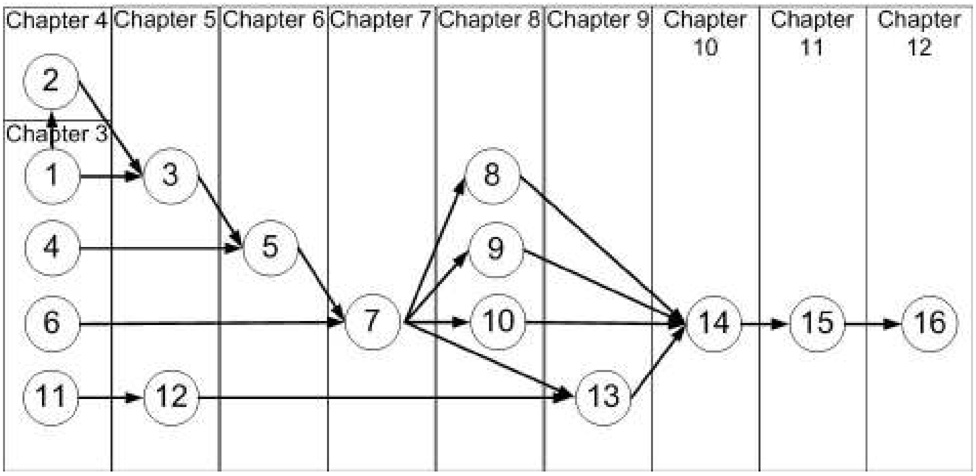

Figure 3: Overview of the research questions answered in the chapters of this report

3. Organizational context

To be able to make correct assumptions for the methodology, researchers have to realize the organizational context. This chapter provides this context. Subsequently, the following topics will pass: facts and figures (3.1), admission management (3.2), patient-centered organization (3.3) and the provisional bed configuration (3.4) of the Erasmus MC. Also, the last section describes the internal discussion about organization of day care (3.5).

3.1 Facts and figures

The Erasmus MC in Rotterdam is with more than 10,000 employees the largest academic hospital in the Netherlands. Each year, over 500,000 patients visit the outpatient clinics. The wards hospitalize yearly more than 36,000 patients, which stay for approximately eight days on average. See Table 1 for an overview of the production figures over the last six years. This table shows that national developments mentioned in Section 2.2 also occur in the Erasmus MC: decreasing LOS and increasing number of day treatments while decreasing number of hospital days. Chapter 6 gives a more detailed description of the number of hospitalizations, hospital days and length of stay.

	2007	**2006**	**2005**	**2004**	**2003**	**2002**
Hospitalizations	37,799	36,808	36,204	35,988	34,574	33,172
Hospital days	298,504	299,621	306,096	306,937	309,044	305,358
Mean Length of stay (in days)	7.9	8.1	8.5	8.5	8.9	9.2
First visits out-patients' clinic	178,433	171,449	172,225	169,021	167,030	165,155
Follow-ups out-patients' clinic	341,350	338,531	347,090	343,558	337,752	335,635
Day treatments	27,717	25,567	24,535	21,818	19,076	18,628

Table 1: Production figures 2002-2007 (Erasmus MC, 2008)

A considerable number of the hospitalizations (17%) concern unplanned patients: 6,451 patients arrived via the Emergency Department (ED) at the wards in 2007. This equals 25% of all arrivals at the ED. A major part (40%) of these admitted emergency patients have a length of stay of less than 48 hours. The other 31,348 admitted patients arrive via the outpatient clinics of the hospital and are called elective admissions. Elective admissions are less urgent than emergency admissions, so some waiting time is permitted. As a result, planning can be used to smooth the admission of these patients. However, some of the patients that arrive via the outpatient clinics have a maximum waiting time and are being called semi-emergencies.

3.2 Capacity planning

This categorization of patients is important to understand the way admission of patients is managed at hospital wards. Based on trend analysis of past years, each ward of the hospital indicates the number of beds annually needed. This figure (the bed capacity) and the expected number of hospital days are registered in the annual production agreements. Each planning period (e.g. each month), the exact number of staffed beds is derived from elective admissions planned each day with a reservation for emergency patients.

Since the Erasmus MC is a trauma center, extra emergency arrivals might occur. When all staffed beds are occupied and no extra staff can be acquired, a so-called over-bed is created. An over-bed is a non-staffed bed, which is forcefully brought into operation and thus burdening the staff with an extra patient. Due to a limited staff capacity and minimal required assistance to the patient, the number of over-beds should be limited. Also, the ward coordinator should monitor the quality of labor and make sure over-bed usage does not occur too often (van Duijn, 2008). Other solutions are: transferring a patient to another hospital, postponing a planned operation and releasing another patient earlier. These solutions also have serious drawbacks for the quality of care.

Therefore, it is important to set the bed capacity right so transferals and waiting times are minimized. This means the Erasmus MC strives to be able to admit arriving patients as much as possible. As a consequence, it is useful to have flexible bed capacity. These topics will be discussed in more detail in Chapter 4 and 9. Also, transparency regarding available bed capacity versus planned admission and arriving patients is important to ensure the undesired situations mentioned above do not occur. At the moment of this research, the Erasmus MC does not have an adequate planning system. That is why we decide to use the outcome of actual admission procedures in the primary analysis described in the Chapters 6 to 9. But since there are plans to implement such a system in the future, the planning might be improved in 2015. We will return on this topic in Chapter 11.

3.3 Patient-centered organization

The Erasmus MC currently comprises of three locations: the Centrum location, the children's hospital Sophia and the cancer center Daniel den Hoed. At this moment, the Erasmus MC is authorized for 1200 beds in total and organized in 17 clusters (based on medical specialties). The number of operational beds is probably approximately 1000 beds (cribs and Intensive Care beds excluded).
In 2015, the Erasmus MC's Centrum and Daniel den Hoed locations will move into a new location. There will be quite some organizational changes in this new location: the total number of beds will reduce to 800 and organized in six themes, based on patient flows. The following table shows the six themes, with the current specialties involved in each theme.

Theme	**Title**	**Involved specialties**
1	Brain and senses	ENT (Ear-nose-throat) Neurology Neurosurgery Ophthalmology Psychiatry
2	Oncology	Hematology Endo-oncology Radiotherapy
3	Defense, metabolism and aging	General surgery Dermatology Internal medicine Gastroenterology Rheumatology
4	Emergency care and locomotor system	Anesthesiology Traumatology Oral surgery Orthopedics Plastic surgery Rehabilitation
5	Circulation	Cardiology Pulmonary diseases Thorax surgery
6	Growth, development and reproduction	Pediatrics Pediatric surgery Child and youth psychiatry Orthodontics Obstetrics and Gynecology Urology

Table 2: Patient-centered themes in new location (Erasmus MC, 2002 & 2006)

As mentioned above, the Sophia location will not move into a new location and remains a separate hospital with its own organization. Therefore, we divide theme 6 in this report into adults and children.
Although this table gives a rough indication of how patients will be distributed over the six themes, it is not entirely realistic. To organize the best patient-centered care, we have to consider the actual care process he/she walks through. For example, oncology patients have to deal with multiple specialties, internal medicine, radiology, general surgery and radiotherapy. We constructed a method to rightly allocate admitted patients to their theme. This method is described in Section 5.3.

The new building will not be constructed and used all at once, but in phases. The Erasmus MC distinguishes between Tranche I (themes 1, 2, 3, 4 and adults of theme 6) and Tranche II (theme 5 and children of theme 6). Tranche I of the new hospital will be finished in 2015, after which the preparations of Tranche II start. For this research, this distinction should be taken into account because it influences location of bed capacity for each theme. And since location determines the distance from and to facilities like the operating rooms and out-patient clinics it affects which organizational scenario is preferred. However, the tranche division is subject to changes and so locations are not fixed yet. Therefore, the distinction should not be leading in capacity allocation decisions. In Chapter 11 we return to the organizational consequences of the scenarios.

3.4 Provisional bed configuration

The 800 beds mentioned in Section 3.3 are used for day care and clinical treatment. The reduction of 400 beds results from an expected decrease of patients' length of stay (LOS), as already explained in Chapter 2.

Table 3 below shows the number of operational beds currently in use, the results of two samples that measure the fraction actually utilized and compares these to the number of beds in the future. The future beds configuration is extracted from a proposal of 2006. This proposal assumes 700 beds in total and allocation based on production numbers of 2004 and a norm occupation rate of 85% (Kaaden, 2007). Note that the numbers in this table only concern clinical beds.

Theme	**Current number of beds (design capacity)**	**Utilized in August 2007**	**Utilized in December 2007**	**Provisional future number of beds (proposal 2006)**
1	108	75*	70	70
2	201	154*	159*	128
3	191	148*	176*	142
4	90	68*	74*	53
5	111	83	91*	83
6	236	148	172	188
IC/PACU	35	11	26	36
Total	972	687	765*	700

Table 3: Provisional bed configuration and number of beds currently utilized (Heel, 2008)
** Number of beds utilized exceeds provisional future bed capacity*

The table indicates the validity of the provisional bed allocation is questionable. The main cause for this discrepancy is that the LOS decrease expected from Section 2.2 does not seem to hold for the Erasmus MC. Table 1 above already showed that. Since all Dutch academic centers have longer mean LOS compared to general hospitals (see Table 4), this is not surprising.

	2000	2001	2002	2003	2004	2005
General hospitals	8.3	8.0	7.7	7.2	6.8	6.6
Academic centers	9.4	9.4	9.4	9.2	8.7	8.5
All	9.0	8.6	8.5	8.0	7.5	7.3

Table 4: Mean length of stay in days over all Dutch hospitals (CBS, 2008b)

Resulting from the DRG financing system introduction, this difference might become even larger, since more complex case mix patients will be treated in the academic centers. The more complex usually suffer from co-morbidity and usually have to stay at the hospital for a longer period of time. Other reasons why the Erasmus MC's bed reduction might be too optimistic are (Kaaden, 2007):
- Increase of care demand (caused by demographic developments like aging population and co-morbidity) in case of constant market share within its care area
- One-bed-per-room policy might not cause the expected LOS decrease
- Comparison with other countries' LOS mentioned in Section 2.2 is irrelevant because of the impact of external factors like governmental policies

However, as mentioned in Chapter 2, due to budget restrictions the Erasmus MC might assume the 800 beds as a given fact. In that case, they should know the consequences of this choice, for example on the availability for arriving patients. Insight in these consequences is therefore necessary. Additionally, the Erasmus MC calls for other measures to maintain their service level to the patients. One example is designing a separate day care center in the new building (3.5).

3.5 Day care patients

As mentioned in Section 2.2 there is some internal discussion about the location of hospitalization of day care patients. Before going into detail about the arguments for and against separate day care centers, we have to clarify some definitions and the decision context.

3.5.1 Definitions

Formally, the definition of day treatment is as follows: "A several hour care period in a hospital, generally foreseeable and necessary because of examination or treatment by a medical specialist at the same day." (NZA, 2006)

A common distinction exists between surgical day care (for recovery/observation after an operation) and non-surgical day care (for treatments like chemotherapy, blood transfusion, scope diagnostics and medicinal perfusion).

Currently, this distinction is also visible in the process design of both types.
For surgical day treatment and care, the patient checks in at the reception, where registration takes place. Subsequently, a nurse informs the patient about the operation during the intake, which takes place in the consultation room at the day care. Hereafter, the nurse prepares the patient for the operation in the beds room. Via the holding, the patient is brought to the OR, where the operation takes place using local or complete anesthesia. After the operation, the patient stays at the recovery (which is the same room as the holding) and is transported to the day care room to recover from the operation. At the end of the day, the medical specialist dismisses the patient and he/she can go home. Figure 4 gives an overview of this process for surgical day treatment and care.
To ensure fast availability of the specialist/anesthetist to the patient and to minimize transport of the patient, it seems favorable to locate surgical day care rooms near the OR complex, where treatment takes place.

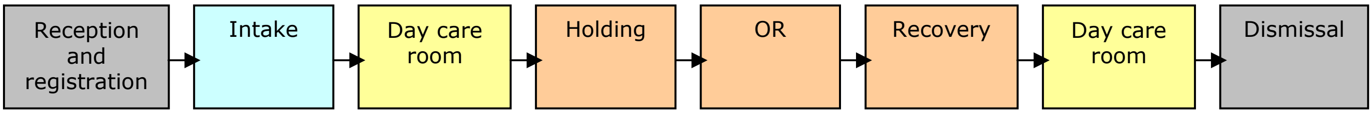

Figure 4: Process design of surgical day treatment and care (Kroon & Emmen, 2007)

For non-surgical day treatment and care, the first two steps of reception, registration and intake are identical to the surgical process. After the intake, the patient is brought to day care beds room, where both the treatment and after-care takes place. Finally, the medical specialist dismisses the patient and he/she can go home. Figure 5 gives an overview of this process for non-surgical day treatment and care.
It seems favorable to locate non-surgical day care rooms near the outpatient clinics and clinical wards, also for availability and transport reasons.

Figure 5: Process design of non-surgical day treatment and care (Kroon & Emmen, 2007)

In practice, there are also some gray areas between day care and clinical hospitalizations. First, none of these terms are bounded to minimum or maximum length of stay. This can be confusing. Second, several treatments usually can be executed in day care, except for patients with co-morbidity (for example diabetes/coronary patients undergoing surgery). The physical status of the patient is usually decisive in the choice between day care and clinical hospitalization. This condition is reflected in the so-called American Society of Anesthesiologists (ASA) score, which is preoperatively assessed by the anesthesiologist. Third, patients might suffer from an unforeseen reaction on the treatment, so extra observation is necessary. This means a day care admission is converted to a clinical admission. Fourth, there is a group of clinical patients that has some characteristics in common, but should not be confused with day care patients. So-called short-stay patients are also predictable, but stay for a longer period in the hospital compared to day care, at most four nights. Just like day care patients, short-stay patients arrive and leave during office hours. Short-stay facilities are also empty/closed during the weekend.

Clearly, the situation regarding day treatment and care is not as straightforward as the definition stated in the beginning of this section. This has some consequences for the methodology of this research. Section 5.3 describes how this research deals with the distinctions and gray areas mentioned above.

3.5.2 Decision context

Nowadays, the Erasmus MC has one central separate day care center to be used by approximately 11 specialties: ENT, Oral surgery, Plastic surgery, Traumatology, General surgery, Gynecology, Urology, Dermatology, Orthopedics, Gastroenterology and Anesthesiology. Besides, Neurology uses the outpatient's operations (called PKV's in Dutch). (Smit, 2008)
Within the Erasmus MC, there is a lot of disagreement whether this center should be maintained, expanded or closed in the new building of 2015. For example, opponents of the center argue that it is too small to be cost-effective and the Erasmus MC should decline day treatments. Supporters say that such a center can execute care processes very efficiently and it should be expanded to more non-surgical treatments as well. Others plead for a surgical day care center but think it is not a good idea to unite surgical with non-surgical activities. Section 3.5.3 discusses the pros and cons of day care centers in more detail.

There clearly is a lot of uncertainty, since it is not decided yet if the surgical day care center will be maintained, expanded or closed in the future. Besides, there are numerous options, because each theme may be included or excluded.
Table 5 displays the number of day treatments per theme in the recent past and the provisional future number of beds. The provisional future number of beds is calculated using the numbers of 2004, a norm efficiency of 90% and 250 workdays.

Theme	**Production 2004**	**Production 2006**	**Provisional future number of beds**
1	1,808	1,888	8
2	7,722*	7,722*	32
3	3,736	2,340	12
4	1,897	1,071	10
5	938	938	6
6	6,278	7,818	32
Total	22,379	21,777	100

Table 5: Production of day care (Kroon & Emmen, 2007)
* *Excl. cytostatica*

Most important, the consequences of in- or excluding certain themes from a center are unclear to all parties. One might think it does not make much difference in needed bed capacity whether day care is organized in centers or not. So in that way, 100 beds would be needed, no matter what organizational decisions are made. This research project will show that this reasoning is too shortsighted and capacity decisions should not be made without considering economies of scale (that occur in large departments). Also, some theme's managers indicate they do not want to participate in a day care center because they think differences between the themes in patient groups and treatment manners are too significant. However, presumably this is because they do not realize the advantages of merging departments. So this research is executed to visualize the consequences of different organizational scenarios. Doing so, the Erasmus MC's managers can make well-founded decisions about the future organization.

Therefore, the methodology described in Section 5.3 will be applied to patients of all themes. However, Chapter 9 will take the organizational difficulties into account and shows results that are most relevant for the Erasmus MC.

3.5.3 Arguments pro and con

The discussion concerns whether it is better to take care of these patients all in the wards of the corresponding theme (clinical setting) or to introduce a separate day care center for all different groups. Supporters of the latter option (a separate day care center) argue:
- Patients should receive the care adjusted to their needs. This aspect also involves experience issues: day care in clinical setting might cause unnecessary anxiety among patient and his/her family.
- Organizing day care in a separate department gives clarity to staff and specialists as well as to patients.
- Specialization results in efficiency. Day care departments involve planned patients and mostly routine operations, so processes can be standardized and organized very efficiently.
- Day care patients cause commotion when accommodated at the clinical wards. Because of their short LOS, day care patients cause many patient replacements and transport. This can be confusing for nurses and/or other patients at the wards. Also, it results in more setups at the clinical wards, so bed efficiency decreases.

Arguments in favor of hospitalizing all patients at the same wards with clinical patients are:

- Patients should receive the care fitting their disease. When patients are admitted at the ward of their disease category (specialty of theme), staff is more competent compared to one combined day care center for all patients.
- Minimization of staff movements. If all patients of the theme stay at the same location, staff members (e.g. specialists) do not have to move between the clinical wards and day care center.
- In case day care patients have to stay over the night, admission management is easier: the patient already has a bed at the right clinical ward.
- Day care patients can improve clinical ward efficiency. Because of their short and low variable LOS, day care patients can "fill the gaps" in capacity planning and increase efficiency as a result.
- Commotion caused by day care patients at the Erasmus MC's wards is lower than expected. The new building will contain only individual rooms, so patient replacements do not confuse nurses and/or other patients at the wards that much.

So each configuration has its advantages and disadvantages, caused by its organizational consequences. These implementation issues will be more extensively discussed in Chapter 12.

3.6 Conclusion

This chapter provided an answer to the questions of how wards currently manage patient admissions, how patients will be distributed over the 6 themes, what the provisional bed allocation over the 6 themes is and which positive and negative aspects a separate day care center can bring out. Together, these aspects make up the organizational context of this research. This context first influences the methodology that is used to analyze bed availability and efficiency (Chapter 5). Furthermore, the distribution of patients over the 6 themes settles patient arrival numbers and LOS to the wards of these themes (Chapter 6). Also, together with the provisional bed allocation over the 6 themes, it determines ward availability and efficiency rates (Chapter 8). Finally, the organizational context also influences what methods can be used to analyze bed availability and efficiency based on capacity, arrival rates and LOS. This theoretical framework is outlined in the next chapter.

4. Theoretical framework

Chapter 3 stated a number of 298504 inpatient hospital days in 2007. One would say that if all beds are 100% utilized, approximately $\frac{298504}{365}$ = 818 beds would be needed. However, an efficiency of 100% is very unlikely to occur. That is also what the Erasmus MC realized in determining the provisional bed configuration. Therefore, they used a standard efficiency (85% for clinical patients and 90% or higher for day care patients, see Sections 3.4 and 3.5) to calculate the total number of beds needed:

$$\text{Bed capacity needed} = \frac{\#\,\text{Inpatient hospital days per year}}{365\text{ days}\cdot\text{Efficiency standard}}$$

And equivalently, when bed capacity is decided upon, the realized efficiency is calculated using: $\text{Efficiency} = \frac{\#\,\text{Inpatient hospital days per year}}{\#\,\text{Operational beds}\cdot 365\text{ days}}$

As described in Section 2.1.2, this approach neglects some important logistic aspects and neglects availability of capacity. This chapter subsequently describes the following aspects that cause this lack: inpatient hospital days (4.1), conflicting objectives (4.2), variability (4.3) and queuing theory (4.4).

4.1 Inpatient hospital days

The first aspect is a definitional one and regards the registration of inpatient hospital days. To be precise, this parameter origins from the hospital's financial administration and is not based on the actual patient's LOS at the ward. The definition of hospital day is as follows: "… a calendar day, that is part of a period from admission to dismissal where both the day of admission (if taken place before 8 p.m.) and the day of dismissal can be registered as a calendar day." (NZA, 2006)

Consequently, the registered number of inpatient hospital days per year does not equal the sum of all patients' LOS in that year. On the one hand, a hospitalization period of less than 24 hours might be registered as one whole inpatient hospital day. So with one bed within one actual day multiple inpatient hospital days can be achieved. As a consequence, the efficiency –when calculated using the formula mentioned above- might exceed the 100% limit.
On the other hand, one inpatient hospital day might actually be a hospitalization period of more than 24 hours (since admissions after 8 p.m. are not counted).
To provide a better insight in the efficiency of a ward, one should therefore use the actual number of patients present instead of the financial parameter inpatient hospital days (De Bruin, Nijman, Caljouw, Visser & Koole, 2007): $\text{Efficiency} = \frac{\text{Average}\,\#\,\text{patients in service}}{\#\,\text{Operational beds}}$

4.2 Conflicting objectives

Logistics is concerned with costs versus service level. So performance does not only involve efficiency. The same holds for health care, and even to a greater extent: see Figure 6.

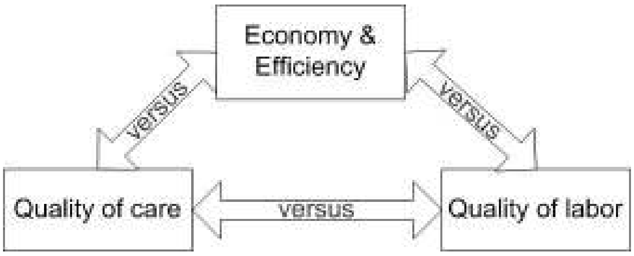

Figure 6: Health care performance from conflicting perspectives (Armado & Dyson, 2005)

First, health care can be considered from the perspective of the patient: in this sense, a hospital's performance considers quality of care. Quality of the care involves both effectiveness and availability of the service. In this report, we focus on availability and leave medical effectiveness out of scope.

Second, a hospital's performance can be considered from the perspective of management: by doing this, economy and efficiency indicators will become more important. Figure 7 shows the different focus of these two perspectives: management issues mainly concern the way money is converted into input resources (like beds, personnel, etc.) and the way these inputs transform into outputs like the number of hospitalization days. On the other side, patient issues have to do with the way outputs affect the outcomes, for example how a hospitalization and/or treatment improves the patient's health (quality of care).

Figure 7: Health care effectiveness differs from economy and efficiency performance indicators (Carter, 2005)

The third conflicting objective stated in Figure 6 is quality of labor and mainly matters to the hospital's specialists and nurses. Indicators representing quality of labor are e.g. workload, amount of overtime and (ir)regularity of work schedules. The last objective might conflict with patient's preferences, for example regarding the treatments' moment of time. Also, it conflicts with management's preferences, as increasing efficiency might increase workload.

As mentioned in Chapter 2, we do not investigate personnel issues in this report. So the quality of labor aspect is out of scope. However, both quality of care and efficiency are central in this study. Chapter 5 explains the way we measure quality of care and efficiency.

4.3 Variability

In many instances, the underlying reason for degraded performance stems from variability, in both process times (LOS) and arrival rates. For ones not familiar with the term variability, Appendix A gives an explanation.
Low variable LOSs have most of its probability concentrated near the mean. Higher variability LOSs are characterized by most likely times lower than the mean. In the low variable case the probability for high LOS is almost zero, where higher variable cases face higher probability LOSs will be extremely long. (Hopp & Spearman, 2000)
As a result, a large group of patients (let's say 80%) will leave the hospital within a short period of time. The remaining small group (20%) has a prolonged LOS and occupies a relatively great part of the available resources (up to 80%) and causes a large fraction of operational problems. This phenomenon is known as Pareto's law (or the 80/20 rule) and is recognized in many quantitative studies. (de Bruin et al, 2006)

A mathematical modeling study (Gallivan, Utley, Treasure & Valencia, 2002) shows the tremendous impact of variability on capacity requirements. The LOS at clinical wards is usually highly variable (Green & Hguyen, 2001). This is also the case in the Erasmus MC: as we will see in Section 6.3, the patients' LOS as well as the arrival rates vary between the themes and per patient type. Also, the variability within each theme and patient type will turn out to be considerable.

4.3.1 Flow variability

In case of multiple workstations in line, another type of variability – flow variability – plays a role. That is because departures from one workstation will be arrivals to next workstations. The following figure shows this is also the case for arrivals to the hospital's wards.

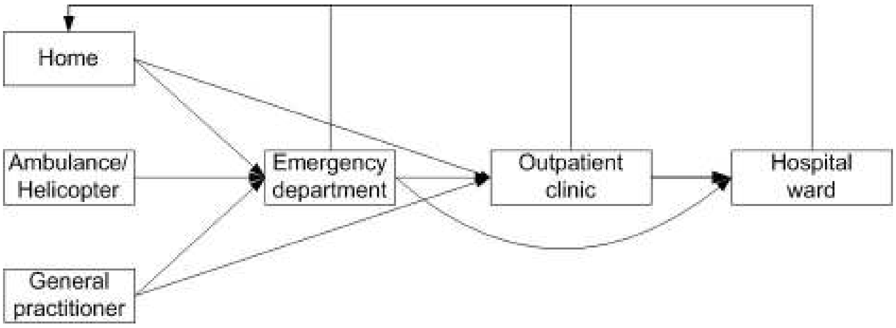

Figure 8: Flow diagram arrival to the hospital wards

Variability in for example the ED's departures c_d depends on both variability in arrivals to the ED c_a and the ED's process time variability c_e. The utilization u of the ED determines the relative contribution of these two factors:

$$c_d^2 = u^2 c_e^2 + (1-u)c_a^2$$

From this formula we can see that if the ED is very busy (utilization close to 1), departures are almost identical to the process times. On the other hand, if the ED is very lightly loaded (utilization almost 0), merely the arrivals determine departures.
At this point, we only mention this phenomenon to give a complete representation of factors influencing bed utilization at the Erasmus MC. At a later stage (from Chapter 7 on) it plays a part in determining an appropriate model to represent the provisional situation.

4.3.2 Economies of scale

As mentioned above, hospitals often use a standard efficiency to calculate the number of beds needed. The target of 85% developed at the federal government level in the 1970's is still widely used as a golden standard within hospitals (Green, 2002). Studies of de Bruin et al (2006, 2007) and Green (2002, 2004) show the impact of economies of scale and its applicability to health care processes. From an Operations Research perspective, the golden standard is counterproductive.
Figure 9 illustrates efficiency of 85% might be adequate for ward A (with length of stay of 6 days and 20 admitted patients per day). For the smaller ward B (with LOS of 6 days and 2 admitted patients per day), 85% efficiency results in an availability of only 64%. The other way around: Wards with higher bed capacity appear to be able to function at a higher efficiency while maintaining equal refusal numbers than smaller wards.

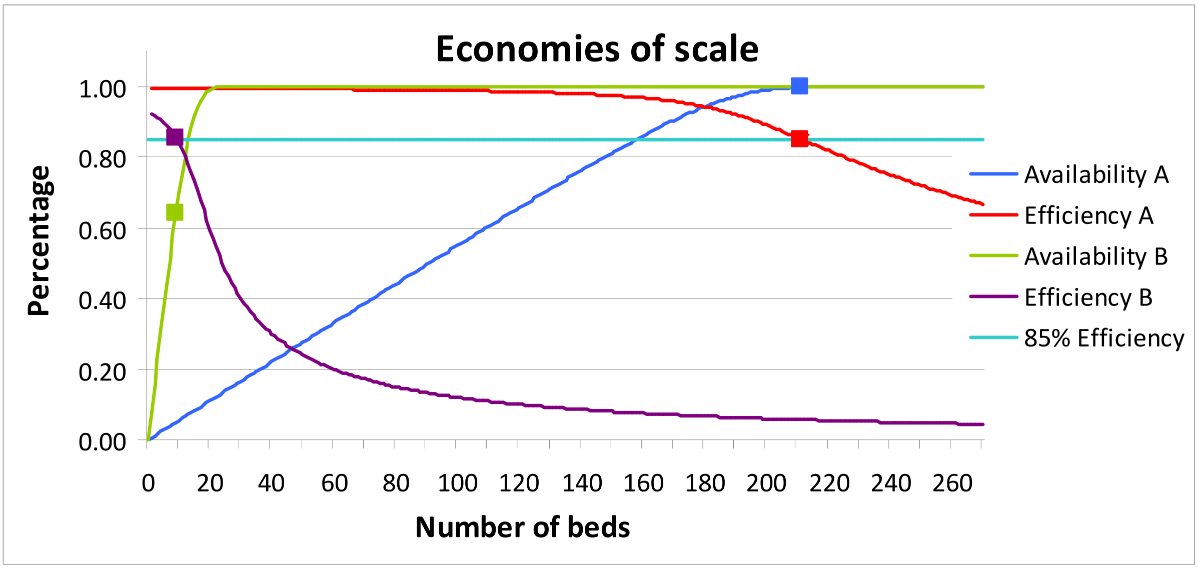

Figure 9: 85% Efficiency is not suitable for small hospital wards

So forcedly sticking to the 85% target might result in an excessive number of refused admissions, particularly for smaller units. On the other hand, merging departments can increase operational efficiency to a great extent. This finding is quite commonly known from queuing theory. Smith and Whitt already indicated in 1981 that the appropriate level of server efficiency typically increases with capacity. Later on, quantitative approximations and the effect of variability in arrival and service processes were studied (Whitt, 1992). However, such theoretical principles are not embraced by the health care sector yet. In this research we show whether this can be justified or yield major opportunities and hospitals should embrace such principles and use them to their advantage.

4.3.3 Variability pooling

The economies of scale mentioned above can be understood using the concept called variability pooling (Hopp & Spearman, 2000), in financial planning also known as the portfolio effect. Since variability always degrades the performance, one searches for ways to reduce this variability. One way to do this is by combining multiple sources of variability, because the combined independent random processes' variability is less than the sum of the variability of the individual processes.

There are many important manufacturing applications of variability pooling, for example batch processing, safety stock aggregation, queue sharing, late customization and flexibility. Considering the example of batch processing, the process time's coefficient of variation (CV, which is a measure of relative variability, as explained in Appendix A) of a single part equals c(part), while the CV of the time to process a batch of n parts is $c(batch) = \frac{c(part)}{\sqrt{n}}$ (see Hopp & Spearman (2000) for the complete derivation).

Thus, the CV of the process time decreases by one over the square root of the batch size n. This is because extremely long or short process times for all n parts are highly unlikely to occur. So the batch tends to "average out" the variability of individual parts.

Similar effects show up in case of queue sharing. Instead of each machine/server/bed having its own arrival stream, the arrival streams are combined into one stream. As a result, average waiting time decreases. This is because arrivals will be served by another machine/server/bed then the one experiencing a long process time. Therefore, long process times no longer have such damaging effects on average waiting time.

Hospitals can also benefit from applying variability pooling techniques: decreased variability results in less needed buffer (beds reserved for emergency admissions). First, the new patient-centered organization of the Erasmus MC's wards (see Section 3.3) might result in reduced variability. Combining multiple specialties into themes and making beds usable for all patients can dampen demand peaks of one specialty by rest capacity of another specialty. As a result, the combined wards of Erasmus MC might need less bed capacity than the sum of dedicated wards per specialty. Research indicated these effects indeed show up (Westeneng, 2008).

Second, the benefits of queue sharing appear when introducing an observatory at the Emergency Department. In this respect, the observatory is a flexible facility for all patients awaiting hospital admission, no matter at which ward. Additionally, the phenomenon called leaving the queue might occur. That is to say, some patients in the observatory can be sent home again even before they arrive at the wards. So besides increasing the plannability of emergency admissions, the observatory also results in lower demand at the hospital's wards. Several researchers (Visser, 2008, VUMC, 2006, Smeets et al, 2008 & Roskam, 2007) showed these positive effects of an observatory, but also reveal negative aspects. Currently, researchers at the Emergency Department investigate whether the Erasmus MC should introduce an observatory and which patients categories are eligible for this facility.

Third, both separate day care wards and integration into the clinical wards call for flexibility and the accompanying need for cross-trained workforce. That means, by treating all day care patients from all specialties in one combined ward or by admitting these patients in clinical beds, variability pooling effects can arise. As already explained in Chapter 2, this is the subject of this report. The effects will be analyzed in Chapter 9.

4.4 Queuing theory

A well-known theory to determine systems' efficiency is queuing theory. See Appendix B for the so-called Kendall's notation frequently used to describe queuing systems.

4.4.1 Arrival process

So besides the patients' LOS, another factor influences the number of patients present at the ward: the patients' arrival process. Little's law describes the relation between these factors: $L = \lambda \cdot W$ where L represents the average number of patients present, λ is the average arrival rate per unit time and W the average time a patient spends in the system (Little, 1961). This W is composed of the average time the patient spends waiting (W_q) and the average time in service (W_s, also referred to as $\frac{1}{\mu}$). Equivalently, L is composed of the average number of waiting patients (L_q) and the average number of patients in service (L_s).

Operations Research applications in health care vary in the choice of queuing system.
Some choose the Erlang Loss model (Davis, Massey & Whitt, 1995) to represent health care processes with limited bed capacity, while others propose a time-dependent model. Sections 4.4.2 and 4.4.3 respectively explain the essences of these two models. Chapter 9 further discusses the application of these models in this research.

4.4.2 Erlang Loss model

Former research (Green & Nguyen, 2001) uses the M/M/s queuing model to describe hospital capacity systems. This model assumes a Poisson arrival process, with exponentially distributed service times, s servers and infinite number of present patients. The size of the calling population is infinite and the service order is a general queue discipline. Since each patient finding no free server (bed) upon arrival waits until one becomes available, this is a delay system (Tijms, 2003). However, this model is only valid in case of waiting lists and infinite waiting possibilities. In reality, hospitals face bounded waiting times for many patient categories.

Moreover, a phenomenon called blocking (Hopp & Spearman, 2000) might occur in reality. That is to say, queues never become infinite, so the total number of patients present in the system is also bounded by a number *b*. The notation M/M/s/b represents this queuing model. As a result, an arriving patient leaves in case the system is full (these are the refusals mentioned in Chapter 2). So to evaluate the performance of such a system, we have to analyze the efficiency and the number of refusals.

With b=s, the Erlang Loss model –that Winston (2004) calls Blocked Customers Cleared (BCC) system- is a specific case of the M/M/s/b model. Opposite to delay systems, patients finding no free bed upon arrival are lost and have no further influence on this M/M/s/s system (Tijms, 2003). Because there is no waiting line, the average number of present patients in the system mentioned in Section 4.4.1 equals the average number of present patients in service (L_q=0, so L=L_s and W_q=0, so W=W_s). This L_s is also known as the load of the system (ρ) and can be calculated by multiplying the average arrival rate with the average service time: $L_s = \lambda \cdot W_s = \frac{\lambda}{\mu}$, which is always smaller or equal to s.

The fraction of patients blocked in the long run equals: $P_{loss} = \dfrac{\left(\dfrac{\lambda}{\mu}\right)^s / s!}{\sum_{k=0}^{s}\left(\dfrac{\lambda}{\mu}\right)^k / k!}$

Where λ is the arrival rate and $\frac{1}{\mu}$ is the average service time, $\frac{\lambda}{\mu}$ the workload offered to the system and s the number of beds. The fraction of patients that do enter the system logically equals $1 - P_{loss}$. Therefore, we have to adjust the formula mentioned in Section 4.2 into:

$$Efficiency = \frac{(1 - P_{loss}) \cdot \lambda}{s \cdot \mu}$$

Above formulas also apply in case of other service time distributions (M/G/s/s). Intuitively, this may seem strange because more variable LOS distributions increase the probability of extremely long LOS. As a consequence, such systems would require more buffer capacity. However, higher variable LOS distributions also increase the probability of extremely short LOS. Because servers are parallel and homogeneous (can be used by all patients) the probability that all servers are occupied is insensitive to the LOS distribution.

Another variant is the Engset model (Erlang loss model with N≠∞). However, we assume an infinite source of patients, so this Engset model will not be considered. Also, the Erlang loss model appeared to be very accurate to represent in-patient flow in previous studies (de Bruin et al, 2006&2008 and McManus, 2004).

4.4.3 Time-dependent model

Although the Erlang loss model explained above seems to accurately describe the number of patients present, it has one restriction: it assumes Poisson arrival rates, independent of time. However, this does not entirely match with reality: arrival rates to most clinical wards are usually higher during office hours in weekdays, outside holidays. This effect especially occurs in case of a relatively large fraction of scheduled arrivals. Therefore, Bekker and de Bruin (2008) propose the time-dependent M_t/H/s/s model. Especially the week-weekend pattern appears to have impact on refused admissions. An Australian case study (Harrison, Shafer & MacKay, 2005) also reveals daily, weekly and seasonal demand patterns and argues peak-based bed capacity decisions result in vacant beds during off-peak periods. As will be seen in Chapter 7, such seasonal effects also occur in the Erasmus MC.

4.5 Conclusion

This chapter investigated what methods can be used to analyze bed availability and efficiency based on capacity, arrival rates and LOS. In Chapter 7, these methods will be used to formulate a model to represent the provisional situation and the effects of a day care center.

5. Methodology

As described in Chapter 3 and 4, the Erasmus MC uses a standard efficiency of 85% to calculate the total number of beds needed and the realized efficiency as output criterion.
Although this output parameter is important, it does not tell us what we actually want to know and can be misleading as a measure of performance (Slack et al, 2007), since large wards can operate at a higher efficiency while maintaining the same service level as smaller wards. This study will verify and illustrate this statement in the Chapters 8 and 9.
Besides, most decisions are based upon averages. However, as mentioned in Chapter 4, care processes are characterized by high variability in process and arrival times.
Good performance measurement does not only use efficiency criteria, but also criteria that measure quality of care, like delay or number of refusals.
This chapter explains the methodology we use to measure both quality of care (5.1) and efficiency (5.2) and the way data should be collected and processed (5.3). Finally, Section 5.4 describes which scenarios regarding day care center(s) are assessed.

5.1 Availability

As mentioned in Section 4.2, quality of the care involves both medical effectiveness and availability of the service. We are able to determine the probability of an arriving patient being refused or not, in case of a given number of available beds. 1 - P_{loss} (with P_{loss} as the fraction of patients blocked in the long run, as mentioned in Section 4.5.1) will be called availability and is used to measure the service level of hospital's wards. The Erlang loss formula mentioned in Chapter 4 will be applied. In case of an M/G/s/s system, the average number of present patients can be calculated as follows:

$$\text{Average number of present patients} = (1 - P_{loss}) \cdot \frac{\lambda}{\mu}$$

with $P_{loss} = \dfrac{\#\ \text{Refused patients}}{\#\ \text{Admitted patients} + \#\ \text{Refused patients}}$

Using this formula, we need to know the number of refusals and the arrival rate of all patients together (admitted + refused) = λ. However, the hospital's information system only registers the number of admissions and the number of refused admission is generally unknown.
So we have to approximate λ using the arrival rate of admitted patients from available data. The method of this approximation is described in Section 7.2.
By using the Erlang loss model and our approximation of λ, we are able to calculate the theoretical availability. For validation purposes, we also extract the actual number of present patients from the Erasmus MC's information system. Section 5.2 discusses the data processing methods used to convert the data of present patients to availability.

By doing this, we can determine the probability of an arriving patient being refused or not, for the provisional number of beds. And moreover, decide what bed capacity is needed to achieve the preferred level of availability.

5.2 Efficiency

High availability is preferred for arriving patients, since they will always be admitted at the right ward. As a consequence, high availability means less refusals and a small number of beds borrowed from other specialties.
However, high availability will result in low bed (and personnel) efficiency, which is not preferred from cost perspectives. Therefore, the Erasmus MC should be aware of the trade-off between availability and efficiency, as graphically represented in Section 4.2.
Determining adequate capacity level means balancing between availability and efficiency.
Recall from Section 4.5.1 that efficiency can be calculated by:

$$Efficiency = \frac{(1 - P_{loss}) \cdot \frac{\lambda}{\mu}}{s}$$

This formula is equivalent to the following definition of efficiency (Slack et al, 2007):

$$Efficiency = \frac{productive\ time}{effective\ capacity \cdot time\ capacity\ is\ available}$$

In a hospital setting, the productive time is the sum of the LOS of all patients (in days). The effective capacity equals the number of beds s. This number is harder to determine than expected at first sight. For example, we stated in Chapter 2 the Erasmus MC currently has approval for 1200 beds. However, Table 3 in Section 3.4 shows the design capacity is only 972 and the number of beds utilized in August and December 2007 is even lower. We decided to use the latter as a measure of effective capacity (see Section 6.4). The time capacity is available equals 24 hours per days and 365 days per year for clinical patients. However, day care centers are usually open only 260 days per year and 9 to 10 hours per day. The way we deal with this characteristic is explained in Section 7.2.

5.3 Data collection

As mentioned in Section 5.1, we use the number of present patients during the year to determine the bed availability at a certain capacity. Since this number of present patients is derived from historical data, it assumes current ways of planning elective patients. As explained in Section 3.2, admission planning might improve in the coming years. If so, the Erasmus MC needs fewer beds than the capacity advised in this study. However, to provide a realistic scenario, historical data is used initially.
This section explains the data collection and data processing methods to convert data obtained from the Erasmus MC's admission database into the number of present patients.

Data regarding patient admissions is collected using the management information system Business Objects[1] of the Erasmus MC. This results in a list of patients with the corresponding hospitalizations with the specialty, hospital location, department, date and time of admission and dismissal. Collected data is validated in interviews with the care managers of the six themes.

Subsequently, admission numbers and patients' length of stay over the year 2007 are determined. To prevent from missing some patients in the beginning and end of 2007, we include all patients that are admitted in 2006 or 2007 and dismissed in 2007 or 2008. Because of the changes in LOS and the number of patients in the last years, the year 2007 represents the current situation best (Westeneng, 2008). Sensitivity analyses will reveal whether this data also represents the future situation. Chapter 10 discusses these analyses including transferals to other hospitals, patients present in 2008 and expected patients in 2015.

We make a further distinction between patient categories based on their specialty, as mentioned in Section 3.3. Such distinction is necessary to determine the needed number of beds per theme. Appendix C displays the conversion table that is used to select the right theme for each specialty.
Note that oncology patients -that are nowadays formally registered at general surgery or internal medicine- actually should be registered at theme 2 (instead of theme 3). Therefore, we decide to allocate all patients currently admitted at the Daniel den Hoed location to theme 2 (regardless of their specialty). A comparative reasoning holds for children, which are admitted in the Sophia location. Therefore, theme 6 child is composed of all patients admitted in the Sophia location (with the exception of the specialty obstetrics, which is theme 6 adult).

[1] Universe: PAT ODS Opnames

We include the hospitalizations where the patient stayed at the specialty's own ward or in a borrowed bed from another specialty.
Admissions at the Intensive Care (IC) and Post Anesthesia Care Unit (PACU) are excluded: these will not be part of the six themes mentioned in Chapter 3. The same holds for patients of the specialties Psychiatry and Child and youth psychiatry: these will be accommodated in a separate facility. A list of excluded departments can also be found in Appendix C.

To process the collected data into the output parameters mentioned in Section 5.1, we apply data mining, which is sometimes called knowledge discovery in databases (KDD) and defined as finding strategic information hidden within a collection of data. This section explains how the data from the hospital's database is converted into the number of present patients.

Note that most admissions, dismissals and takeovers of clinical patients occur during the morning or afternoon. Therefore we can assume that the most clinical patients present at the end of the morning will be present in the afternoon and patients present at midnight will stay during the night. Day surgery hours are during weekdays from 8:00 in the morning to 15:30 in the afternoon. These patients need relatively short after-care, so it is best to measure both in the morning and in the afternoon.
Therefore, we would like to know the number of present patients at three fixed moments of each day, to be exact at 11:00, 15:00 and 00:00. Using the following calculation method, the presence of patients at these three moments of the day can be determined per DBC-code:

p = patients (1, 2, …, m)
t = measure moments (1, 2, …, n=1095)
x_{pt} = whether patient p is present at moment t
y_t = number of patients present at moment t

$$x_{pt} = \begin{cases} 1 \text{ if dismissal of patient } p \geq t \text{ and admission of patient } p \leq t \\ 0 \text{ otherwise} \end{cases} \qquad \forall p, t$$

$$y_t = \sum_{p=1}^{m} x_{pt} \qquad \forall t$$

Using the DBC conversion list mentioned in Appendix C, the patient can be allocated to the corresponding theme.

The admissions of theme 1 to 5 will be analyzed at theme level. For theme 6, we make a distinction between adults and children. Doing so, we also determine needed bed capacity at theme level, not at specialty level. The research of Westeneng mentioned in Chapter 4 already convinced the Erasmus MC sharing of beds within the themes yield major advantages and is organizationally achievable.

5.4 Day care

As already indicated in the gray areas described in Section 3.5, the spectrum with possible organizational configurations regarding day care centers is broad: from hospitalizing all patients (day care included) in the clinical wards to establishing separate day care centers for all specialties/themes. Several intermediate configurations exist, like only one separate day care center or separate centers for only some themes while other themes only use clinical wards.

To provide clear insight in the possible improvement, this study will investigate several scenarios. The scenarios most relevant for the Erasmus MC are:
- Establishing one separate day care center for all specialties/themes together, while hospitalizing all clinical patients in the clinical wards.

- Establishing one separate center for surgical day care for all themes, while hospitalizing all non-surgical day care patients in the clinical wards of their theme
- Establishing one separate center for surgical day care for all themes and several centers for non-surgical day care.
- Hospitalizing all patients in the clinical wards

We will investigate the effects of those scenarios in a similar way as described in Sections 5.1 and 5.2.

A straightforward and reliable way to distinguish day care patients from clinical ones is to select on type of admission. Namely, every admission is registered as one of the four following admission types:
1. Out-patient childbirth
2. Screening admission (preceding surgery)
3. Day care admission
4. Clinical admission

There are some internal rumors that part of the clinical admissions could be executed in day care, but are registered as clinical admissions because of financial reasons. As a consequence, the group of day care patients might be larger than registered as day care admission in the hospital's information system.
So we considered using the patient's DBC diagnosis code to determine whether the admitted patient can be treated in day care. However as stated in Section 3.5.1, the choice for day care or clinical care cannot be made that easily. Therefore, we will not decide upon diagnosis code, but use the specialist's decision (so the admission type) to calculate the number of present patients. So the group day care patients only consists of patients admitted as type 3. In Chapter 10, we will see what happens if we would increase the number of day care patients.
Type 2 admissions occur on Friday in case surgery followed by a clinical admission is planned next Monday. In fact these types 2 are the first parts of type 4 admissions.
Admissions of type 1 (out-patient childbirths) occur at another facility. Therefore, we will show this portion in Section 6.1, but will not include them in the capacity calculations in Chapter 7 and further.

In the continuation of this report, capacity is expressed in number of beds. This term encompasses also the chairs used for day care.
Besides, day care needs other facilities than just beds, like rest, preparation and after-treatment sites. Although these facilities are not focused upon in this research, it should be realized these facilities are necessary to provide appropriate care.

Nowadays, the surgical day care department also executes outpatient's operations (called PKV's in Dutch). However, these patients are not admitted and use other resources than clinical and day care patients. Also, in the new organization, PKV's will no longer be executed in the surgery complex, but at the outpatient's clinics. Therefore, they do not matter to our question of needed bed capacity and we will exclude these patients from our analysis. Patients that visit the outpatient's clinics for a treatment might also use non-surgical day care facilities. However, in case they care not admitted as day care, they will not be included in this research project.

5.5 Conclusion
This chapter gave answers to the questions of which assumptions should be made for the methodology and how changes caused by day care center(s) should be measured.
These methodological decisions will be used to study the trade-off between availability and efficiency in Chapter 8 and to determine the impact of merging day care departments with each other and with clinical departments (Chapter 9).

6. Patient characteristics

As already described in Section 3.1 the Erasmus MC's wards hospitalized 37,799 patients in 2007, which stay for approximately eight days on average. These figures count to a production of nearly 300,000 hospital days per year. Besides, 27,717 day treatments took place in 2007. Using the methodology described in Chapter 5, these 65,516 admissions together can be allocated to the themes. This chapter gives a more detailed analysis of these admissions. The first paragraph analyses the distinction into the patient's admission types (6.1). The second paragraph zooms in at one of the patient types, to be precise, at day care patients (6.2). The third paragraph discusses a characteristic that considers all hospital admissions: variability (6.3).

6.1 Patient's admission type

Section 3.1 already revealed that a considerable amount of the yearly hospitalizations concern day treatments. A simple analysis of the collected data confirms this: the blue parts in Figure 10 show that in some themes the number of day care patients exceeds the number of clinical admissions.

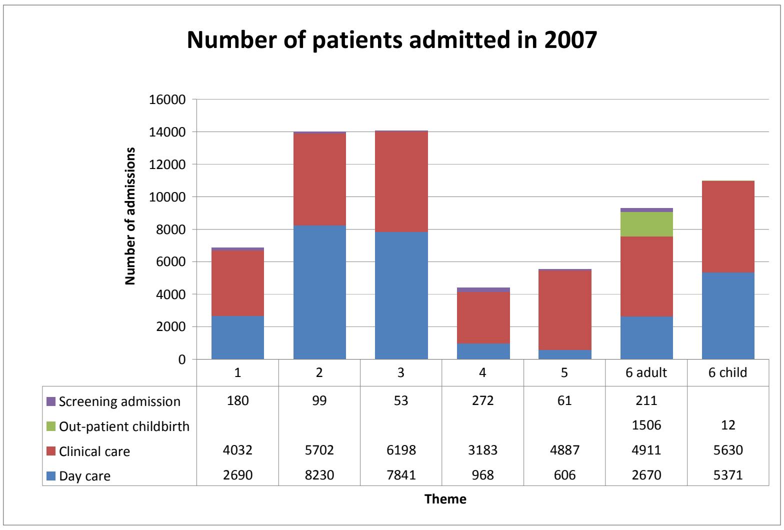

Figure 10: Admitted patients in 2007 allocated to the 6 themes, displayed per admission type (Psychiatry and Intensive Care excluded)

The fact that day care patients form such a considerable part of the hospitalizations does not automatically mean that the part of capacity these patients use is also that large. This is because day care patients usually have a much shorter length of stay than clinical patients: see Figure 11.

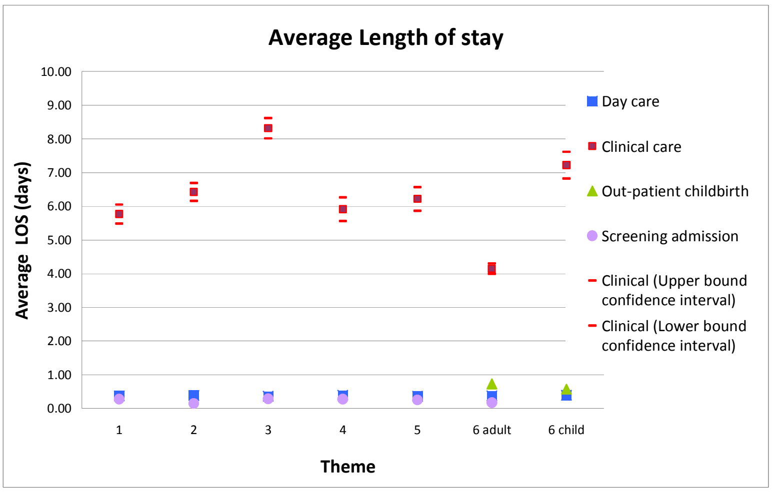

Figure 11: Average length of stay per theme and per admission type (Psy and IC excluded)

Day care patients stay 0.38 days on average, which is approximately 9 hours.
We see the average length of stay of clinical patients varies per theme: while theme 3 has a LOS of 8-9 days, adults of theme 6 only stay 4-5 days on average. Because of the patient mix of the themes (described in Section 3.3) this variation is not surprising.
Note that for clinical patients we do not only show the mean LOS but also the 95% confidence interval of the mean. For the other admission types, the lower and upper bounds almost equal the mean. So the confidence intervals provide no additional information and are therefore not displayed.

Figure 12 shows the sum of the length of stays per theme per admission type. We see day care patients only use a relatively small amount of bed capacity – despite the large portion of admitted patients they form (shown in Figure 10). This low bed occupancy by day care patients indicates it might not be profitable to establish separate departments per theme for such patients. Chapter 9 discusses this topic in more detail.

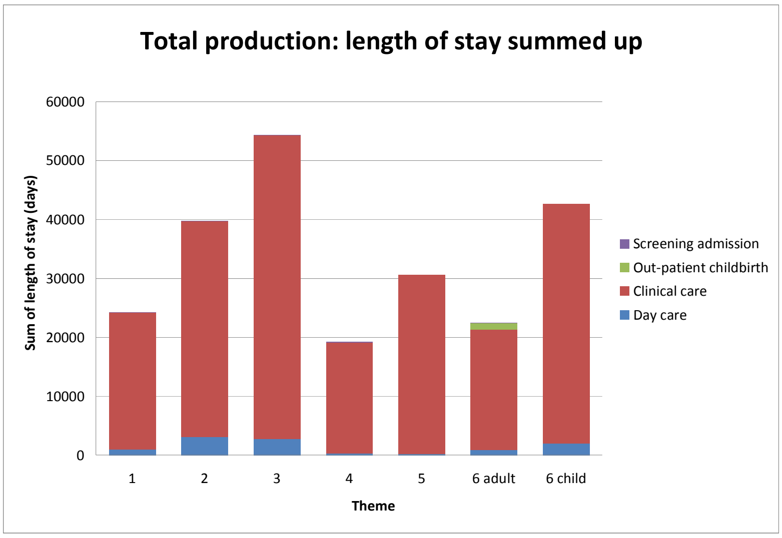

Figure 12: Length of stay summed up per theme and per patient type (Psy and IC excluded)

As mentioned in Section 5.3, admissions of type 1 (out-patient childbirths) occur at another facility and will not be considered from this point on.
Type 2 admissions are in fact the first parts of type 4 admissions, so the LOS of each type 2 should actually be added to the LOS of the corresponding type 4 admission. However, because of the small volume of types 2, we assume this compound LOS can be represented by the LOS of type 4 only. For the same reason, the type 2 arrival process will not be considered separately.
However, types 2 use the same bed capacity as types 4, so should be included when measuring the bed occupancy.

Type 3 admissions (day care patients) will be considered separately, because the volume is significant and because their bed configuration is explicitly subject of this study.

6.2 Admission process

As already described in Chapter 4, hospital admissions are heavily influenced by variability. This paragraph will show whether the admission process is characterized by high variability, for clinical and day care patients.

6.2.1 Admissions of clinical patients

Table 6 summarizes the basic admission statistics of the clinical admissions in 2007. The average number of clinical admissions per day was approximately 13.54 patients per day per theme, ranging from 8.72 for theme 4 to 16.98 for theme 3.
Also, we see relatively high variance, var/mean ratio and coefficient of variation. This means that the numbers of annual admissions per theme shown in Figure 10 are not

uniformly distributed over the year: the daily number of admissions varies within each theme. Note that variability in these admissions does not mean that planning is bad.
A good planning means that the present patients are mostly equal (not variable) from day to day. As will be seen in Section 6.3, the LOS is variable as well, deterministic admissions do not guarantee deterministic load. So good planning mainly means the admissions process is balanced with the departure process.

Theme	Mean	Var	Var/Mean	Cv
1	11.05	24.98	2.26	0.45
2	15.62	102.70	6.57	0.65
3	16.98	78.60	4.63	0.52
4	8.72	23.48	2.69	0.56
5	13.39	59.00	4.41	0.57
6 adult	13.45	35.01	2.60	0.44
6 child	15.42	46.98	3.05	0.44

Table 6: Number of clinical admissions per day (n=365) Psy and IC excluded

Many arrival processes have been shown to be well approximated by a Poisson process. We constructed histograms for clinical patients for each theme to test this hypothesis.
Figure 13 gives an example for theme 3, where the observed admission pattern is compared with the Poisson distribution with a mean of 16.98 patients per day.

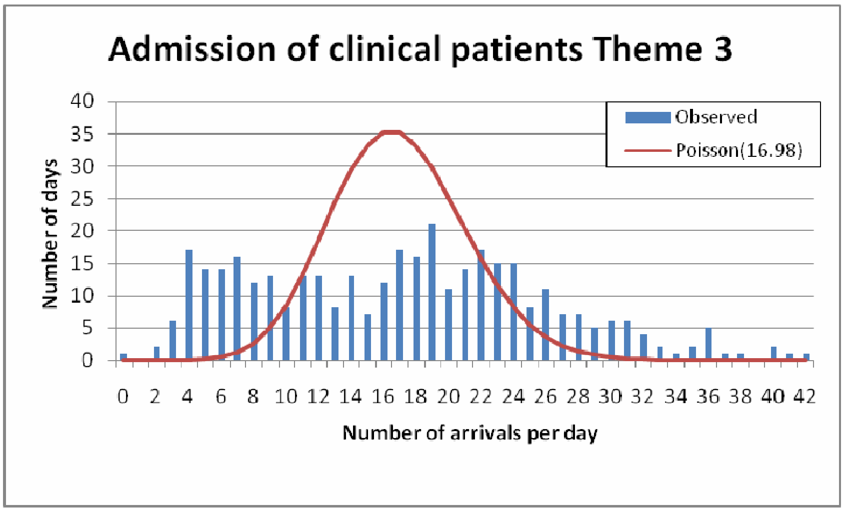

Figure 13: Distribution of clinical patients admitted for theme 3 per day (n=365)

Clearly, the Poisson distribution does not give a good fit with the observed admission pattern. It even looks more like a uniform distribution. A possible explanation that the number of admitted patients is generally lower during weekends compared to weekdays. Figure 14 shows the results when we split admission during weekdays from the weekends and proves the inadequacy of the uniform distribution.

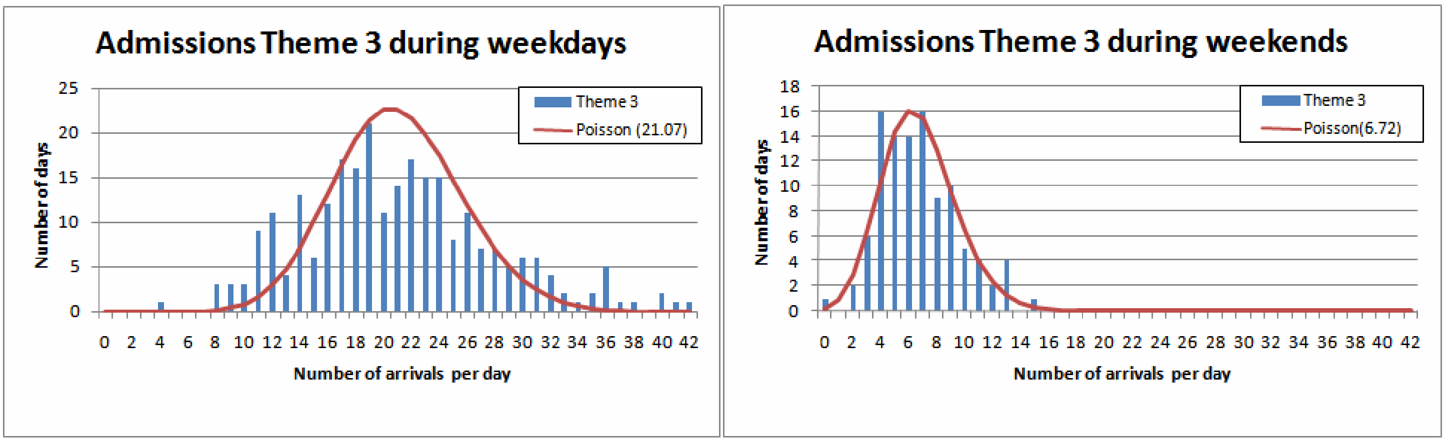

Figure 14: Distribution of clinical patients admitted for theme 3 split in weekdays and weekends

We see different admission patterns indeed: where weekdays seem to be represented by a Poisson process with on average 21.07 patients arriving per day, the weekends can be approximated by a Poisson process with on average 6.72 arriving patients per day. This distinction does not only occur for theme 3, but also for the other themes.
Table 7 shows the average number of admissions for each theme, split in weekdays and weekends.

Theme	Weekdays	Weekends	All
1	12.73	6.82	11.05
2	20.18	4.17	15.62
3	21.07	6.72	16.98
4	10.05	5.38	8.72
5	16.92	4.54	13.39
6 adult	15.90	7.32	13.45
6 child	18.56	7.56	15.42
Average	16.49	6.07	13.52

Table 7: Average number of clinical admissions split in weekdays and weekends
Psychiatry and Intensive Care excluded

Whether the Poisson process really gives a good fit when weekdays are split from weekends can be assessed using goodness-of-fit tests. A formal goodness of fit test is Pearson’s chi-square test. The execution of the test can be found in Appendix D.

We can therefore conclude a Poisson distribution can much better represent the clinical admissions if weekdays and weekends are considered apart from each other for each theme.
We also applied two other tests to the question whether the Poisson distribution with λ=Mean is rightly chosen to represent the daily number of admitted clinical patients per theme (see Appendix E). The result does not differ much from the Pearson’s chi-square test.

Compared to the tests mentioned above, higher statistical power (probability that the test will reject a false null hypothesis) can be obtained using the Poisson dispersion test (Rice, 2007).
This test is based on a special characteristic of the Poisson distribution: that is to say, mean and variance are equal. As a result the ratio $\frac{variance}{mean}$ equals 1. From Table 8, we see this ratio usually is a lot higher than 1 when we consider weekdays and weekends together.

Again, when we split weekdays from weekends, this ratio seems to become closer to what we expect from Poisson admissions (see Table 8):

Theme	Weekdays	Weekends	All
1	1.50	2.17	2.26
2	3.38	1.31	6.57
3	2.28	1.18	4.63
4	2.13	2.46	2.69
5	2.07	2.11	4.41
6 adult	1.51	1.37	2.60
6 child	1.51	1.07	3.05
Average	2.93	1.88	4.43

Table 8: Ratio var/mean of clinical admissions split in weekdays and weekends
Psychiatry and Intensive Care excluded

Under the null hypothesis, the test statistic $T = n \cdot \frac{variance}{mean}$ has a chi-squared distribution with n-1 degrees of freedom (with n = the number of observations). The execution of this test can be found in Appendix F.

The general conclusion is that for most of the themes the clinical admission process, if separated in weekdays and weekends, is described well by a Poisson distribution.

Chapter 7 will use this finding to formulate a model that represents bed capacity availability. A validation for this model can also be found in that chapter.

6.2.2 Admission of day care patients

In the previous section, we studied the admission process of clinical patients. Since day care patients consist only of scheduled patients, their admission process is expected to be less variable. Following a similar structure as Section 6.2.1, we will investigate here if this statement is valid.
As mentioned in Section 3.5, a common distinction exists between surgical and non-surgical specialties. Chapter 9 will analyze the effects when we no longer use this distinction. But in this section and in Chapter 8 we use the distinction as a starting point for day care.

Table 9 again summarizes the basic admission statistics. The average number of day care admissions per day was approximately 15.37 patients per day per theme, ranging from 2.32 for theme 5 to 31.50 for theme 2. Also, we see that the variances, var/mean ratios and the coefficients of variation are comparable with the figures of clinical patients. So in that respect, the admission process is not that different.

Theme	Mean	Var	Var/Mean	Cv
1	10.28	25.93	2.52	0.50
surg	3.54	11.73	3.31	0.97
non-surg	6.74	16.14	2.39	0.60
2	31.50	72.84	2.31	0.27
surg	1.80	2.44	1.36	0.87
non-surg	29.70	68.95	2.32	0.28
3	30.00	66.85	2.23	0.27
surg	1.21	7.41	6.14	2.26
non-surg	28.80	76.84	2.67	0.30
4	3.70	12.02	3.24	0.94
surg	3.70	12.02	3.24	0.94
non-surg	0.00	0.00		
5	2.32	4.36	1.88	0.90
surg	0.00	0.00		
non-surg	2.32	4.36	1.88	0.90
6 adult	9.22	23.04	2.50	0.52
surg	2.72	6.63	2.44	0.95
non-surg	6.51	10.38	1.60	0.50
6 child	20.54	45.79	2.23	0.33
surg	8.52	15.44	1.81	0.46
non-surg	12.02	20.24	1.68	0.37

Table 9: Number of day care admissions per day (n=261) Psychiatry and Intensive Care excluded

Considering the characteristics, the day care admission processes might also be well approximated by a Poisson process. Figure 15 gives an example for non-surgical patients of theme 2, where the observed admission pattern is compared with the Poisson distribution with mean of 29.70 patients per day.

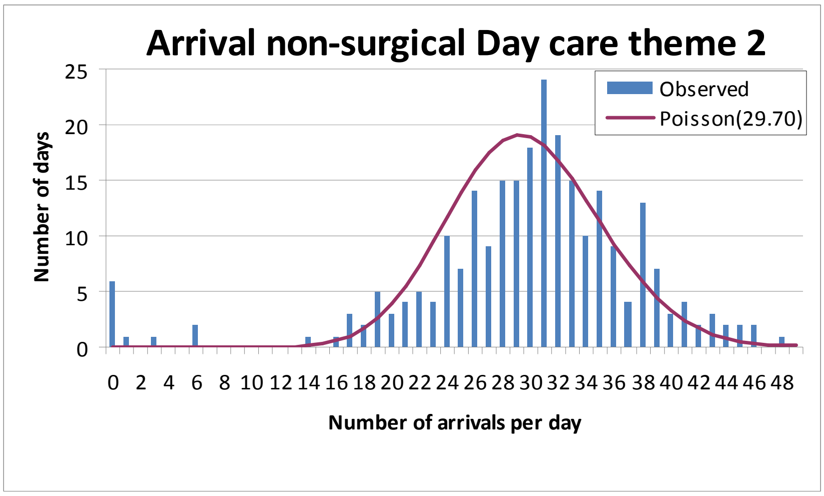

Figure 15: Distribution of day care patients admitted for non-surgical patients of theme 2 per day (n=261)

Clearly, the admission of patients is not as deterministic as assumed and the Poisson distribution gives a reasonable good fit with the observed admission pattern. This does not only occur for non-surgical patients of theme 2, but also for the other themes. Whether the Poisson processes with λ=Mean as stated in Table 9 really give a good fit can again be assessed using goodness-of-fit tests. The execution of these tests can be found in Appendix G.

Pearson's chi-square test indicates the Poisson distribution is a not very good representation for the observed day care admissions. The Kolmogorov-Smirnov, Anderson-Darling and Poisson dispersion test confirm this conclusion.
However, as will be shown in Section 7.2.2, the Erlang loss model still is a very useful model for our study objectives.

6.3 Length of stay

Information of average LOS as stated in paragraph 6.1 is important, but does not give any information about the variation in LOS. This variability (differences between patients' LOS - see Section 4.3) influences the possible extent of planning and efficiency at the ward.
The commonly used measure CV (coefficient of variation, see Appendix B) shows a difference between the LOS of clinical and day care patients. From Table 10 we see that the clinical patients' LOSs have relatively high CV's, which means LOS does not only vary between the themes, but also within each theme. So the theory of variable LOS we expressed in Section 4.3 especially holds for clinical care patients.

Theme	Clinical care		
	ALOS	StDev	Cv
1	5.77	9.13	1.58
2	6.42	10.32	1.61
3	8.32	12.18	1.46
4	5.91	10.09	1.71
5	6.22	12.57	2.02
6 adult	4.15	5.52	1.33
6 child	7.22	15.14	2.10
Average	6.42	11.35	1.77

Table 10: LOS characteristics clinical patients

Theme	Surgical			Non-surgical		
	ALOS	StDev	Cv	ALOS	StDev	Cv
1	0.41	0.04	0.10	0.36	0.07	0.20
2	0.36	0.08	0.23	0.38	0.05	0.13
3	0.38	0.04	0.11	0.36	0.08	0.21
4	0.39	0.06	0.16	0.00	0.00	
5	0.00	0.00		0.37	0.06	0.17
6 adult	0.40	0.05	0.12	0.36	0.10	0.29
6 child	0.41	0.04	0.10	0.38	0.05	0.13
Average	0.40	0.05	0.13	0.37	0.07	0.18

Table 11: LOS characteristics day care patients

For day care patients, this CV is usually a lot lower, so patient's LOS is less variable.
Because of the high CV, clinical patients' LOS might be exponentially distributed and the M/M/s/s model (mentioned in Section 4.5.1) would be very appropriate. For day care patients this does not hold.
However, as explained in Chapter 4, this is no problem for the Erlang loss model because the formulas also hold for all other service time distributions.

Nevertheless, the difference in LOS variability is an extra reason why it might be advantageous to separate day care from clinical patients. To be precise, for day care patients it will be easier to predict the dismissal time and to balance admissions to this departure process. So it will be easier to plan these patients and achieve a higher efficiency.

6.4 Efficiency

The result of both admissions and LOS is the occupancy, which can be calculated using the formula:

$$Occupancy = \frac{\text{Average number of occupied beds}}{\text{Number of operational beds}} = \frac{\text{Admissions (per day)} \cdot \text{Average LOS (in days)}}{\text{Number of operational beds}},$$

which is always smaller or equal to 100%.
This occupancy is the same as the efficiency used earlier in this report. To prevent confusion, we will use the term efficiency for this variable.

In Section 6.2, we saw the number of admissions per weekday differs from the number of admissions during the weekends. The efficiency calculated using the formula above differs dependent on which admission rate is used.
Table 12 shows the efficiency per theme for clinical patients, where the number of operational beds is based on the number of beds utilized in December 2007 mentioned in Table 3 (Section 3.4). For the distinction between adults and children of theme 6, we consulted this theme's manager.

			Weekdays + weekends			Weekdays only		
Theme	**# beds**	**ALOS**	**Adm**	**Occ beds**	**Eff**	**Adm**	**Occ beds**	**Eff**
1	70	5.77	11.05	63.71	91.0%	12.73	73.43	104.9%
2	159	6.42	15.62	100.36	63.1%	20.18	129.67	81.6%
3	176	8.32	16.98	141.22	80.2%	21.07	175.22	99.6%
4	74	5.91	8.72	51.55	69.7%	10.05	59.41	80.3%
5	91	6.22	13.39	83.23	91.5%	16.92	105.15	115.6%
6 adult	68	4.15	13.45	55.82	82.1%	15.90	65.97	97.0%
6 child	117	7.22	15.42	111.35	95.2%	18.56	133.98	114.5%
Total	**755**							

Table 12: Efficiency per theme for clinical patients

In general (for weekdays and weekends together) the efficiency varies from 63.1% for theme 2 to 95.2% for theme 6 child. When we consider admissions during weekdays only, the efficiency exceeds 100%. This can be explained by temporarily opening a few extra beds in periods when patient demand is high. Of course this puts the available staff under great workload, as described in Section 3.2.
In the Erlang loss model, the efficiency can not exceed 100% because the number of beds is fixed. We will see in Section 7.2.1 that for all themes except theme 2, the arrival rate exceeds the admission rate and refusals occur ($P_{loss} > 0$).
Section 7.3 will show which arrival rate (weekdays only or weekdays and weekends together) represents reality best. This arrival rate will be used in the model.

Because the number of operational beds for day care patients per theme is usually unknown, we cannot calculate the efficiency for this category. Chapter 7 will explain the way this study deals with this fact.

6.5 Conclusion

This chapter described the patient admission numbers and LOS in the future theme organization, based on current patient characteristics and the way patients will be distributed over the 6 themes.
These admission numbers and LOS will be used in Chapter 7 to formulate a model that represents the provisional situation. Chapter 8 uses this model to evaluate the provisional bed allocation over the 6 themes (already stated in Section 3.4).

7. Mathematical model

This chapter describes the relevant model, based on the models available from theory (Chapter 4), the patient admission rates and LOS characteristics (Chapter 6). First, it will explain the model we choose to use and why (7.1). Second, we describe the input parameters needed to apply the model (7.2). Finally, we validate the usage of the model (7.3).

7.1 Erlang loss queuing model

As described in Section 4.5, the Erlang loss model seems to be very accurate to represent hospital capacity systems. The model is graphically displayed in Figure 16.

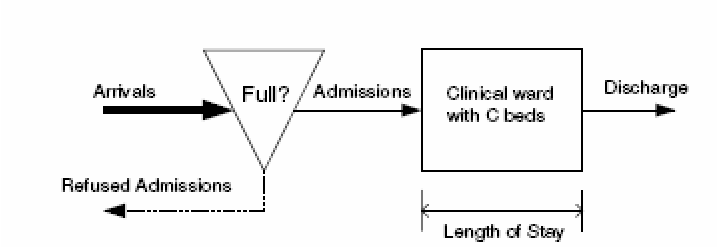

Figure 16: Patient flow through a clinical ward (de Bruin et al, 2008)

Recall that this model assumes a phenomenon called blocking (so no waiting room) and Poisson arrivals. Especially this latter characteristic calls for extra clarification. Namely, it declares interarrival times are exponentially distributed and memory-less. The latter means that at any point in time, the time until the next arrival does not depend on how much time has passed since the last arrival. Section 7.1.1 explains more about Poisson arrivals and Section 7.1.2 investigates whether time dependency occurs in our case study. Section 7.1.3 pays some extra attention to the blocking phenomenon.

7.1.1 Poisson arrivals

The Poisson process is an arrival process for which the interarrival times are i.i.d. (independent and identically-distributed) exponential random variables. This means that the stochastic process $\{N(t), t \geq 0\}$ (the number of arrivals at time t) is a Poisson process if (Law & Kelton, 2000):
- Customers arrive one at a time.
- The number of arrivals in the time interval $(t, t+s]$ $(= N(t+s) - N(t))$ is independent of $\{N(y), 0 \leq y \leq t\}$.
- The distribution of $N(t+s) - N(t)$ is independent of t for all $t,s \geq 0$.

Reasons why an arrival process would not be Poisson can be explained as a violation of (one of) these characteristics. If customers arrive in batches instead of one at a time, the first characteristic would be violated. The second property states that the number of arrivals in an interval is independent of the number of arrivals in the earlier time interval. The third property implies that the arrival rate of customers does not depend on the time of day.

We can argue whether the above events occur in the case of patients arriving to the hospital. First, batch arrivals are not likely for patients to a hospital: patients usually arrive individually. Also, hospital beds are so-called parallel servers and always serve one patient at the time. So the first criterion is not violated.
Second, the phenomenon called blocking occurs in hospitals (as explained in Section 4.5). As a result, the number of admissions depends on the occupancy of the system: an arriving patient is blocked in case the system is full. In this way, the number of admissions is not a Poisson process. The Erlang loss model preempts this by restricting

the number of present patients to the number of servers (beds). In this way, admissions depend on the occupancy of the system but arrivals are a Poisson process.
The third characteristic is in contradiction with the time-dependent model mentioned in Section 4.5 that states arrival rates are usually higher during office hours in weekdays, outside holidays. Section 7.1.2 investigates whether this is also the case for the Erasmus MC.

7.1.2 Time-dependency

To check the hypothesis whether arrivals are independent of month, week, day of the week and hour of the day, both for clinical and day care admissions, we constructed the figures displayed in Appendix H.
We see the number of admissions is fairly constant over the months of the year. On week level, the variation is higher, but not so much the hospital should take this into account in her strategic capacity allocation.
Per day of the week, we see differences. However, this is exactly what we already stated in Section 6.2: the major differences exist between weekdays and weekends. The impacts of this difference will be further analyzed in Section 7.3 and further.
On day-level, we see most clinical admissions occur during office hours (8:00 – 18:00). For day care the peak is even more clustered: admissions (based on data from the hospital's registration system) mainly occur at 8:00 o'clock in the morning.
This means all the admissions mentioned in 6.2.2 do not occur spread over the day but almost all at 8:00 o'clock in the morning. As a consequence, the number of present patients after 8:00 AM equals the admission rate per day. During the day, this number decreases to zero in the evening. This means the occupancy and the P_{loss} are higher early in the morning compared to the rest of the day.
We handle this difference by distinguishing two situations: the average and peak situation, with each their own availabilities and efficiencies. Section 7.2.2 describes both situations in more detail.

Doing so, we are able to use the Erlang loss model after all. Still, we do not include the (minor) fluctuations among the months and weeks of the year. However, such fluctuations are not leading in strategic decisions like determining bed capacity and merging of departments. However, the Erasmus MC should be aware that these fluctuations occur and include them in planning decisions at the tactical and operational level.

7.1.3 Blocking

We define the state of the system by the number of patients present in the system. The state follows a birth-and-death process, for which the state transition rate diagram is shown in Figure 17.

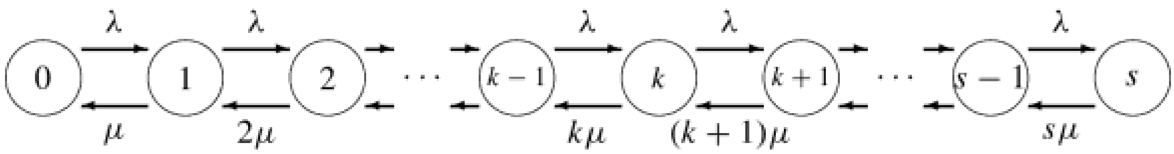

Figure 17: State transition rate diagram for an Erlang loss system (Takagi & Walke, 2008)

Let p_k be the probability that there are k patients in the system at an arbitrary time, where k= 0, 1, 2, …, s. Then $k \cdot \mu \cdot p_k = \lambda \cdot p_{k-1}$.
The probability distribution for the number of patients in the system equals

$$p_k = p_0 \cdot \frac{(\lambda / \mu)^k}{k!} = \frac{(\lambda / \mu)^k / k!}{\sum_{j=0}^{s}((\lambda / \mu)^j / j!)}, \ 0 \le k \le s$$ (Chee-Hock & Boon-Hee, 2008).

Patients who arrive if all beds are occupied, are blocked. From the so-called PASTA (Poisson arrivals see time averages) property, it follows that the probability that there are k patients in the system immediately before an arrival time equals the probability that there are k patients in the system at an arbitrary time. Therefore, the blocking probability equals (Takagi & Walke, 2008):

$$p_s = \frac{(\lambda/\mu)^s / s!}{\sum_{j=0}^{s}((\lambda/\mu)^j / j!)}$$

7.2 Patient arrivals and LOS

In order to apply the Erlang loss model and for purposes of validation (7.3) we need to quantify the number of arrivals (λ). As the hospital's information system only registers the number of admissions (as described in Section 6.2) and the number of refused admission is generally unknown, we have to approximate λ. This can be accomplished by using the formulas mentioned in Section 4.5.1.

The fraction of patients blocked in the long run equals $P_{loss} = \frac{\left(\frac{\lambda}{\mu}\right)^s / s!}{\sum_{k=0}^{s}\left(\frac{\lambda}{\mu}\right)^k / k!}$ and the efficiency is $\frac{(1-P_{loss})\cdot\lambda}{s\cdot\mu}$, with s the number of beds.

Note that the formula to calculate P_{loss} can cause problems while implementing it in Excel for large values of $\left(\frac{\lambda}{\mu}\right)^s / s!$. In these cases, one can also use a recursive formula for the P_{loss} of bed capacity s>0, which is:

$$P_{loss}(s) = \frac{\left(\frac{\lambda}{\mu}\right)\cdot P_{loss}(s-1)}{s + \left(\frac{\lambda}{\mu}\right)\cdot P_{loss}(s-1)}$$

7.2.1 Clinical patients

Because we know the number of beds s, the average LOS $\frac{1}{\mu}$ as well as the efficiencies calculated in Section 6.4, we can determine the arrival rate for clinical patients. This normally is a manual procedure of varying λ until the known parameters are correct, but can be executed quite easily with help of an online tool developed by de Bruin et al (2008).

Note that we only know the number of s in general (for weekdays and weekends together). Temporarily opening a few extra beds occurs during weekdays, but we do not know the amount of this extra capacity. As a result, we cannot calculate the actual efficiency in such cases. Therefore, we do no longer distinct weekdays from weekends and use the λ for weekdays and weekends together. Section 7.3.1 will validate this decision and shows using the λ's for weekdays and weekends together results in an even better representation for bed occupation during weekdays.

			Weekdays + weekends		
Theme	# beds	1/μ	Eff	λ	Ploss
1	70	5.77	91.015%	12.12	8.90%
2	159	6.42	63.119%	15.63	0.00%
3	176	8.32	80.240%	16.98	0.06%
4	74	5.91	69.661%	8.73	0.06%
5	91	6.22	91.463%	14.38	6.96%
6 adult	68	4.15	82.094%	13.71	1.87%
6 child	117	7.22	95.168%	17.52	11.98%
Total	755				

Table 13: λ en P_{loss} per theme for clinical patients

As can be seen in Table 13, the P_{loss} of theme 2 equals zero and the parameter λ appears to be similar to the admission rates described in Section 6.2. So using the current number of operational beds mentioned in Section 3.4 results in an efficiency that is low enough to maximize the availability of the clinical wards. This finding supports the hospital's management decision to decrease bed capacity.

However, for the other themes we see P_{loss} exceeds zero. This means the arrival rate exceeds the admission rate and refusals occur. In Chapter 10, we will evaluate whether this P_{loss} is realistic to refusals currently registered at the ED. Besides λ, the Erlang loss model requires another parameter: $\frac{1}{\mu}$, which is the average patient's LOS. For clinical patients, we use the ALOS stated in Section 6.3.

7.2.2 Day care patients

As described in Section 6.4, we cannot calculate the efficiency for day care patients because the current number of operational beds is unknown. However, we know the admission of these patients is always planned, so there are no unscheduled arrivals. Therefore, we assume no refusals occur (so P_{loss} equals zero) and λ is equal to the admission rates mentioned in Section 6.2.2.
As described in Section 7.1.2, time dependency occurs for day care patients. That is why two situations are distinguished, both explained below.

Average situation

As explained in Section 5.2, the capacity of day care facilities is not available 24 hours per days and 365 days per year, but usually only 260 days per year and 9 to 10 hours per day. The λ's mentioned in Section 6.2.2 are the average number of admissions per day. So if we would use the same formulas as for clinical patients, the total arrivals per day are correct. However, day care centers usually are open only during office hours. This means that admissions do not occur over a full-day period of 24 hours, but are clustered in the office hours (from 8:00 to 18:00, so in a period of 10 hours). So the arrival rate per hour is actually higher than the λ's mentioned in Section 6.2.2 divided by 24. During office hours, the hourly arrival rate equals the λ's mentioned in Section 6.2.2 divided by 10. So using the formulas mentioned in the introduction of 7.2 results in an underestimation of present patients during office hours, with underestimated P_{loss} and efficiency (and overestimated availability). This means these efficiencies and availabilities represent a positive scenario. The recommended capacities (presented in the Sections 8.2 and 8.3 and Chapter 9) calculated in this way is therefore the level at least required. Besides λ, the Erlang loss model requires the parameter $\frac{1}{\mu}$ (the average patient's LOS). For day care patients, we also use the ALOS stated in Section 6.3. Note that Section 4.5.1 stated the Erlang loss model also applies in case LOS is not exponentially distributed but less variable like for day care patients.

Peak situation

Like described in Section 7.1.2, we distinguish two situations for day care patients: the average situation as just described and the busy period in the morning. Both the efficiency and P_{loss} are higher in the latter situation. We formulate a model that represents the availability and efficiency during the peak time in the morning. Doing so, these two variables only depend on the arrival rate, not on the length of stay. That is because the LOS is such that every morning starts with all beds unoccupied.

Section 6.2.2 showed the admission of day care patients is not deterministic as assumed and the Poisson distribution does not give a perfect fit but variability is comparable.
Because the PASTA characteristic (see Section 7.1.3) is no longer valid when we consider present patients at the peak time in the morning, we cannot use the Erlang loss model for peak times. That is because refusals simply occur when the daily number of arrivals exceeds bed capacity. This means availability is one in case the number of arrivals is equal to or smaller than the bed capacity. In case the number of arrivals exceeds bed capacity, availability is the ratio of bed capacity and the number of arrivals. In formula:

$$Availability\ (peak) = \sum_{i=0}^{s} P(n=i)\cdot 1 + \sum_{i=s+1}^{\infty} P(n=i)\cdot \frac{s}{i} = P(n \le s) + \sum_{i=s+1}^{\infty} P(n=i)\cdot \frac{s}{i}$$

Where n is the number of arrivals (Poisson distributed with mean λ) and s the bed capacity.

At the application of this formula, one should concern the last part: a summation from i=s+1 until infinity. However, this does not cause major problems, since $\lim_{i\to\infty} P(n=i) = 0$ and $\lim_{i\to\infty} \frac{s}{i} = 0$ for all values of s, so $\lim_{i\to\infty} P(n=i)\cdot\frac{s}{i} = 0$ as well. This means the terms of the summation converge to zero as i increases; it is a convergent series. So after a certain value of i, the term $P(n=i)\cdot\frac{s}{i}$ does not contribute much to the availability anymore. For example, for the theme with the highest arrival rate (λ=29.70), we could approximate the availability with ∞=85, because P(n=85) is only $1.1102 \cdot 10^{-16}$. To be sure, we decide to approximate ∞ with 1200, because even in case λ=1000, P(n=1200) is only $7.9927 \cdot 10^{-11}$.
Efficiency is the number of arrivals as a part of the bed capacity (with a maximum of 100%):

$$Efficiency\ (peak) = min(\frac{n}{s}, 1)$$

Note that the efficiency (peak) equals 100% in case the number of beds is smaller than or equal to the number of arrivals. This means the formula calculates the efficiency at the peak time in the morning only, so it is not the efficiency over the whole day. Because the number of present patients is highest during the peak time and only decreases during the day, the efficiency over the whole day is lower than calculated above. Determining the efficiency over the whole day is only possible if the LOS distribution is known. Because of the low variability of day care LOS (see Table 11), LOS looks almost deterministic. However, because of registration biases (as will be explained in Section 12.2.1), we do not know the actual LOS distribution and cannot determine the efficiency over the whole day.

Also, these formulas assume all admissions occur at 8:00 o'clock in the morning. In reality, some patients arrive during the day. So using these formulas results in a slight overestimation of present patients during the peak period of the day, with overestimated P_{loss} and efficiency (and underestimated availability). This means these efficiency and availability represent a negative scenario. The recommended capacity (Chapter 8) calculated in this way is therefore the level required at most.

Practically, the number of daily arrivals can be planned. This means n can become deterministic, although this was not the case in 2007. In a deterministic situation, the number of arrivals always equals n. Chapter 12 discusses which of the two situations described above is most realistic for day care patients and the consequences of this elimination of variability on required bed capacity.

7.3 Model validity

In Sections 6.2 and 7.2 we approximated λ of both clinical and day care patients using the Erlang loss equation. The assumptions for this model regarding the arrival process (Poisson) and the LOS distribution (general) were discussed in the previous sections of Chapter 7. One of the main objectives of this study is to determine the number of required beds at clinical ward and day care facilities. Therefore, we first have to determine the distribution of the number of occupied beds.

7.3.1 Clinical patients

This section evaluates whether the Erlang loss model with the parameters of λ and $\frac{1}{\mu}$ presented in Section 7.2.1 matches with reality. This is the model that does not distinct the arrival rate during weekdays from weekends and uses the λ for weekdays and weekends together.

Figure 18 compares the observed distribution of occupied beds with the expectation using the Erlang loss model, as an example, for clinical patients of theme 1. Note that it is possible that the observed number of occupied beds exceeds the number of operational beds, as mentioned in Section 6.4. Remember that this is only possible in practice, whereas the Erlang loss model does not incorporate such options.

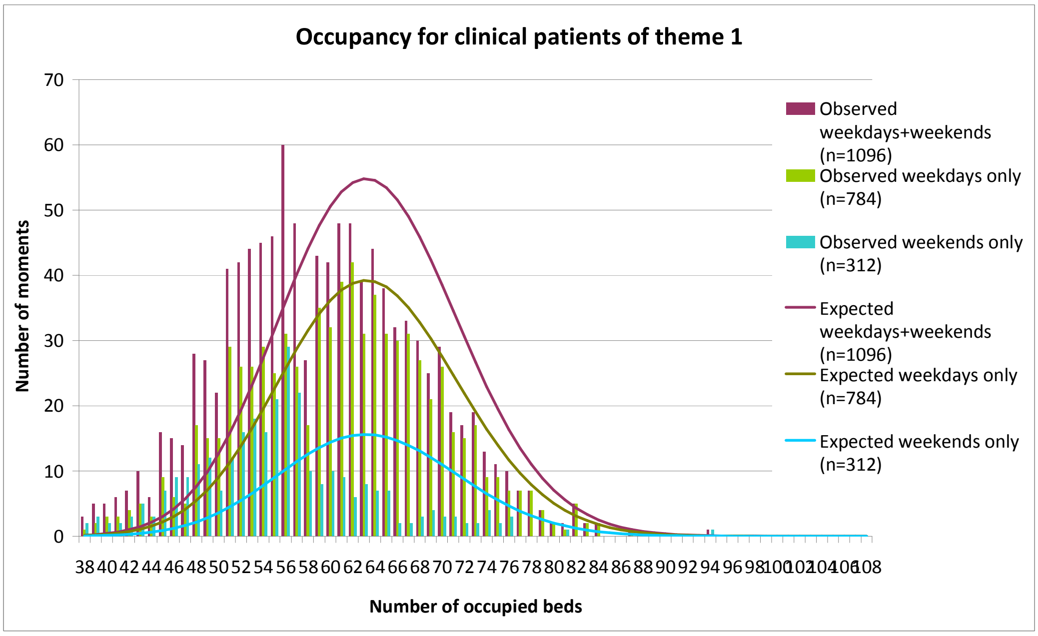

Figure 18: Number of occupied beds for clinical patients of theme 1 (Psychiatry and Intensive Care excluded)

In general (for weekdays and weekends together) the expected distribution of occupied beds using the Erlang loss model with λ=12.12, $\frac{1}{\mu}$=6.53 and P_{loss}=8.90% (see 7.2.1) matches quite well with the observed distribution of present clinical patients of theme 1.

However, the number of occupied beds is higher on weekdays relatively to weekends. We evaluate whether the model with λ=12.12, $\frac{1}{\mu}$=6.53 and P_{loss}=8.90% also matches the distribution of occupied beds during weekdays. Comparing the green line chart with the green column chart, we see this clearly is the case. Most likely, this has to do with the fact that bed occupation during weekdays is not only effected by arrivals that occur from Monday to Friday, but also by arrivals that occur in the weekends. To be precise, average LOS ranges from 4 to 8 days.
During weekends (blue columns), the number of occupied beds is relatively low. We see the model (blue line) does not match, but overestimates the number of occupied beds.

To quantify the goodness-of-fit we use the validation measure also used by de Bruin et al (2008), inspired on the average absolute prediction error (Kleijnen et al, 2000):

$$\textit{Goodness of fit} = 1 - \frac{1}{2}\sum_{i=0}^{s} |D_i|$$

with $D_i = Pobs_i - Pexp_i$
$Pobs_i$ = probability that s beds are occupied (observed)
$Pexp_i$ = probability that s beds are occupied (expected from Erlang loss model)

The measure is a number between 0 and 1, where 0 indicates a poor fit and 1 means the probabilities are equal for all number of occupied beds (exact match between distribution functions). Table 14 shows the outcomes of this measurement for clinical patients of all the themes.

Observed	Theme						
	1	2	3	4	5	6 adult	6 child
Week+weekend	0.768	0.741	0.814	0.839	0.755	0.875	0.646
Week only	0.850	0.693	0.873	0.821	0.855	0.856	0.759
Weekend only	0.530	0.450	0.380	0.524	0.299	0.711	0.335

Table 14: Goodness-of-fit of the Erlang loss model describing the bed occupancy

For example, a goodness of fit of 0.855 means that the observed and expected bed occupancy distribution have 85.5% of the probability mass in common. For most wards, the model that uses the arrival rates of both weekdays and weekends represents the observed bed occupancy quite good, for occupancy observed both in- and exclusive weekends. Clearly, it matches with observed bed occupancy during the weekend only a lot worse. This means the results of this study indicate the required bed capacity during weekdays. During weekends, the capacity required should be adjusted by decreasing staff level. This however is not a subject of this research. Concluding, we will use the arrival rates of weekdays and weekends together for the parameter λ in our model.

Recall from Section 7.2.1 that the Erasmus MC's information system only registers the number of admissions (as described in Section 6.2) and the number of refused admission is generally unknown. Therefore, we had to determine the number of clinical arrivals (λ) numerically, using the efficiencies per theme (Section 6.4), the number of beds s and average LOS by $\frac{1}{\mu}$.
The number of emergency patients transferred to other hospitals is registered at the Emergency Department. In 2007, 5677 patients from the ED were admitted in the hospital. Also, 496 transferals to other hospitals (which is about 8.0%) occurred. (Steenoven, 2008) Since the Sophia location has its own ED, these numbers regard all themes except theme 6 child.

Unfortunately, we were not able to distinguish the number of transferals per theme. Also, we do not know whether the registration is complete. This is because probably not all transfers are registered and general practitioners adjust their redirected patients based on the information about the Erasmus MC's clinical occupation they receive by phone.
However, this grand total can be used to evaluate the appropriateness of the approximated λ's after all. We do this by comparing the total number of refusals to what would be expected from the P_{loss} calculated in Section 7.2.1. Remember that for all themes except theme 2, the arrival rate exceeds the admission rate and refusals occured ($P_{loss} > 0$) in 2007. We can calculate the average number of refusals per day for each theme by multiplying this P_{loss} with the average arrival rate.

			Number of refusals	
Theme	**λ**	**Ploss**	**Per day**	**Per year**
1	12.12	8.90%	1.08	393.72
2	15.63	0.00%	0.00	0.00
3	16.98	0.06%	0.01	3.72
4	8.73	0.06%	0.01	1.91
5	14.38	6.96%	1.00	365.31
6 adult	13.71	1.87%	0.26	93.58
6 child	17.52	11.98%	2.10	766.10

Table 15: Average number of refusals per theme

Adding up the yearly refusals for all themes expect 6 child, results in 858.24 in total. This is a lot more than the 496 registered at the ED in 2007. This means the λ's (and required bed capacities) are not likely to be underestimated in this report. Note that it is also possible the registration at the ED is not completely sound. Finally, our main concern was that the λ's were underestimated. Clearly this is not the case, so there is no reason to adjust our findings.

7.3.2 Day care patients

For day care patients, the Poisson arrival distribution seemed to fit to a less extent. Just as for clinical patients in 7.3.1, we determine whether this is so crucial that the Erlang loss model should not be used to decide upon bed capacity or that the model is feasible.

We evaluate the Erlang loss model with the λ's en $\frac{1}{\mu}$'s presented in the following table (as stated in Sections 6.2.2 and 6.3 before):

Theme	Surgical		Non-surgical	
	1/μ	**λ**	**1/μ**	**λ**
1	0.41	3.54	0.36	6.74
2	0.36	1.80	0.38	29.70
3	0.38	1.21	0.36	28.80
4	0.39	3.70	0.00	0.00
5	0.00	0.00	0.37	2.32
6 adult	0.40	2.72	0.36	6.51
6 child	0.41	8.52	0.38	12.02

Table 16: $1/\mu$'s and λ's for day care patients

Appendix I compares the average situation of observed number of occupied beds with the expectation using the Erlang loss model. To quantify this goodness-of-fit we use the same validation measure as applied on clinical patients in Section 7.3.1. Table 17 shows the outcomes of this measurement for day care patients of all the themes. For most wards, the model that determines average expected occupation represents reality quite good.

Theme	Goodness of fit	
	Surgical	Non-surgical
1	0.625	0.704
2	0.842	0.706
3	0.579	0.697
4	0.585	0.870
5	0.856	0.446
6 adult	0.703	0.768
6 child	0.778	0.719

Table 17: Goodness-of-fit of Erlang loss model describing the average bed occupancy for day care patients

As described in Section 7.1, we distinguish two situations for day care patients: the average as just described and the busy period in the morning.
We can also evaluate whether this peak period can be represented by the formulas mentioned Section 7.2.2 (so the number of present patients equals λ).

Appendix I also compares the peak situation of observed number of occupied beds in the morning with the expectation using the formulas described in Section 7.2.
To quantify this goodness-of-fit we again use the same validation measure as applied above. Table 18 shows the outcomes of this measurement for the peak period of all themes' day care patients:

Theme	Goodness of fit	
	Surgical	Non-surgical
1	0.626	0.696
2	0.845	0.838
3	0.560	0.797
4	0.639	0.874
5	0.862	0.515
6 adult	0.668	0.834
6 child	0.782	0.801

Table 18: Goodness-of-fit of Erlang loss model describing the peak bed occupancy for day care patients

From this figures, we conclude the bed occupancy at peak time can be described adequately by the model using the formulas mentioned in Section 7.2.2.

7.4 Conclusion

Based on the models available from theory (Chapter 2) and the patient arrival rates and LOS (Chapter 6) this chapter formulated a model that represents the bed occupation.
It does not seem to be a problem that the admission process slightly mismatches the Poisson process, because expected bed occupancy is comparable with observed values.

When the average daily arrival rate (λ) and the average length of stay ($\frac{1}{\mu}$) are known, the Erlang loss model can be used to determine the availability and efficiency as a function of the number of beds – no matter what values λ and $\frac{1}{\mu}$ adopt.

Chapter 8 uses this Erlang loss model to evaluate the provisional capacity configuration of clinical departments and assists in deciding upon bed capacity for day care patients. In Chapter 9, the model determines the impact of merging day care departments with each other and with clinical departments. Also, it will be used in Chapter 10, which executes sensitivity analyses to test whether the results of Chapters 8 and 9 are robust to changing patients' arrival rates, length of stay and opening hours.

8. Case study: provisional organization

The previous sections already indicated neither the current number of operational beds nor the provisional bed allocation over the 6 themes is optimal. This chapter uses the model suggested in Chapter 7 to evaluate this statement and suggests bed capacity levels based on various availability and efficiency levels.
In this chapter, we assume separate theme-based wards for clinical care (8.1), separate theme-based wards for surgical care (8.2) and separate theme-based wards for non-surgical care (8.3). In Chapter 9, we will study the effects of alternative scenarios for organization of day care.

Following the methodology explained in Chapter 5 and the mathematical model of Chapter 7, we can calculate the required bed capacity level to achieve sufficient service level. This service level is measured using the variable availability, which is 1 – P_{loss}. To calculate this availability, we use the $\frac{1}{\mu}$'s (average lengths of stay) and λ's (average arrival rates) stated in Section 7.2. This methodology is validated in Section 7.3. Inserting these $\frac{1}{\mu}$'s and λ's in the formula

$$Availability = 1 - P_{loss} = 1 - \frac{\left(\frac{\lambda}{\mu}\right)^s / s!}{\sum_{k=0}^{s}\left(\frac{\lambda}{\mu}\right)^k / k!}$$ or the recursive formula mentioned in Section 7.2

we can numerically determine the number of beds (s) necessary to achieve a certain availability level.

But besides the availability, we should also consider the efficiency involved with these bed capacities. After all, maximum availability (100%) will only be achieved using an infinite amount of beds. However, these beds would remain unoccupied most of the time. Therefore, we use the occupancy introduced in Section 6.4 as a measure of efficiency.
Inserting these $\frac{1}{\mu}$'s, λ's, P_{loss} and s in the formula $Efficiency = \frac{(1 - P_{loss}) \cdot \lambda}{s \cdot \mu}$ we can calculate the efficiency accompanying a certain availability level.

Finally, we should make a trade-off between availability and efficiency to decide upon the appropriate bed capacity per theme. Namely, as bed capacity increases, availability increases, while efficiency decreases. We will display graphs to show the relation between these three variables.
We will see the $\frac{Availability}{Efficiency}$ ratio is not a constant, but increases with bed capacity. This means larger departments can indeed achieve higher availability at the same efficiency level (or: can operate at higher efficiency while attaining the same availability level). We can conclude the ratio increases linearly with bed capacity. This is in line with what we would expect, as efficiency is calculated using the formula $\frac{(1 - P_{loss}) \cdot \lambda}{s \cdot \mu}$. That is because efficiency can be rewritten as $\frac{Availability \cdot \lambda}{s \cdot \mu}$ and the ratio as $\frac{s \cdot \mu}{\lambda}$.
Hospital managers are responsible for taking the decision whether or not the increase in availability is worth the decrease in efficiency. Our method supports hospital managers to make this trade-off between availability and efficiency.

Interviewing several managers revealed the Erasmus MC has not formulated norms for both availability and efficiency yet.
Also, ethical reasons probably cause the availability norms to be different per theme. For example, nationwide supply of care facilities for oncology (theme 2) is lower than for most other themes. As a consequence, the Erasmus MC might set norm availability for theme 2 patients relatively high. Also, some themes might experience higher demand than other themes in case of major disasters and should have a higher availability.
These thoughts should be considered in determining availability and efficiency norms.

A possible method is to optimize the sum of availability and efficiency. $Sum = a \cdot Availability + e \cdot Efficiency$. The value of this sum also depends on the bed capacity and will be displayed in the same graphs as the ratio mentioned above. Consequently, the recommended bed capacity equals the number of beds where the sum is maximal. This method will reveal to be straightforward and results in availability and efficiency that are very likely within ranges that are tolerable for the Erasmus MC. We will apply the case where efficiency is equally important as availability (a=e) and also analyze the effects of changing the weights assigned to availability (a) or efficiency (e).

8.1 Clinical patients

For clinical care, the Erasmus MC plans to establish theme-based wards, where both surgical and non-surgical care is provided. For this reason, the former chapters did not make distinction in clinical patients, otherwise than per theme. In this section, we will not do any different.

In Section 7.2, we saw the current effective number of beds is for some themes so capacious that P_{loss} is almost zero and occupancies are low. This means the Erasmus MC would have been able to cope with the patients present in 2007 using fewer beds than the design capacity mentioned in Table 3 of Section 3.4. On the other side, for other themes P_{loss} is rather high and the current number of beds does not seem to be sufficient.

Table 18 shows the number of required clinical beds for different availability levels:

			Beds required for availability =			
Theme	**1/μ**	**λ**	**99%**	**98%**	**95%**	**90%**
1	5.77	12.12	85	82	76	69
2	6.42	15.63	118	113	105	97
3	8.32	16.98	161	155	145	134
4	5.91	8.73	66	63	58	52
5	6.22	14.38	106	102	95	87
6 adult	4.15	13.71	71	68	63	57
6 child	7.22	17.52	145	140	131	121
Total			**752**	**723**	**673**	**617**

Table 18: Number of required clinical beds for different availability levels (Psy and IC excluded)

We see the provisional future number of beds (mentioned in Section 3.4) indeed falls short of availability, since this variable is below 90% for most themes. Theme 2 however seems to be overestimated: can manage with fewer beds. This indicates the provisional configuration should be revised.

Table 19 displays the efficiency for the different availability levels, corresponding with the values of Table 18.

			Efficiency for availability =			
Theme	1/μ	λ	99%	98%	95%	90%
1	5.77	12.12	81.4%	83.8%	87.9%	91.4%
2	6.42	15.63	84.3%	87.1%	90.8%	93.4%
3	8.32	16.98	86.8%	89.3%	92.5%	95.0%
4	5.91	8.73	77.6%	80.6%	85.2%	89.4%
5	6.22	14.38	83.5%	86.0%	89.7%	92.8%
6 adult	4.15	13.71	79.3%	82.1%	86.2%	90.1%
6 child	7.22	17.52	86.4%	88.6%	92.0%	94.5%
Total						

Table 19: Efficiencies for the different availability levels

We see the efficiency that can be achieved at a norm availability of 95% varies between 85.2% and 92.5%. This means a reserve capacity/buffer of 14.8% to 7.5% is necessary to counterbalance the variability in present patients.

8.1.1 Trade-off

Deciding upon the appropriate bed capacity per theme is a trade-off between availability and efficiency. Therefore, we displayed these two variables with capacity in Appendix J. The graphs show whether increasing capacity results in higher availability and the size of this improvement. Also, one can see the corresponding decrease in efficiency. We indeed see that as bed capacity increases, availability increases, while efficiency decreases.
We see the availability first highly increases when capacity increases. But as availability approaches 100%, the slope diminishes. This phenomenon is also referred to as the law of diminishing returns (de Bruin et al, 2007).

We use the sum of availability and efficiency (also displayed in Appendix J) to support making the trade-off.
The recommended bed capacity equals the number of beds where the sum is maximal:

Theme	Capacity	Availability	Efficiency
1	76	95.5%	87.9%
2	107	95.9%	90.0%
3	149	96.5%	91.5%
4	57	95.0%	86.0%
5	96	95.9%	89.3%
6 adult	62	94.8%	87.0%
6 child	134	96.4%	91.0%
Total	681		

Table 20: Bed capacities for clinical care (Psy and IC excluded) using trade-off method (with a=e)

When increasing beyond this number of beds, the efficiency decreases faster than the availability increases, i.e. the advantage of adding an extra bed to capacity diminishes.
The corresponding availability and efficiency are also stated in Table 20. We see availabilities are almost all above 95%. The Erasmus MC's managers indicate this is preferred. Also, efficiencies are within tolerable ranges (above the currently used 85%).

As a part of this research project, we developed a tool that is useful to illustrate the trade-off between availability and efficiency. The tool is formulated using the software program Borland Delphi 7. The application consists of four parts: The most left part is the place to insert the input data (average LOS and the average number arrivals per day). The second part displays the capacities and efficiencies belonging to a certain required availability (like presented in the Tables 18 and 19). The third part displays the capacities and availabilities belonging to a certain required efficiency. The fourth part concerns the trade-off method described in Section 8.1.1, where the Erasmus MC can assign different weights to availability and efficiency herself. Figure 19 provides a screenshot of the application.

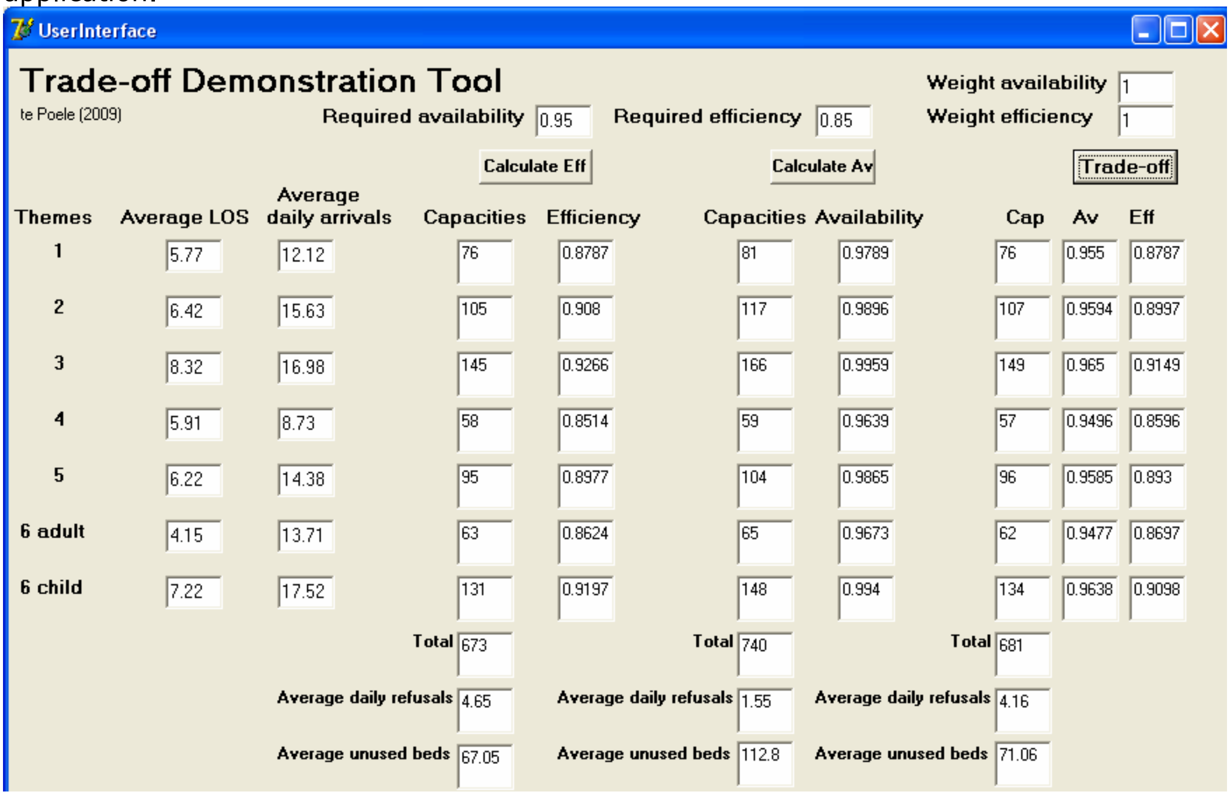

Figure 19: The trade-off demonstration tool consists of an input part and three output parts

We can use the latter part to see what happens to required capacity in case the weights assigned to availability and efficiency are not equal (as in Table 20), but differ. As the availability weight relatively increases, the capacity of each theme also increases. As a result, the availability increases and the efficiency decreases. The other way around, increasing the efficiency weight results in decreased capacity of each theme. The capacity changes are not equal for all themes.

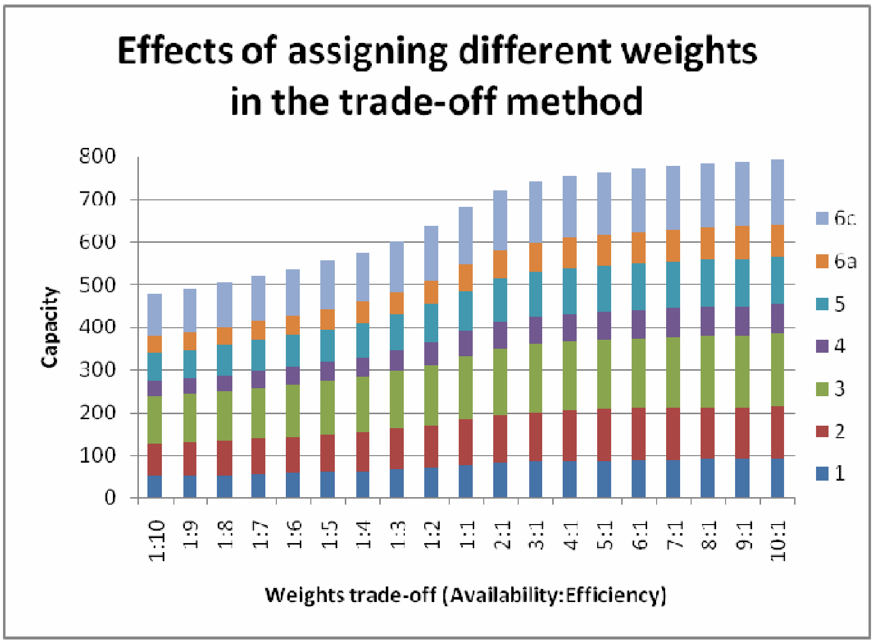

Figure 20: Required bed capacity depends on the weights assigned to availability and efficiency

Figure 20 shows the relation between the required capacity and the difference in weights assigned to availability and efficiency. The relation is clearly not linear: the change in capacity decreases as the difference in weights increases. Moreover, we want to emphasize the required capacity is not given, but depends on the perceived mutual importance of availability and efficiency too a large extent.

8.1.2 Bed allocation instrument

One can also imagine the Erasmus MC decides to use a certain number of clinical beds in total and has to decide how to distribute these beds over the themes to achieve the same availability level for each theme. Table 19 can also be helpful in these decisions.
For example, in case the Erasmus MC has 700 beds to allocate, availability level for each theme will be between 95% and 98%. Varying the required availability reveals a level of 96.8% can be achieved and the 700 beds from theme 1 to 6 child are: 79, 110, 150, 60, 99, 66 and 136.

Maximize total availability

However, it might not be advantageous for the total hospital to maintain the same availability level for each theme. A goal for the Erasmus MC might be to minimize the total number of refusals:

$Min\sum_{t=0}^{6} Ploss_t \cdot \lambda_t$ with t the theme number (1, … 6 child).

From this formula, one can see it is advantageous in case themes with a relatively high arrival rate have relatively low loss rates.
This is equivalent to maximizing the sum of all products of availability and the arrival rate per theme:

$$Max\sum_{t=0}^{6} Availability_t \cdot \lambda_t \ .$$

Maximize total efficiency

Just like it is more advantageous for the hospital in total to have relatively low loss rates for themes with a relatively high arrival rate, it is also more advantageous to have relatively high efficiencies for themes with relatively many beds. In this case, the total number of unused beds will be minimized. Therefore, a second goal for the Erasmus MC might be to maximize the sum of all products of efficiency and the capacity per theme:

$Max \sum_{t=0}^{6} Efficiency_t \cdot s_t$ with t the theme number (1, … 6 child).

Trade-off

Obviously, the hospital wants to minimize both the total number of refusals and the number of unused beds. The question is: are the two objectives equally important or is one of the two more important than the other? And if so: how much more important? So for the hospital in total, the trade-off between availability and efficiency remains important. Analogous to the method described in Section 8.1.1, we maximize the sum of total availability and total efficiency:

$$Sum = a \cdot \sum_{t=0}^{6} Availability_t \cdot \lambda_t + e \cdot \sum_{t=0}^{6} Efficiency_t \cdot s_t$$

To encourage hospitals to use this method, we also developed a tool that maximizes this objective, based on a restricted total bed capacity.

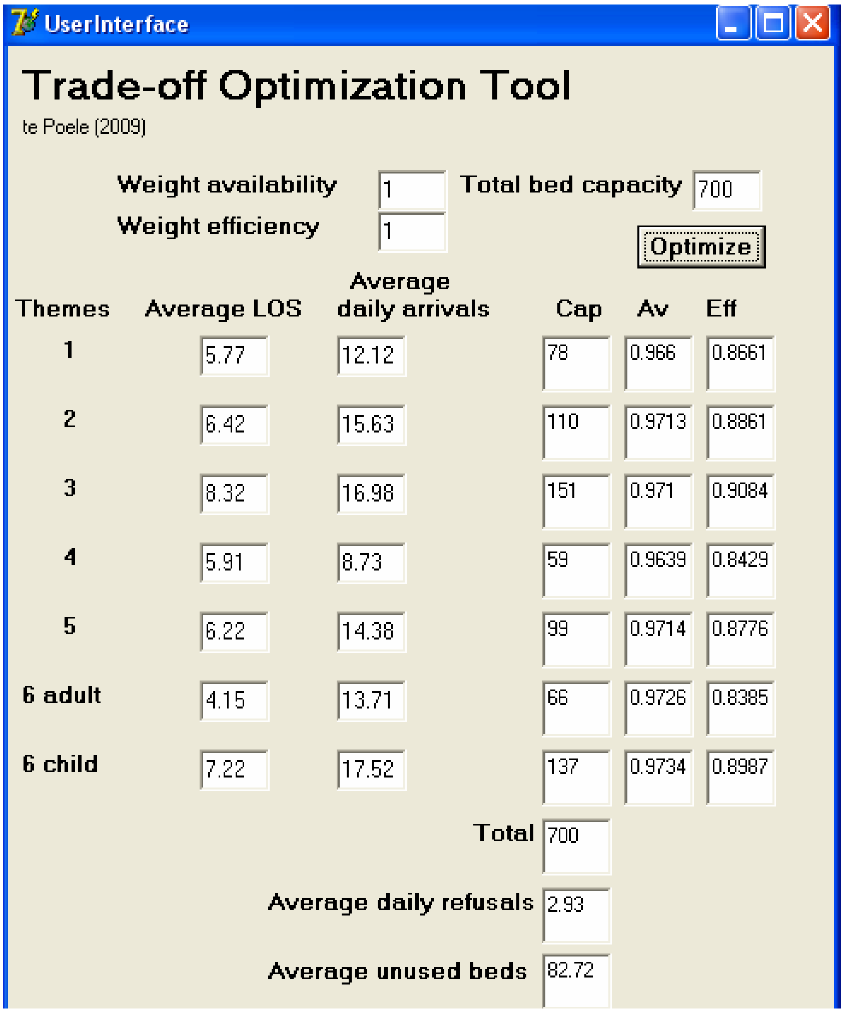

Figure 21: The trade-off optimization tool consists of an input part and an output part

The application looks as displayed in Figure 21 and consists of two parts:
The leftmost part is again the place to insert the input data (average LOS and the average number of arrivals per day). Also, the user should insert the total bed capacity and the relative weights assigned to availability and efficiency. The right part is the

optimization method described in this section. It judges for each bed adding it to which theme would result in the highest increase of the objective. This procedure runs until the total bed capacity is reached. This tool can be used for any average length of stay and arrival rate per theme to determine how the hospital should allocate the total bed capacity over the themes.

Applying this instrument also provides some useful information about the adequacy of using methods that assume infinite capacity and do not evaluate performance hospital-wide but on theme basis (as described in Section 8.1.1). For example, if we would use a fixed required availability of 95%, the beds are distributed over the themes as presented in Table 18. The total required capacity equals 673 beds. If we insert this number in the trade-off optimization tool with equal availability and efficiency weights, we see some beds are allocated to another theme and average daily refusals reduces slightly (from 4.65 to 4.08) without changing the number of unused beds. Similar differences exist with using a fixed required efficiency of for example 85%, which requires 740 beds. Inserting this number in the trade-off optimization tool with equal availability and efficiency weights results in average daily refusal reduction (from 1.55 to 1.23). Also compared to the trade-off method with capacity of 681 beds, the average daily refusals reduce (from 4.16 to 4.08).

Another difference with the theme performance methods arises if one inserts the input in a way that the load is similar for all departments, but average LOS and daily arrivals vary. The methods based on theme performance will assign the same bed capacity to all departments. The hospital-wide trade-off method assigns relatively more beds to departments with higher arrival rate (or relatively low LOS). However, the difference in bed capacity between such departments decreases as the weight assigned to efficiency increases.

8.2 Surgical day care

For day care patients, the Erasmus MC distinguishes surgical and non-surgical care. We will continue this distinction, so describe surgical day care here and non-surgical day care in Section 8.3.
It is not yet decided whether each theme should have its own surgical day care beds or if these can be shared among the themes. Therefore, we study the option of adjudging all themes their own surgical day care beds in this section and analyze the effects of merging the themes in Section 9.1.

To calculate required bed capacity to achieve different availability levels, we use the formulas explained in the introduction of this chapter. Table 21 shows the number of required surgical day care beds for different availability levels.
Recall from Section 7.2.2 that the average situation indicates the minimally required bed capacity and the peak situation the maximally required bed capacity.
Appendix K shows availabilities differ between the average and the peak situation. As a result, the required bed capacity levels differ. That is why both the average situation and the peak situation are displayed here.

			Average situation				Peak situation			
Theme	1/μ	λ	99%	98%	95%	90%	99%	98%	95%	90%
1	0.41	3.54	6	5	4	4	7	6	5	4
2	0.36	1.80	4	4	3	3	4	4	3	3
3	0.38	1.21	3	3	3	2	3	3	2	2
4	0.39	3.70	6	5	4	4	7	6	5	4
5	0.00	0.00								
6 adult	0.40	2.72	5	4	4	3	6	5	4	4
6 child	0.41	8.52	9	8	7	6	13	12	10	9
Total			33	29	25	22	40	36	29	26

Table 21: Number of required surgical day care beds for different availability levels

Differently from clinical patients (8.1), we see $\frac{1}{\mu}$'s do not vary much between the themes. This means differences in required bed capacity are mostly caused by differences in arrival rate.

When we consider the differences between the average and peak situation, we see for themes with relatively low λ's the required bed capacity is almost equal. However, as λ increases, the difference between these minimum and maximum capacity also increases. For these themes, it is harder to determine the right capacity level. In Chapter 12, we will assist the Erasmus MC to decide upon which situation (average or peak) is most realistic.

Just as for clinical patients the Erasmus MC can also calculate the availability level and distribution of beds over the themes in case the hospital has a certain number of total clinical beds at her disposal. Besides the availability, we should also consider the efficiency involved with these bed capacities. These efficiencies for the average situation are displayed in Table 22.

			Average situation				Peak situation			
Theme	1/μ	λ	99%	98%	95%	90%	99%	98%	95%	90%
1	0.41	3.54	24.0%	28.6%	34.6%	34.6%	50.6%	59.0%	70.8%	88.5%
2	0.36	1.80	16.2%	16.2%	21.2%	21.2%	45.0%	45.0%	60.0%	60.0%
3	0.38	1.21	15.0%	15.0%	15.0%	21.2%	40.2%	40.2%	60.3%	60.3%
4	0.39	3.70	24.0%	28.5%	34.6%	34.6%	52.9%	61.7%	74.1%	92.6%
5	0.00	0.00								
6 adult	0.40	2.72	21.4%	26.4%	26.4%	33.2%	45.3%	54.3%	67.9%	67.9%
6 child	0.41	8.52	38.3%	42.7%	47.7%	53.2%	65.5%	71.0%	85.2%	94.7%

Table 22: Efficiencies for the different availability levels, corresponding with values of Table 21

Striking are the extremely low efficiencies accompanying the availabilities above 90%. To achieve 95% availability, surgical day care departments operate at efficiency of only 15.0% to 47.7% in the average situation. In the peak situation, efficiencies are higher (60.0% to 85.2%), as explained in Section 7.2.2, these are the efficiencies at the peak times in the morning only, over the whole day.

Also the question whether the increase in availability is worth the decrease in efficiency becomes even more inevitable.
So again, we make the trade-off between availability and efficiency to decide upon the appropriate bed capacity per theme. The relation between the two variables with capacity can be found in Appendix K.
As for clinical care, availability increases and efficiency decreases with increasing bed capacity. Also, larger departments achieve higher availability at the same efficiency level.

To ease making the trade-off between availability and efficiency, Appendix K also displays the relation ratio as well as the sum of availability and efficiency. Where the sum is maximal, the following bed capacities are recommended for surgical day care:

	Average situation			Peak situation		
Theme	**Capacity**	**Availability**	**Efficiency**	**Capacity**	**Availability**	**Efficiency**
1	4	95.6%	34.6%	3	81.8%	100.0%
2	3	97.6%	21.2%	2	88.8%	90.0%
3	2	93.4%	21.2%	1	80.6%	100.0%
4	4	95.6%	34.6%	4	90.3%	92.6%
5						
6 adult	3	92.8%	33.2%	3	89.9%	90.5%
6 child	6	91.9%	53.2%	8	88.0%	100.0%
Total	**22**			**21**		

Table 23: Recommended bed capacity for surgical day care using trade-off method (with a=e)

What is striking is that using this trade-off method, recommended bed capacities in the average situation are almost equal to the peak situation (the largest difference is two beds, for theme 6 child). Availability and efficiency are however very different in each situation.
Regarding the average situation, availabilities are relatively high, but efficiencies are low. The low efficiencies should however be seen in perspective, because (as can be seen from the graphs in Appendix K) efficiency is even low at a capacity of one bed. On the contrary, availabilities are even high at capacity of one bed. This is because of the low λ's (arrival rates).
Considering the peak situation, the development of availability and efficiency is different: efficiency usually starts at 100% for 1 bed and availability starts often below 50%. Furthermore, the point where efficiency decrease exceeds availability increase is reached faster than in the average situation. So for the recommended bed capacity mentioned in Table 23, efficiency is high but availability relatively is low.

As seen for clinical patients in Section 8.1.2, the distribution of beds over the themes might differ from the theme-based methods described in this section if we use a hospital-wide optimization method. For example, if we would use a fixed required availability of 95%, the beds are distributed over the themes as presented in Table 21. The total required capacity equals 25 beds. If we insert this number in the trade-off optimization tool with equal availability and efficiency weights, we see one bed of theme 3 is reallocated to theme 6 child and average daily refusals reduces slightly (from 0.76 to 0.63). This exact movement also holds for more varying weights (we tested 1:1000 to 1000:1).
Similar differences exist with using the trade-off method with capacity of 22 beds and peak situation results of for example 29 and 21 beds.

But where both availability and efficiency where satisfying for clinical patients (see Section 8.1), for surgical day care patients organized per theme this is clearly not the case. Most probably, this has to do with the relatively low arrival rate of surgical day care patients per theme. As a consequence, separate departments for each theme are too small to achieve both high availability and efficiency. This indicates it might be profitable to share surgical bed capacity.
In practice, this is not as easy as it sounds: there is a broad spectrum of options. For example, surgical beds can be shared between the themes or maybe we should make a combination with non-surgical day care capacity too. Also, we could maintain the theme-based allocation, but share beds with clinical capacity within each theme. These scenarios will be tested in Chapter 9.

8.3 Non-surgical day care

The same as for surgical day care, the Erasmus MC has not yet decided whether each theme should have its own non-surgical day care beds or if these can be shared among the themes. Therefore, we study the option of adjudging all themes their own non-surgical day care beds in this section and analyze the effects of merging the themes in Section 9.2.

Using the formulas explained in the introduction of this chapter (with $\frac{1}{\mu}$'s stated in Section 6.3 and λ's stated in Section 6.2.2), we can calculate the required bed capacity level to achieve sufficient availability. Table 24 shows the number of required non-surgical day care beds for different availability levels.

Again we display both the average situation (good case scenario that indicates the minimally required bed capacity) and the peak situation (bad case scenario to determine the maximally required bed capacity):

			Average situation				Peak situation			
Theme	$1/\mu$	λ	99%	98%	95%	90%	99%	98%	95%	90%
1	0.36	6.74	7	7	6	5	11	10	8	7
2	0.38	29.70	20	18	16	14	36	34	31	28
3	0.36	28.80	18	17	15	13	35	33	30	27
4	0.00	0.00								
5	0.37	2.32	4	4	3	3	5	5	4	4
6 adult	0.36	6.51	7	7	6	5	11	10	8	7
6 child	0.38	12.02	11	10	9	7	17	16	14	12
Total			**67**	**63**	**55**	**47**	**115**	**108**	**95**	**85**

Table 24: Number of required non-surgical day care beds for different availability levels

Because of the difference in λ's for the themes, we see the required bed capacity varies considerable among the themes. The average LOS is almost equal for all themes and therefore hardly important in the distribution of beds between the themes.
Again, just as for clinical and surgical day care patients (8.1 and 8.2) the Erasmus MC might decide upon a fixed number of total clinical beds. In this case, the corresponding availability level and distribution of beds over the themes can be calculated by numerically varying the availability.

For non-surgical day care, bed capacities are usually higher than for surgical day care patients (compare Table 24 with Table 22 in Section 8.2). As a consequence, the differences between the average and peak situation are larger. So it is harder to determine the right capacity level. In Chapter 12 we will discuss which situation (average or peak) is most realistic.
The efficiencies accompanying these availability and bed capacity levels are displayed in Table 25. Again, to achieve 95% availability, non-surgical day care departments should operate at relatively low efficiencies, which means a great part of the capacity functions as a buffer.

			Average situation				Peak situation			
Theme	1/µ	λ	99%	98%	95%	90%	99%	98%	95%	90%
1	0.36	6.74	34.3%	34.3%	39.3%	45.3%	61.3%	67.4%	84.2%	96.3%
2	0.38	29.70	56.4%	61.9%	67.7%	73.3%	82.5%	87.3%	95.8%	100.0%
3	0.36	28.80	56.7%	59.6%	65.8%	71.8%	82.3%	87.3%	96.0%	100.0%
4	0.00	0.00								
5	0.37	2.32	21.0%	21.0%	27.0%	27.0%	46.4%	46.4%	58.0%	58.0%
6 adult	0.36	6.51	32.9%	32.9%	37.8%	43.7%	59.1%	65.1%	81.3%	92.9%
6 child	0.38	12.02	41.4%	45.2%	49.5%	59.2%	70.7%	75.1%	85.8%	100.0%

Table 25: Efficiencies for the different availability levels, corresponding with values of Table 24

The appropriate bed capacity per theme is again a trade-off between availability and efficiency. Appendix L provides graphs to support making this decision. The procedure applied for clinical and surgical day care also pertains for non-surgical day care. Table 26 displays the recommended bed capacities (at maximum sum of availability and efficiency) for non-surgical day care.

	Average situation			Peak situation		
Theme	Capacity	Availability	Efficiency	Capacity	Availability	Efficiency
1	5	93.6%	45.3%	7	91.1%	96.3%
2	15	93.2%	70.6%	30	94.5%	99.0%
3	13	90.6%	71.8%	29	94.3%	99.3%
4						
5	3	95.6%	27.0%	2	81.8%	100.0%
6 adult	5	94.3%	43.7%	6	86.5%	100.0%
6 child	7	90.6%	59.2%	12	91.6%	100.0%
Total	48			86		

Table 26: Recommended bed capacity for non-surgical day care using trade-off method (with a=e)

For the themes with low arrival rates, recommended bed capacities in the average situation are almost equal to the peak situation. This however does not hold for the themes with higher required bed capacities.
Again, availabilities are relatively high, but efficiencies are low in the average situation and vice versa in the peak situation. This can be explained by the graphs shown in Appendix L. Compared to the average situation, the efficiency in the peak situation starts at 100%, stays at this level for a long time and decreases slowly. On the other hand, availabilities in the peak situation start lower and increase slower as well.

Again, the distribution of beds over the themes differs from the theme-based methods described in this section if we use a hospital-wide optimization method. For example, if we would use a fixed required availability of 95%, the beds are distributed over the themes as presented in Table 24. The total required capacity equals 55 beds. If we insert this number in the trade-off optimization tool with equal availability and efficiency weights, we see the themes' 2 and 3 bed capacity increases at the cost of the other themes and average daily refusals reduces (from 3.32 to 2.81). Similar differences exist when using the trade-off method with capacity of 48 beds and peak situation results of for example 95 and 86 beds.

Finally, availability and efficiency for the recommended bed capacities are higher than those of surgical day care patients. However, they are not satisfying when the Erasmus MC establishes a non-surgical day care department for each theme. This is because separate departments for each theme are too small to achieve both high availability and efficiency.

So the conclusion is the same as for surgical day care: we should definitely investigate whether it is profitable to share non-surgical day care bed capacity. Similar scenarios as mentioned in Section 8.2 will be studied for non-surgical day care in Chapter 9.

8.4 Conclusion

This chapter studied ward availability and efficiency with the provisional ward capacities in theme-organization, using current patient arrival numbers and LOS. We showed departments with higher bed capacity can afford high efficiencies/occupancies while ensuring the same bed availabilities compared to smaller wards.
Also, we suggested bed capacities in case of separate theme-based wards for clinical care, separate theme-based wards for non-surgical care and separate for surgical care. In the next chapter, we will see the effects of alternative scenarios for organization of day care.

9. Alternatives: economies of scale

Section 4.3.2 explained that wards with higher bed capacity are able to function at a higher efficiency while maintaining equal availability than smaller wards. This is because the combined independent random processes' variability is less than the sum of the variability of the individual processes. This chapter determines whether merging day care departments results in improved availability and efficiency. Just as for the original situation in the previous chapter, the mathematical model described in Chapter 7 can be used for assessing the effects of merging departments here. So the formulas for calculating the variables availability and efficiency remain valid.

An advantage of Poisson arrivals is that in case of merging departments, one can simply add up the arrival rates of each department to calculate the arrival rate of the new (merged) department. If we would merge m departments: $\lambda_{new} = \sum_{i=1}^{m} \lambda_i$. For the patient's LOS, we should calculate the weighted average of the departments to be merged: $\mu_{new} = \frac{\sum_{i=1}^{m} \mu_i \cdot \lambda_i}{\sum_{i=1}^{m} \lambda_i} = \frac{\sum_{i=1}^{m} \mu_i \cdot \lambda_i}{\lambda_{new}}$. These λ_{new} and μ_{new} have to be inserted in the formulas mentioned in Section 7.2. So in case we would merge the m departments, the new availability is: $Availability(new) = 1 - P_{loss}(new) = 1 - \frac{\left(\frac{\lambda_{new}}{\mu_{new}}\right)^s / s!}{\sum_{k=0}^{s} \left(\frac{\lambda_{new}}{\mu_{new}}\right)^k / k!}$ or the recursive formula $1 - P_{loss}(s) = \frac{\left(\frac{\lambda_{new}}{\mu_{new}}\right) \cdot P_{loss}(s-1)}{s + \left(\frac{\lambda_{new}}{\mu_{new}}\right) \cdot P_{loss}(s-1)}$. The efficiency of such merged departments can be calculated by: $Efficiency(new) = \frac{(1 - P_{loss}) \cdot \lambda_{new}}{s \cdot \mu_{new}}$.

Using these formulas, the number of required beds can be determined for the merged departments. Note that doing so, we assume beds (and staff assigned to the beds) are mutually interchangeable.

Because of the large number of departments discussed in Chapter 8, there are a lot of options of merging departments. We developed a tool that simplifies the evaluation of the effects of this merging. Figure 22 at the next page provides a screenshot of this departments merging tool.

In this chapter, we will illustrate the usage of the departments merging tool by evaluating the following scenarios: a surgical day care center (9.1), a non-surgical day care center (9.2), one day care center for both surgical and non-surgical patients (9.3) and day care in the clinics (9.4).

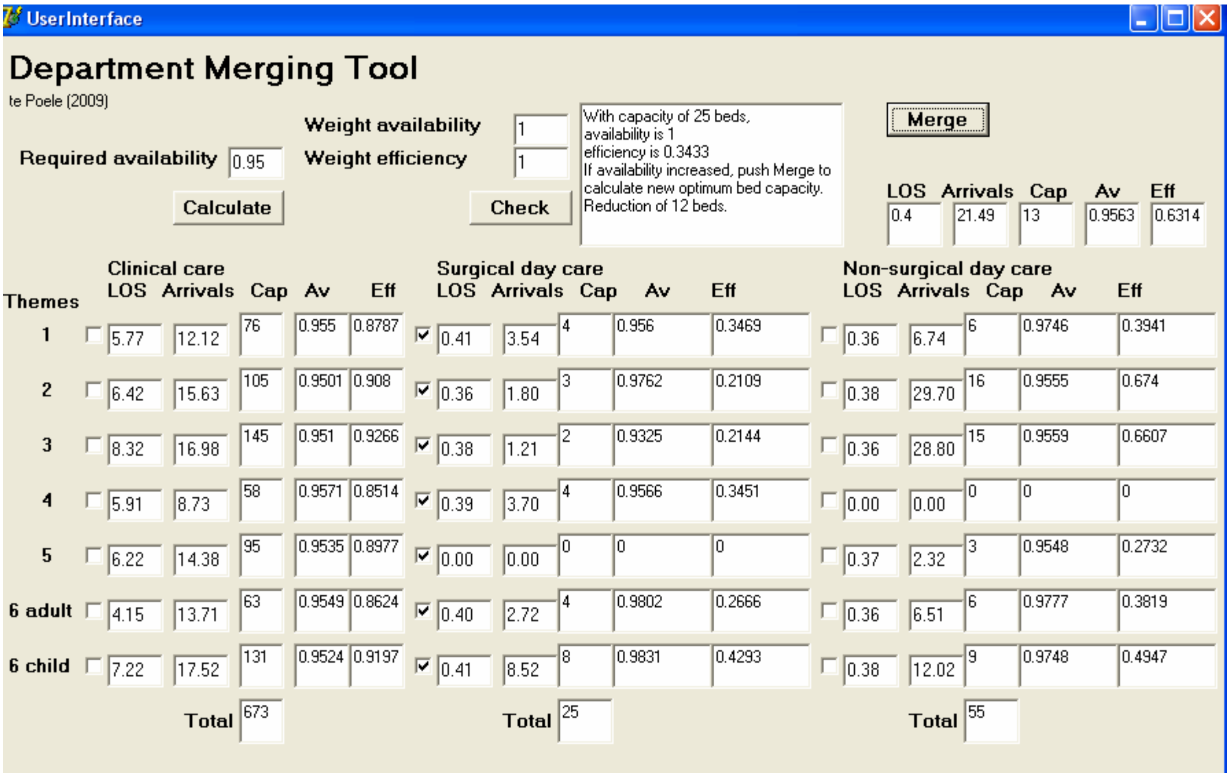

Figure 22: The department merging tool that supports evaluating organizational alternatives

9.1 Surgical day care center

To show economies of scale that occur when surgical day care is organized in a merged department instead of separate departments per theme, we compare required capacity and efficiency. To make a useful comparison, we maintain the availability at the same level. For this example, we use an availability level of 95%. This is just to give a clear overview of the merging advantages; the same effects arise when any other availability level is used as a norm. Just like in Chapter 8, we distinguish both the average and the peak situation.

9.1.1 Average situation

The capacity and efficiency before merging the surgical day care departments can be found in Section 8.2. So in total 25 beds are required to achieve an availability of 95% for each theme and efficiency ranges from 15.0% to 47.7% and is 33.0% on average.

Using the department merging tool, we first check whether these 25 beds can be distributed over the themes in a better way. In this sense, better means maximizing the sum of weighted total availability and weighted total efficiency (similar to the trade-off optimization tool used in Chapter 8). Independent of the weights, we see it is better to switch one bed of theme 3 to theme 6 child. Because of this movement, availabilities and efficiencies of these themes change slightly (see Figure 22).

Second, the tool determines whether merging of the themes' surgical day care is advantageous for the availability of the department. Therefore, we calculate the λ_{new} and $\frac{1}{\mu_{new}}$ of the merged departments together. Because the average LOS does not vary much between the themes, the value of $\frac{1}{\mu_{new}}$ hardly changes compared to the distinct $\frac{1}{\mu}$'s.

After merging all themes, λ_{new}=21.49 and $\frac{1}{\mu_{new}}$ =0.40. The accompanying availability and efficiency are displayed in Figure 23.

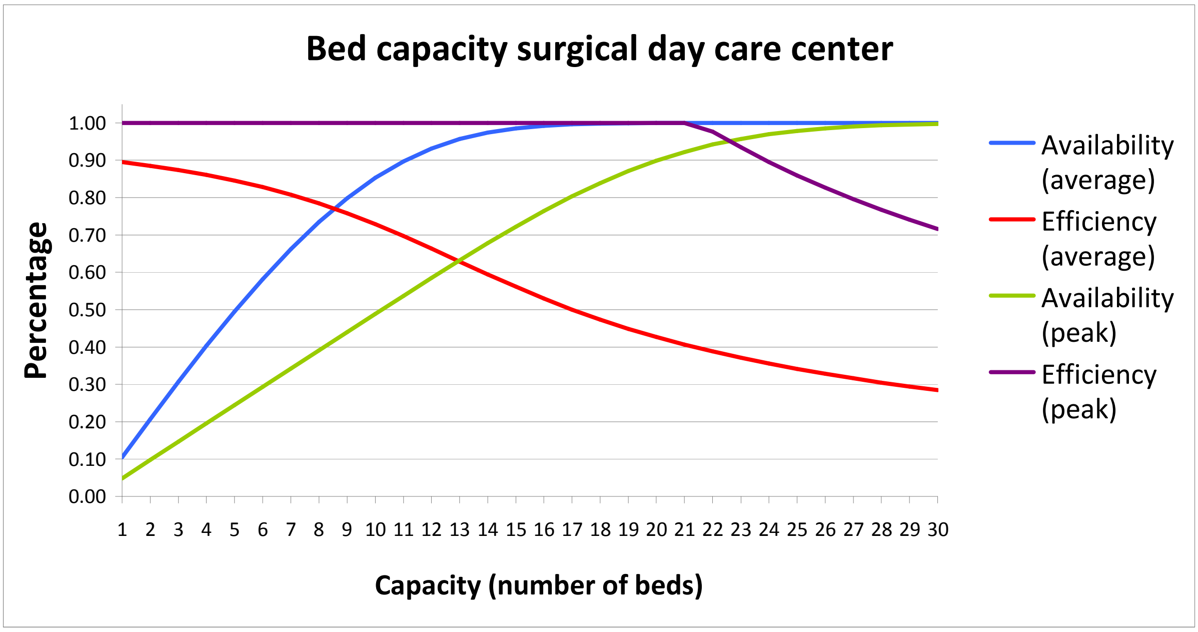

Figure 23: Capacity of a surgical day care center (average and peak situation)

So in the average situation, availability of the merged department would be almost 100% in case the 25 beds are maintained. Clearly, this availability is an improvement compared to availabilities of the separated departments. Therefore, it is advantageous to establish a merged department.
Because of the high availability (and the efficiency of only 34.2%), this merged department does not need a bed capacity of 25 beds and can manage with fewer beds. For example, to achieve 95% availability only 13 beds are required. So this is a decrease of 12 beds. The accompanying efficiency equals 63.1%. Compared to the efficiencies mentioned in Section 8.2, this is a considerable improvement. The improvement is caused by the variability pooling effects, which decrease the need for reserve/buffer capacity.
Note that (just as explained in 8.1) also in this case the Erasmus MC might decide upon a fixed number of total surgical day care beds. The corresponding availability level and distribution of beds over the themes can be calculated by numerically varying the availability.

Another realistic scenario in practice is a surgical day care center for all themes, except children of theme 6. Considering the results displayed in Section 8.2 this theme is also the most likely to be excluded from a collective center and to establish a separate capacity for. This is because surgical day care patients of theme 6 child need the highest bed capacity and can achieve the highest efficiency (see 8.2).
Merging all themes except theme 6 child results in λ_{new}=12.97 and μ_{new}=0.39 for the merged department. This department needs 9 beds to achieve 95% availability. The accompanying efficiency equals 54.1%. As mentioned in Section 8.2, the separate capacity for theme 6 child should equal 7 beds and efficiency is 47.7%.
So if the decision is made to organize surgical day care of theme 6 child separate from the other themes, total capacity for surgical day care patients increases to 16 beds and the hospital should accept lower efficiency.

9.1.2 Peak situation

When we consider the peak situation, the capacity before merging the surgical day care departments equals 29 beds in total to achieve an availability of 95% for each theme. In this case, efficiency ranges from 60.0% to 85.2% and is 74.1% on average.

Return to Figure 23 to see the merged department does not need a bed capacity of 29 beds and can manage with fewer beds (availability of nearly 100% and efficiency 74.1%). When we assume the peak situation, only 23 beds are required to achieve 95% availability. This is a decrease of 6 beds. The accompanying efficiency equals 93.4%. So the reserve/buffer capacity decreases to 6.6% because of variability pooling effects. The department merging tool is also developed for the peak situation, so the effects of other merging scenarios can be determined easily.

The scenario of a surgical day care center for all themes, except children of theme 6 is again relevant. The merged department needs 15 beds to achieve 95% availability (with efficiency of 86.5%) and the separate capacity for theme 6 child should equal 10 beds (85.2% efficiency). Thus, organizing surgical day care of theme 6 child separate from the other themes, total capacity for surgical day care patients increases to 25 beds and the hospital again should realize efficiency decreases.

9.2 Non-surgical day care center

This section shows that similar economies of scale also occur when non-surgical day care is organized in a merged department instead of separate departments per theme. Again, we compare required capacity and efficiency to achieve an availability of 95%.

9.2.1 Average situation

The capacity and efficiency before merging the non-surgical day care departments can be found in Section 8.3. So in total 55 beds are required to achieve an availability of 95% for each theme and efficiency is 55.6% on average and ranges from 27.0% to 67.7%.

Using the department merging tool, we first check whether these 55 beds can be distributed over the themes in a better way. Independent of the weights assigned to availability and efficiency, we see it is better to allocate extra beds to the themes 2, 3 and 6 child (at the cost of the other themes).

Second, the tools checks whether merging of the themes' surgical day care is advantageous for the availability of the department. Therefore, we calculate the λ_{new} and $\frac{1}{\mu_{new}}$ of the merged departments together. After merging all themes, λ_{new}=86.06 and μ_{new}=0.37. The accompanying availability and efficiency are displayed in Figure 24.

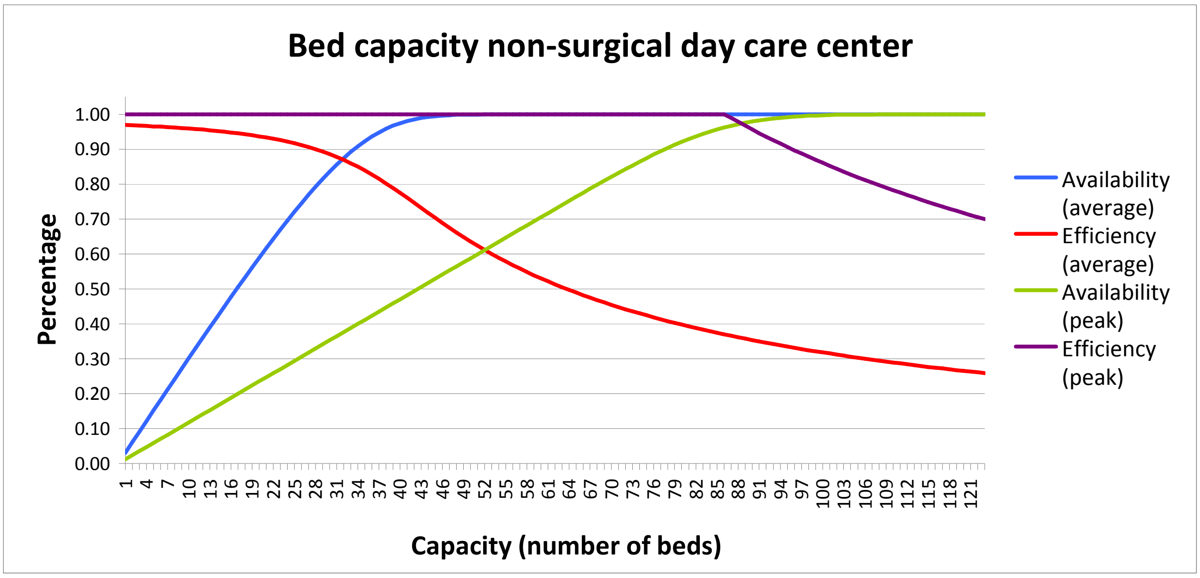

Figure 24: Capacity of a non-surgical day care center (average and peak situation)

So in the average situation, availability of the merged department would be almost 100% in case the 55 beds are maintained. This improved availability indicates it is advantageous to establish a merged department.
Because of the high availability (and the efficiency of only 57.9%), this merged department does not need a bed capacity of 55 beds and can manage with fewer beds. When we assume the average situation, only 38 beds are required to achieve 95% availability. So 17 beds less are needed. The accompanying efficiency equals 80.3%.
So compared to the efficiencies mentioned in Section 8.3, merging of non-surgical departments causes an efficiency improvement, while maintaining the same availability level.

Again the scenario of a non-surgical day care center for all themes, except children of theme 6 is a realistic one. However, non-surgical day care patients of theme 6 child do not need the highest bed capacity (see 8.3.1) and can achieve the highest efficiency (see 8.3.2). So it might be even more justified to exclude non-surgical day care patients of theme 2 and/or theme 3 from the collective center.
Because there are more possible options, the resulting bed capacities and efficiencies will not be described one-by-one but are summarized in the following table. Note that in case multiple themes are excluded, these have their own non-surgical beds (without sharing between these themes).

Excluded	Excluded dpt		Merged dpt				Total
theme	Cap	Eff	$1/\mu$	λ	Cap	Eff	cap
2	16	67.7%	0.36	56.38	26	75.3%	42
3	15	65.8%	0.38	57.28	27	76.1%	42
6c	9	49.5%	0.37	74.06	33	78.9%	42
2 and 3	16+15		0.37	27.58	15	65.1%	46
2 and 6c	16+9		0.36	44.36	21	72.3%	46
3 and 6c	15+9		0.37	45.26	22	73.4%	46
2, 3 and 6c	16+15+9		0.36	15.57	10	54.1%	50

Table 27: Capacity and efficiency for non-surgical day care, for several organizational scenarios

From this table, we see the total required capacity decreases for all these scenarios, compared to the 55 beds needed when all themes have their own non-surgical day care capacity. The benefit increases with an increasing number of themes included in the merged department.

9.2.2 Peak situation

Considering the peak situation, the capacity before merging the non-surgical day care departments equals 95 beds in total to achieve an availability of 95% for each theme. In this case, efficiency ranges from 58.0% to 96.0% and is 90.6% on average.

Again, the merged department does not need a bed capacity of 95 beds and can manage with fewer beds (otherwise availability of nearly 100% and efficiency 90.6%). When we assume the peak situation, only 84 beds are required to achieve 95% availability. The capacity decrease is 11 beds this time. The accompanying efficiency equals 100.0%, which again makes the needed reserve/buffer capacity to decrease from 9.4% to 0.0%.

As stated in Section 9.2.1, there are more possible options. The bed capacities and efficiencies for the most relevant options are summarized in the following table. Again in case multiple themes are excluded, these have their own non-surgical beds (without sharing between these themes).

Excluded	Excluded dpt		Merged dpt			Total
theme	Cap	Eff	λ	Cap	Eff	cap
2	31	95.8%	56.38	56	100.0%	87
3	30	96.0%	57.28	57	100.0%	87
6c	14	85.8%	74.06	73	100.0%	87
2 and 3	31+30		27.58	29	95.1%	90
2 and 6c	31+14		44.36	45	98.6%	90
3 and 6c	30+14		45.26	46	98.4%	90
2, 3 and 6c	31+30+14		15.57	17	91.6%	92

Table 28: Capacity and efficiency for non-surgical day care, for several organizational scenarios

Again the total required capacity decreases for all these options, compared to the 95 beds needed when all themes have their own non-surgical day care capacity. The benefit increases with an increasing number of themes included in the merged department.

9.3 One day care center

When it appears to be possible to merge surgical and non-surgical day care in collective centers, it is also considerable to organize both together in one day care center. This organization might even result in higher economies of scale. Whether this is the case indeed, will be investigated in this paragraph. Again, we compare required capacity and efficiency at an availability level of 95%.

9.3.1 Average situation

The capacity and efficiency before merging any day care departments can be found in Sections 8.2 and 8.3: in the average situation, capacity would equal 25+55=80 (efficiency ranges from 15.0% to 67.7%). When the Erasmus MC establishes one surgical day care (9.1) and one non-surgical day care center (9.2), 13+38=51 beds are needed with efficiency of 62.9% and 80.3%. These economies of scale result from variability pooling effects, since the arrival process is not deterministic.

Again, the 80 beds in total should be allocated slightly different to maximize the sum of weighted availability and efficiency. However, this does not outweigh the advantages of merging the departments.
After merging all themes' day care (both surgical and non-surgical), λ_{new}=107.55 and μ_{new}=0.38. The accompanying availability and efficiency are displayed in Figure 25.

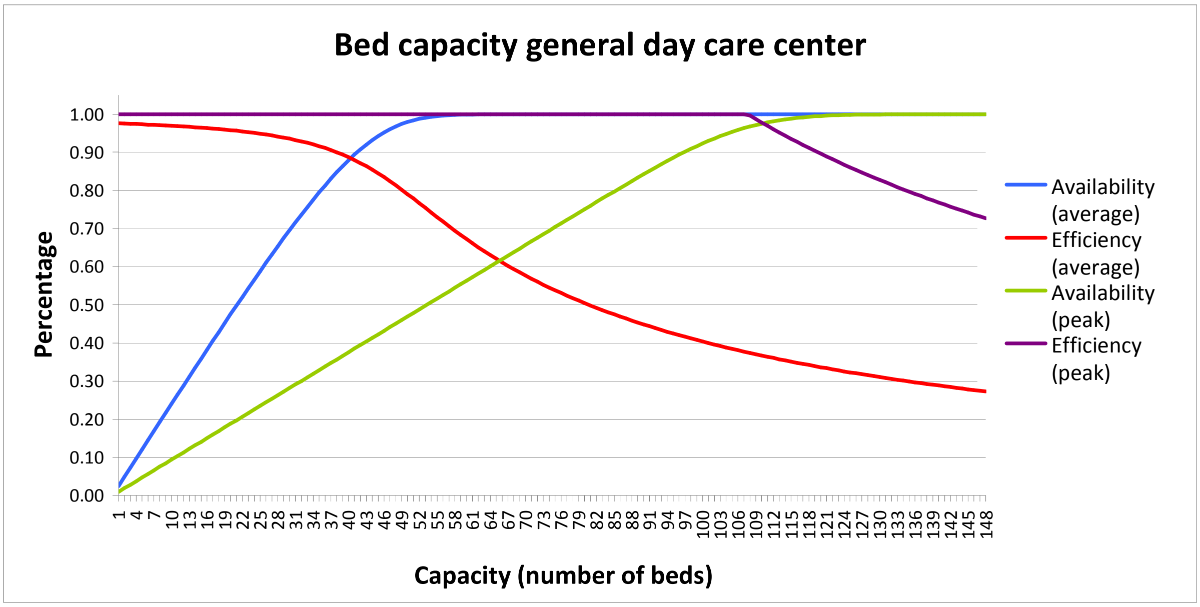

Figure 25: Capacity of a general day care center (average and peak situation)

We see that a capacity of 80 beds would result in availability of almost 100% and efficiency of only 50.5%. The merged department does not even need a capacity of 51 beds and can reduce the number of beds (otherwise availability of 98.4% and efficiency 77.9%). When we assume the average situation, 46 beds are required to achieve 95% availability. The accompanying efficiency equals 83.5%. The required reserve/buffer capacity will be 16.5% in this case. This is an improvement compared to the numbers mentioned in 8.2 and 8.3. Also, the efficiency is higher and reserve capacity is lower than in a separate surgical and a separate non-surgical day care center (respectively 37.1% and 19.7% buffer capacity).

Just like described in the previous paragraphs of this chapter, the Erasmus MC might choose to exclude some of the themes from the merged day care center. Table 29 shows the consequences of some decisions of this kind.

Excluded	Excluded dpt				Merged dpt				Total
theme	1/μ	λ	Capacity	Efficiency	1/μ	λ	Capacity	Efficiency	cap
1	0.38	10.28	8	47.1%	0.38	97.29	42	82.6%	50
2	0.38	31.50	17	67.8%	0.37	76.07	34	79.6%	51
3	0.36	30.00	16	64.9%	0.38	77.56	35	80.4%	51
4	0.39	3.70	4	34.6%	0.37	103.86	45	82.7%	49
5	0.37	2.32	3	27.0%	0.38	105.25	45	83.5%	48
6a	0.37	9.22	7	46.8%	0.38	98.34	43	82.2%	50
6c	0.39	20.54	13	59.9%	0.37	87.03	38	81.1%	51

Table 29: Capacity and efficiency for one day care center, excluding one of the themes

We see the total capacity always exceeds the 46 beds of merging all themes. Depending on which themes to exclude, the required bed capacity varies. While the λ of the theme increases, the penalty (in the form of higher required total capacity and lower efficiency) of excluding this theme increases. For example, excluding theme 5 results in two extra beds, while excluding theme 2, 3 or 6 child adds five beds to the total capacity. These are also the themes that are able to function at the highest efficiency when they have their own capacity.

Recall from Section 8.1 that the Erasmus MC may decide to use a certain number of day care beds in total and has to decide on how to distribute these beds over the themes to achieve the same availability level for each theme. The tools described in Section 8.1 can again be helpful in these decisions since corresponding availability level and distribution of beds over the themes can be calculated by numerically varying the availability.

9.3.2 Peak situation

Considering the peak situation, the capacity before merging any day care departments would equal 29+95=124 beds (required from Sections 8.2 and 8.3). In case of one surgical day care (9.1) and one non-surgical day care center (9.2), 23+84=107 beds are needed.
Again, after merging the surgical with the non-surgical day care department, bed capacity can be less than 107 beds (otherwise availability of 96.3% and efficiency of 100.0%). However, the difference is only 2 beds: when we assume the peak situation, 105 beds are required to achieve 95% availability. The accompanying efficiency equals 100.0%. The required reserve/buffer capacity will be 0.0% in this case: no difference compared to the separate non-surgical day care center, but an improvement compared to the 6.6% of the separate surgical day care center.

Table 30 shows the consequences of choosing to exclude some of the themes from the merged day care center.

Excluded	Excluded dpt			Merged dpt			Total
theme	λ	Capacity	Efficiency	λ	Capacity	Efficiency	cap
1	10.28	12	85.7%	97.29	95	100.0%	107
2	31.50	33	95.4%	76.07	75	100.0%	108
3	30.00	31	96.8%	77.56	77	100.0%	108
4	3.70	5	74.1%	103.86	101	100.0%	106
5	2.32	4	58.0%	105.25	103	100.0%	107
6a	9.22	11	83.8%	98.34	96	100.0%	107
6c	20.54	22	93.3%	87.03	85	100.0%	107

Table 30: Capacity and efficiency for one day care center, excluding one of the themes

We see the total capacity always exceeds the 105 beds of merging all themes. The differences vary between one and three extra beds.

9.4 Day care in clinics

So far, we have seen in Section 8.1 the Erasmus MC needs 673 clinical beds in total to achieve 95% availability for clinical patients of each theme.
Section 9.1 showed the bed capacity for surgical day care patients can be reduced from 25 to 13 when a surgical day care center is established (or from 41 to 29 regarding peak situation). For non-surgical day care, a center only needs a capacity of 38 beds instead of 55 (peak situation: 102 instead of 122). When both kinds of day care patients are collected in one center, required bed capacity reduces further to 46 (or 125 during peaks).
As stated in Section 5.4 another scenario is to hospitalize all patients in the clinical wards. This means day care patients use the same capacity as clinical patients of their own theme. Roughly, we distinguish two options: admit both kinds of day care patients in the clinics (9.4.2) or only the non-surgical day care patients (9.4.3). But first, Section 9.4.1 summarized the results from previous sections which will be used to make a useful comparison.

9.4.1 Comparative results

Section 8.1 displayed the way the 673 beds are distributed over the themes when availability would be equal 95%. Also, it showed the efficiency that each department would achieve. Table 31 recalls these results:

Theme	$1/\mu$	λ	Capacity	Efficiency
1	5.77	12.12	76	87.9%
2	6.42	15.63	105	90.8%
3	8.32	16.98	145	92.5%
4	5.91	8.73	58	85.2%
5	6.22	14.38	95	89.7%
6 adult	4.15	13.71	63	86.2%
6 child	7.22	17.52	131	92.0%
Total			**673**	

Table 31: Capacity and efficiency for theme-based clinical departments

For day care patients, there are multiple options possible. In Sections 9.1 and 9.2 we have seen it is possible to establish two kinds of day care centers: either for surgical or for non-surgical day care patients. Section 9.3 revealed these two kinds of patients can also be united in one combined day care center. The following characteristics hold for each of these options:

			Average		Peak	
Scenario	**$1/\mu$**	**λ**	**Capacity**	**Efficiency**	**Capacity**	**Efficiency**
Surgical	0.40	21.49	13	62.9%	23	93.4%
Non-surgical	0.37	86.08	38	80.3%	84	100.0%
Total			51		107	
Collective	0.38	107.57	46	83.5%	105	100.0%

Table 32: Capacity and efficiency for day care centers

Thus the total number of beds would be between 673+13+38=724 (average situation) and 673+23+84=780 (peak situation) if the Erasmus MC would choose to establish a separate day care center for each of the two kinds of day care patients. In case of one combined day care center, required capacity is minimally 673+46=719 and maximally 673+105=778 beds.

We choose to make the comparison regarding the average situation only. This is because for the scenario of admitted day care patients in the clinics, the peak situation is difficult to evaluate. Ideally, we would construct a model in which we could evaluate the economies of scale of combining the peak situation for day care patients with the average situation of clinical patients. This however is very complex. There are some ways to reduce this complexity, but these have their drawbacks as well.
First, we could simply calculate per theme the sum of the clinical capacity mentioned in Section 9.4.1, the surgical day care capacity of Section 8.2 and the non-surgical day care capacity of Section 8.3. However, doing so we ignore the economies of scale that occur as a result of combining all patients per theme (which is also the reason 729 instead of 754 beds are required in the average situation).
Second, we could pretend the clinical patients can also be evaluated using the peak situation described in Section 7.2.2. If so, the average LOS no longer matters because availability and efficiency are calculated using arrival rates only. We think the peak situation is not very suitable for clinical patients, since it assumes all daily admissions occur during one busy period of the day and overlooks the differences of LOS between the themes.
Because of these drawbacks, we make the comparison evaluating the average situation only.

9.4.2 Surgical and non-surgical day care in clinics

As stated before, the Erasmus MC might choose to admit both kinds of day care patients in the clinics. To be able to determine the consequences on availability, we first use the department merging tool to check whether bed capacity per theme can be distributed over the departments (clinical, surgical day and non-surgical day care) in a better way. Doing so, we see there is a difference between the merging of day care departments and admitting day care patients into the clinical departments. That is, where the weights assigned to availability and efficiency do not matter in the previous sections, they do influence the distribution in case of merging clinical with day care departments.

Second, we calculate the new $\frac{1}{\mu}$'s en λ's using the formulas mentioned in the introduction of this chapter. With these new parameters, we can determine the new availability of the merged department. Here arises another difference with the Sections 9.1 to 9.3: the new availability is usually not that close to 100%, but varies between 96.4% (theme 5) and 98.6% (theme 6 adult).

As a result, it is not that undisputable that admitting day care patients into the clinical departments is advantageous. That is, the availability of (one of) the separate departments is higher than the merged departments. Only for theme 6 adult, it reveals to be advantageous to merge clinical with day care departments no matter which weights are assigned to availability and efficiency. For the other themes, it depends on the relative weights assigned. Table 33 displays the requirement for each theme that should be valid to make merging advantageous.

	Weight Availability : Efficiency
Theme	Availability/Efficiency ≤
1	2.79
2	0.59
3	0.46
4	1.39
5	11.86
6a	
6c	0.98

Table 33: Values of weight availability required to make merging advantageous

So for the themes 2, 3 and 6 child, merging is only advantageous if efficiency is more important than availability. For the themes 1, 4 and 5, merging is no longer advantageous if the relative weight of availability exceeds the values displayed in Table 33.

In case the Erasmus MC argues these requirements are valid, we can use the new parameters to determine the number of beds needed to achieve 95% availability and its accompanying efficiency:

Theme	1/μ	λ	Capacity	Efficiency
1	3.30	22.40	80	88.2%
2	2.38	47.13	117	91.3%
3	3.24	46.99	156	92.9%
4	4.27	12.43	59	85.7%
5	5.40	16.70	96	89.9%
6a	2.63	22.93	66	87.0%
6c	3.53	38.06	139	92.3%
			713	

Table 34: Capacity and efficiency if all day care patients are admitted at the clinical wards of their theme

Quite obvious, required capacity is much less than the (674+25+55=) 754 beds when clinical patients are split from both day care patients and there is no day care center where patients of multiple themes are accommodated. It is also less than the capacities advised in case the Erasmus MC would hospitalize day care patients in centers (see Section 9.4.1).
But what attracts attention is that the availabilities of the merged departments decrease compared to the separate departments, unless the weights assigned to availability and efficiency meet certain requirements. Judging by these results, we can conclude it might not be advantageous to admit all day care patients in the clinics, compared to establishing day care centers.

9.4.3 Non-surgical day care in clinics

Another possibility is to admit non-surgical day care patients in the clinics only, while accommodating surgical day care patients in a center (like described in Section 9.1).
Again we first check whether bed capacity per theme can be distributed over the departments (clinical, surgical day and non-surgical day care) in a better way. Second, we calculate new $\frac{1}{\mu}$'s en λ's and use these to determine the new availability of the merged department. Again, it is not that unambiguous that merging clinical with day care departments is advantageous. This time, the requirements regarding weights assigned to availability and efficiency are as follows:

	Weight Availability : Efficiency
Theme	Availability/Efficiency ≤
1	2.46
2	0.32
3	0.27
4	
5	11.86
6a	0.59
6c	0.34

Table 35: Values of weight availability required to make merging advantageous

So for the themes 2, 3 and 6 adult and child, merging is only advantageous if efficiency is more important than availability. For the themes 1 and 5, merging is no longer advantageous if the relative weight of availability exceeds the values displayed in Table 35.

In case the Erasmus MC argues these requirements are valid, the new parameters can be used to determine the number of beds needed to achieve 95% availability and its accompanying efficiency:

Theme	1/μ	λ	Capacity	Efficiency
1	3.83	18.86	78	88.3%
2	2.47	45.33	117	91.1%
3	3.31	45.78	155	93.0%
4	5.91	8.73	58	85.2%
5	5.40	16.70	96	89.7%
6a	2.93	20.22	65	86.8%
6c	4.44	29.54	135	92.3%
			704	

Table 36: Capacity and efficiency if only non-surgical day care patients are admitted at the clinical wards of their theme

This time the total required capacity equals these 704 beds plus the 13 beds of the surgical day care center. So there are (720-717=) 3 beds less needed than in case of one combined day care center and (725-717=) 8 beds less compared to a separate day care center for each of the two kinds of day care patients.

Judging by these results, we can conclude it is advantageous to admit non-surgical day care patients in the clinics while establishing a day care center for surgical day care. However, the advantages are only valid if the weights assigned to availability and efficiency match the restrictions displayed in Table 35.

Because of the great variety of possible options, we were only able to display the results of a limited number of scenarios in this chapter. For example, it is also possible to other variants like: one center for both surgical and non-surgical day care for all themes except one theme and hospitalizing this theme's day care patients in the clinics. Also, the Erasmus MC can calculate consequences of other scenarios herself, using the department merging tool. For example, we displayed the results of excluding one theme at the time in Section 9.3, but it is also possible to exclude multiple themes.

9.5 Conclusion

This chapter determined the effects of hospitalizing day care patients in the clinical wards versus in day care center(s). We showed the effects of several scenarios regarding organization of capacity for day care patients. It appeared that sharing capacity (or what is called merging departments) results in economies of scale. For example, combining surgical day care patients of all themes in one surgical day care center makes capacity request decrease with 6 to 12 beds (depended on whether the average or peak situation is considered). Combining all non-surgical day care patients in one department causes needed capacity to decrease with 11 to 17 beds. Establishing one day care center for both surgical and non-surgical patients results in another decrease of 2 to 5 beds. These economies of scale also appear when we would merge all patients of each theme (so clinical and both types of day care patients together) at the clinical department of that theme. However, the availabilities of the merged departments decrease compared to separate day care departments, unless the weights assigned to availability and efficiency meet certain requirements. We leave the decision of which scenario to execute in the new building to the Erasmus MC, but want to stress it is not advantageous to admit all day care patients in the clinics, compared to establishing day care centers.

As explained in Section 5.3, we used admission numbers and patients' length of stay over the year 2007 in the Chapters 6 to 9. But since this report advises about strategic decisions, which are long term, we have to determine whether the used data also represents the future situation. Therefore, we execute several sensitivity analyses, which will be discussed in Chapter 10.

10. Sensitivity Analysis

We made assumptions regarding data collection and theme configurations in the previous chapters. Doing so, we formulated the mathematical model described in Chapter 7. This chapter executes sensitivity analyses to test whether the results of Chapters 8 and 9 are robust to changing patients' arrival rates and length of stay. The sensitivity analyses will concern several fields. Section 10.1 determines the impact of each of the parameters used in the Erlang loss model. Subsequently, we evaluate how these parameters might change. First, we evaluate the appropriateness of the theme configuration described in Chapter 5 (10.2). Second, we compare admission data of 2008 to data regarding the year 2007 (10.3). Finally, we glance at the future situation by analyzing trends regarding arrival rates and LOSs (10.4).

10.1 Parameter impact

In Chapter 7 we presented and validated the Erlang loss model and used it in Chapter 8 and 9 to display availability and efficiency as a function of the number of beds. The bed allocation tool presented in Section 8.1.2 already revealed changing the load results in changed bed capacities. In this section we will investigate how sensitive the bed capacity is to λ and $\frac{1}{\mu}$ (that together make up the load).

Using the parameters of 2007, the load of clinical patients varies between 51.61 (for theme 4, with an arrival rate of 8.73 patients per day and average LOS of 5.91 days) and 141.22 (for theme 3). From Figure 26 we see the recommended bed capacities diverge as the required availability level increases.

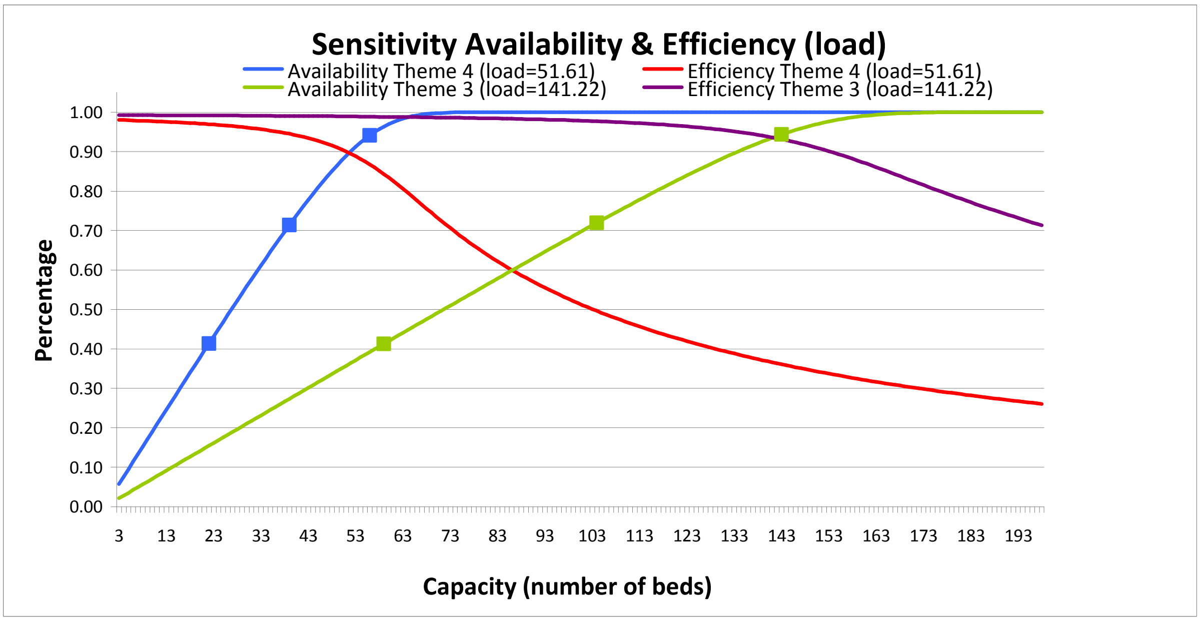

Figure 26: Availability and efficiency for theme 3 and 4

To illustrate the impact of the load on recommended bed capacities, we display the relation between the two variables for several availability levels.

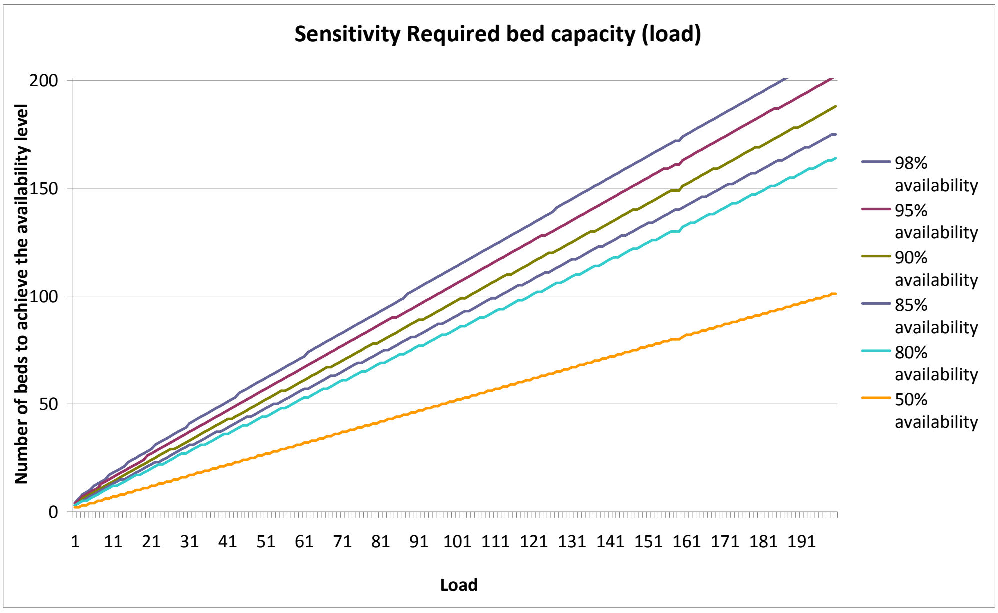

Figure 27: Bed capacity as a function of the load, for several availability levels

We see the relation between the load and required bed capacity is almost perfectly linear. The strength of the relation depends on the used availability level: the higher the availability level, the steeper the slope. For low availabilities, the slope is almost equal to the availability (the 50% availability graph has a slope of 0.505). As availability increases, the slope diverges from it (e.g. slope of 1.01 at 95% availability and slope of 1.07 at 98% availability). So as the load $\frac{\lambda}{\mu}$ increases with 1, the required capacity to achieve 95% availability also increases with 1 bed.

To determine the impact of the arrival rate on the required bed capacity, we have to consider the load $\frac{\lambda}{\mu}$ with constant $\frac{1}{\mu}$. And obviously, to determine the impact of the LOS on the required bed capacity, we have to consider the load $\frac{\lambda}{\mu}$ with constant λ. Apparently, the relation between recommended bed capacity with arrival rate is again perfectly linear and the slope does not only depend on the availability level, but also on $\frac{1}{\mu}$. For example, if we would pursue 95% availability, an increase of λ by one patient per day leads to required capacity increase of approximately $\frac{1}{\mu}$. If a lower availability is pursued, the slope is almost equal to $\frac{1}{\mu} \cdot \textit{Availability}$ (e.g. the 50% availability graph with $\frac{1}{\mu}$ = 5 days has a slope of 2.525). For higher availabilities, the slope exceeds little more (e.g. at 98% availability and $\frac{1}{\mu}$ =5 days, $\frac{1}{\mu} \cdot \textit{Availability} = 4.90$ while the slope is actually 5.35).

For LOS counts a similar relation with recommended bed capacity: the relation is linear and the slope depends on the availability level and on the parameter λ. For low availabilities, the slope is almost equal to $\lambda \cdot \textit{Availability}$ and for 95% availability it equals λ. So as the LOS decreases with 1 day, the required capacity to achieve 95% availability decreases with λ beds. As availability increases, the slope exceeds $\lambda \cdot Availability$ little more.

10.2 Alternative theme distribution

In Section 5.3 we presented a methodology to distribute admitted patients over the six themes: patients admitted in the Daniel den Hoed location belong to theme 2, in the Sophia location to theme 6 child and patients admitted in the Centrum location are allocated to a theme based on their specialty.
However, we can also organize patients based on their DBC-code, which characterizes the combination of diagnosis and treatment. One of the theme's managers composed a DBC-theme conversion table. Because of its extensive size, the complete table of all DBC-codes and the corresponding theme is not added to this report (but can be acquired on demand).
We were able to obtain a data record with admitted patients and their theme based on this conversion method. In this section, we compare the results of inserting this data in the Erlang loss model with the results displayed in Chapter 8 and 9. Note that the data record did not include day care patients of theme 6 child. Also, it comprised an imaginary theme 10 for traumatology, which we decided to include at theme 4.

10.2.1 Clinical patients

Just as described in Section 7.2, we calculated the parameter $\frac{1}{\mu}$ for each theme as the average patient's LOS in days. The occupancy rates were recalculated using the formula $Occupancy = \frac{Admissions\ (per\ day) \cdot Average\ LOS\ (in\ days)}{Number\ of\ operational\ beds}$. Just as in Section 6.4, the number of operational beds is based on the number of beds utilized in December 2007.
Subsequently, we recalculated the number of clinical arrivals (λ) numerically, because s and μ are also known.

Finally, with these new $\frac{1}{\mu}$'s and λ's, we can determine the capacities required to achieve several availability levels (and the corresponding efficiencies). Table 37 summarizes the results for clinical patients.

			Beds required for availability =				Efficiency for availability =			
Theme	**1/μ**	**λ**	**99%**	**98%**	**95%**	**90%**	**99%**	**98%**	**95%**	**90%**
1	5.83	10.56	76	73	67	62	80.2%	82.8%	87.3%	90.3%
2	6.24	17.49	127	122	114	105	85.1%	87.7%	91.1%	93.8%
3	8.28	18.12	170	164	154	142	87.4%	89.7%	92.8%	95.2%
4	5.99	7.99	61	59	54	49	77.6%	79.7%	84.6%	88.5%
5	6.14	13.81	101	97	90	83	83.2%	85.8%	89.6%	92.5%
6 adult	5.22	13.88	88	84	78	72	81.5%	84.5%	88.4%	91.4%
6 child	6.06	13.71	99	95	89	81	83.1%	85.7%	89.2%	92.5%
Total			**722**	**694**	**646**	**594**				

Table 37: Required bed capacity for different availability levels and corresponding efficiency levels

We see the $\frac{1}{\mu}$'s are comparable with the ones used in Section 8.1. Differences vary from a difference in average LOS of -1.16 days for theme 6 child to +1.07 days for theme 6 adult. The difference between λ's is greater and varies between −3.18 patients per day for theme 6 child and +1.86 patients per day for theme 2. The cumulative λ excl. theme 6 child equals 81.85 patients per day, almost similar to the cumulative λ excl. 6 child used in the former model (81.55 patients per day). As a consequence, required bed capacities should be adjusted higher for theme 2, 3 and 4 than indicated in Chapter 8.

For theme 1, 5, 6 adult and 6 child, capacity should be lowered. In total, the Erasmus MC is able to achieve the same availability with 30 beds less, mainly explained by the major reduction for theme 6 child. These results also arise when we make the trade-off between availability and efficiency based on the sum of these two variables:

Theme	Capacity (Δ)	Availability	Efficiency
1	67 (-9)	95.1%	87.3%
2	116 (+9)	96.1%	90.4%
3	158 (+9)	96.6%	91.7%
4	53 (-4)	94.8%	85.5%
5	91 (-5)	95.6%	89.2%
6 adult	78 (+12)	95.2%	88.4%
6 child	89 (-45)	95.5%	89.2%
Total	**652 (-29)**		

Table 38: Recommended bed capacity for clinical care using trade-off method (with a=e)

The total capacity decreases from 681 beds (see Section 8.1.1) with 29 beds to a capacity of 652. Per theme, the difference is also displayed in Table 38.

10.2.2 Day care patients

Just as described in Section 7.2.2, we assume no refusals occur and λ is equal to the admission rates. The parameter $\frac{1}{\mu}$ for each theme is again calculated as the average patient's LOS in days. Table 39 summarizes the new $\frac{1}{\mu}$'s and λ's for both surgical and non-surgical day care patients.

Theme	Surgical		Non-surgical	
	$1/\mu$	λ	$1/\mu$	λ
1	0.40	3.80	0.34	4.34
2	0.36	1.52	0.38	28.25
3	0.38	1.35	0.36	29.33
4	0.39	3.77	0.40	2.36
5	0.00	0.00	0.37	2.85
6 adult	0.40	2.53	0.36	6.95
6 child	0.00	0.00	0.00	0.00

Table 39: $1/\mu$'s and λ's for day care patients, with alternative theme distribution

We see non-surgical day care treatments occur for theme 4 this time, where they do not in the previously used theme distribution. Comparing the results for the other themes with the ones stated in Section 7.3.2, the $\frac{1}{\mu}$'s are as good as equal. Regarding the λ's, we see small but insignificant differences. As a consequence, we presume the required capacities to achieve certain availability levels are also comparable to those mentioned in Section 8.2 (for surgical day care patients) and 8.3 (for non-surgical). Appendix M displays the capacities required (and the corresponding efficiencies) in case each theme would establish a separate department for surgical day care patients and one for non-surgical day care.
Note that theme 6 child patients are missing in the new data file, so we should compare with the results of Chapter 8 excluding patients of theme 6 child. The capacities do not change much, as expected.

More interesting are the required capacities when we would establish day care centers with shared capacity among the themes. For 95% availability, these are:

			Average		Peak	
Scenario	$1/\mu$	λ	Capacity	Efficiency	Capacity	Efficiency
Surgical	0.39	12.97	9	54.1%	15	86.5%
Non-surgical	0.37	74.07	33	78.9%	73	100.0%
Total			42		88	
Collective	0.37	87.04	38	81.1%	85	100.0%

Table 40: Capacity and efficiency for day care centers

Again we should compare with the results of Chapter 9 excluding patients of theme 6 child. For a surgical day care center, $\frac{1}{\mu}$'s and λ's are exactly the same, so required capacity does not change either. For a non-surgical day care center as well as one collective day care center, λ is only 0.01 patients per day higher, which does not cause any difference in required bed capacity.

All in all, we see a considerable decline in beds for clinical care but no difference in day care beds.

10.3 Present patients in 2008

As described in Section 5.3, we used admission numbers and patients' length of stay over the year 2007 to base our analysis on. This paragraph studies whether this data also represents the situation of 2008. The data was obtained at 08-01-2009.

10.3.1 Clinical patients

We again recalculate the parameter $\frac{1}{\mu}$ (the average patient's LOS in days) for each theme. We use this parameter together with the number of admissions per day and the number of operational beds to determine the new number of clinical arrivals (λ).
Finally, we determine the capacities required to achieve several availability levels (and the corresponding efficiencies). Table 41 summarizes the results for clinical patients using 2008 admission data.

			Beds required for availability =				Efficiency for availability =			
Theme	$1/\mu$	λ	99%	98%	95%	90%	99%	98%	95%	90%
1	5.61	11.93	82	79	73	66	80.8%	83.2%	87.5%	91.3%
2	6.16	15.44	112	108	100	92	84.1%	86.5%	90.4%	93.2%
3	7.55	17.44	151	145	136	126	86.5%	89.1%	92.2%	94.6%
4	5.75	8.35	62	59	54	49	76.9%	80.0%	84.9%	88.7%
5	4.86	16.13	95	91	84	77	81.9%	84.7%	89.0%	92.1%
6 adult	3.91	14.89	73	70	64	59	79.2%	81.9%	86.7%	89.9%
6 child	6.61	16.84	129	125	116	107	85.5%	87.5%	91.3%	93.9%
Total			**704**	**677**	**627**	**576**				

Table 41: Required bed capacity for different availability levels and corresponding efficiency levels

Compared to the results of 2007, we cannot extract a general trend regarding the daily arrival rate: there are themes with increased arrival rate, while others decrease. The difference varies between -0.68 patients per day for theme 6 child and +1.18 patients per day for theme 6 adult. For the average LOS however, we see the $\frac{1}{\mu}$'s of all themes

are decreased in 2008. The smallest difference equals 0.16 days (theme 1 and 4), while the largest decrease is as much as 1.36 days (theme 5).
As a result, the required bed capacity is also considerably lower: at 95% availability, the decrease is (674-627=) 47 beds in total.

Not surprising, this trend also persists in the trade-off between availability and efficiency:

Theme	Capacity (Δ)	Availability	Efficiency
1	73 (-3)	95.5%	87.5%
2	102 (-5)	96.0%	89.5%
3	139 (-10)	96.3%	91.3%
4	53 (-4)	94.6%	85.7%
5	85 (-9)	95.8%	88.4%
6 adult	64 (+2)	95.2%	86.7%
6 child	118 (-16)	96.0%	90.6%
Total	**634 (-47)**		

Table 42: Recommended bed capacity for clinical care

The total capacity decreases from 681 beds (see Section 8.1.1) with 47 beds to a capacity of 634. Table 42 also displays the difference per theme.

10.3.2 Day care patients

Again, the new λ's and $\frac{1}{\mu}$'s determine the required bed capacity to achieve a certain availability level. Table 43 displays these new parameters, for both surgical and non-surgical day care patients.

Theme	Surgical		Non-surgical	
	1/μ	λ	1/μ	λ
1	0.41	5.85	0.31	8.87
2	0.37	1.98	0.47	28.43
3	0.40	1.66	0.35	28.84
4	0.39	3.73	0.00	0.00
5	0.00	0.00	0.31	3.05
6 adult	0.40	2.81	0.36	6.79
6 child	0.41	8.97	0.39	11.83

Table 43: 1/μ's and λ's for day care patients, with data of 2008

We see the LOS of surgical day care patients hardly changed (only an increase of 0.01 to 0.02 days). For non-surgical day care patients, the change is greater but still relatively small: from -0.06 days to +0.09 days compared to 2007.
Regarding the arrival rate of non-surgical day care patients, we cannot extract a general trend: there are themes with increases (max +2.13 patients per day for theme 1) as well as decreases (max -1.27 patients per day for theme 2).
For the surgical day care patients however, we see arrival rates of all themes are increased in 2008. The smallest difference equals only +0.03 patient per day (theme 4), while the largest decrease is as much as 2.31 patients per day (theme 1).
As a result, the capacities required to achieve certain availability levels might change compared to Section 8.2 (for surgical day care patients) and 8.3 (for non-surgical).
Appendix N displays the capacities required (and the corresponding efficiencies) in case of a separate department for surgical day care patients per theme and one per theme for non-surgical day care.
Regarding both surgical and non-surgical in the average situation, required capacities are more or less the same, apart from differences of 1 or 2 beds per theme. Considering the

peak situation, the difference is a little higher, mostly caused by the increased arrival rate for patients of theme 1.

Here, we focus on the required capacities when the Erasmus MC would establish day care centers with shared capacity among the themes. For 95% availability, these are:

			Average		Peak	
Scenario	**$1/\mu$**	**λ**	**Capacity**	**Efficiency**	**Capacity**	**Efficiency**
Surgical	0.40	25.00	15	64.3%	26	96.1%
Non-surgical	0.39	87.81	40	81.6%	86	100.0%
Total			55		112	
Collective	0.39	112.81	50	84.3%	110	100.0%

Table 44: Capacity and efficiency for day care centers

The $\frac{1}{\mu}$'s remain the same (surgical), increase with 0.02 days (non-surgical) and increase with 0.01 days (collective). Arrival rates of surgical day care increases with 3.51 patients per day and λ of non-surgical day care increases with 1.75 patients per day (thus a collective increase of 5.26 patients per day).
As a result, the required bed capacity to achieve 95% availability is also higher. In case of one surgical day care center and one non-surgical day care center, the increase in beds equals 2+2=4 (average situation) or 3+2=5 (peak situation). For one collective day care center, the increase is 4 beds in the average situation and 5 beds in the peak situation.

All in all, comparing 2008 to 2007 we see a considerable decline in beds required for clinical care and a slight increase of day care beds.

10.4 Trend analysis

Nationally and worldwide, patients' length of stay (LOS) in hospitals reduces (as described in Section 2.2). However, as explained in Section 3.4, Dutch academic centers and the Erasmus MC more specifically do not seem to be able to keep up with this development.

In Section 10.3, we also saw some differences in LOS and arrival rates in the comparison of the situation of 2008 with 2007. To predict the situation in 2015, we could extrapolate these differences. However, before we can justify this extrapolation, we should determine whether these differences are even significant. Using a two sample t-test we can determine if LOSs and arrival rates of 2008 significantly changed to those of 2007. One can discuss whether the arrival samples of 2007 and 2008 are paired or not. On the one hand, arrivals occur at a certain date and the date influences the number of arrivals on that day. However, 2008 is a leap year so has one observation more than 2007 (paired tests require equal number of observations in both samples). Also, the number of admissions on a day depends more on the day of the week (weekend usually lower), than it depends on the date. Therefore, we choose to apply the t-test for independent samples (just as used for the LOSs).
Note that the daily arrival rates of clinical patients were unknown and derived from the number of admissions per day. Therefore, to test whether 2008 differs from 2007, we test whether the mean admission numbers are significantly different. The execution and results of the tests can be found in Appendix O.
Concluding for clinical patients, the change in LOS is not significant for the themes 1, 2 and 4. So only the LOS reduction of theme 3, 5, 6 adult and 6 child are significant. The change in admission is even less significant: only the increase for the themes 5 and 6 adults is significant.
For day care patients, the LOS change for theme 3 and 6 child is significant for both surgical and non-surgical patients. This is also the case for the change in arrival rate of

theme 1. Additionally, for non-surgical day care patients only, the LOS change for theme 1 and 5 and the arrival rate for theme 5 is significant.

Generally speaking, we expect an increased number of arrivals in the future, with a shorter LOS. We saw in Section 10.1 that as the LOS decreases with 1 day, the required capacity decreases with approximately $\lambda \cdot Availability$ beds.

In the most optimistic case, the hospital-wide average LOS will be decreased to 6 days (inclusive psychiatry, see Section 2.1). Compared to the 7.9 days mentioned in Section 3.1, this is a decrease of 24.1%. If this reduction will be achieved for all themes, the LOS reduction is between 1 and 2 days (respectively theme 6 adult and theme 3). As a result, required capacity decreases, varying from 14 to 30 beds per theme (136 beds in total).

If both LOS and arrival rate change, we should determine whether this results in a change in $\frac{\lambda}{\mu}$, the load of the system. Section 10.1 revealed that as the load $\frac{\lambda}{\mu}$ increases with x, the required capacity increases at least with $x \cdot Availability$ beds. To neutralize the possible LOS decrease of 24.1%, the arrival rate should increase with $\frac{24.1\%}{100\% - 24.1\%} = 31.8\%$. This would mean a hospital-wide increase of approximately 8000 patients per year. In our opinion, this is not very likely to occur.

Additionally, we can question our definition of a day care patient. As described in Section 5.4, we decide upon the registered admission type whether a patient can be admitted in day care. As also explained in that section, the group of day care patients might actually be larger. Therefore, we can change the day care patient definition into all patients that have equal admission and dismissal date (both not at Saturday or Sunday). Additionally, admission should occur between 7 AM and 4 PM and dismissal between 8 AM and 8 PM. As a consequence, the number of clinical care admissions are replaced by day care admissions. Also, the LOS of clinical care patients increases because some patients with short LOS are now defined as day care patients. The decreased arrival rate and increased LOS seem to neutralize each other: the required capacities displayed in Table 45 hardly deviate from the capacities presented in Section 8.1.1.

				Required capacity	
Theme	**1/μ**	**# Adm**	**λ**	**95% av**	**Trade-off**
1	6.12	10.38	11.34	75	75
2	6.67	15.02	15.03	105	107
3	8.57	16.46	16.47	145	149
4	6.11	8.43	8.43	57	57
5	7.60	10.85	11.55	93	94
6 adult	3.36	17.53	18.30	67	67
6 child	7.69	14.44	16.30	130	133
				672	682

Table 45: Clinical patient characteristics and capacities using alternative day care definition

Table 46 displays the new λ and $\frac{1}{\mu}$ parameters, for both surgical and non-surgical day care patients.

Theme	Surgical		Non-surgical	
	$1/\mu$	λ	$1/\mu$	λ
1	0.37	4.84	0.36	7.09
2	0.32	2.20	0.38	30.55
3	0.34	1.85	0.36	29.12
4	0.36	4.96	0.28	0.20
5	0.24	0.30	0.32	5.80
6 adult	0.37	3.29	0.33	7.82
6 child	0.40	9.23	0.37	12.77

Table 46: $1/\mu$'s and λ's for day care patients using alternative day care definition

Day care patients' LOS decline slightly. Arrival rates have increased for practically all themes. As a result, the capacities required to achieve certain availability levels slightly increase compared for both surgical and non-surgical day care patients. When the Erasmus MC would establish day care centers with shared capacity among the themes and strive for 95% availability, the required capacities are:

			Average		Peak	
Scenario	$1/\mu$	λ	Capacity	Efficiency	Capacity	Efficiency
Surgical	0.37	26.67	15	63.7%	28	95.3%
Non-surgical	0.36	93.35	40	81.0%	91	100.0%
Total			55		119	
Collective	0.36	120.02	50	83.7%	117	100.0%

Table 47: Capacity and efficiency for day care centers

In case of one surgical day care center and one non-surgical day care center, the increase in beds equals 2+2=4 (average situation) or 5+7=12 (peak situation). For one collective day care center, the increase is 4 beds in the average situation and 12 beds in the peak situation. So if the Erasmus MC prefers to treat more clinical patients in day care environment in the future, it should account for this growth when establishing the day care center(s).

10.5 Conclusion

This chapter used sensitivity analyses to test whether the results of Chapters 7 and 8 are robust to changing patients' arrival rates and length of stay. It appeared that required bed capacity is approximately linearly related to the load of the system and 2008 arrival rates and LOS are similar to 2007. We conclude the data of 2007 is indeed adequate enough to base required bed capacity upon. The next chapter uses these results to conclude if and how the Erasmus MC should change their bed capacity and allocation to optimize availability and efficiency.

11. Additional considerations

From the analyses described in Chapter 9, we saw the Erasmus MC can benefit from combining day care department facilities among the themes because of major reduction of required bed capacity. Hospitalizing non-surgical day care patients in the clinical wards combined by a surgical day care center results in similar benefits compared to a collective (surgical and non-surgical) day care center for all themes together.
Therefore, we would advise to establish at least a center for surgical day care for all themes. For non-surgical day care patients, the Erasmus MC can choose to add them to the same day care center or to the clinical wards. Establishing separate non-surgical day care facilities for each theme is not desirable, because the load is too small to achieve both high availability and efficiency. This chapter describes considerations that help to select the most appropriate alternative (11.1, 11.2 and 11.3), organizational consequences of the alternatives (11.4) and topics for further research (11.5).

11.1 Strategic considerations

Current way of thinking in hospitals is comparable with the famous work of Woodward in the 1960's. Each patient is different, requires perfectly adjusted care and therefore needs a unique product. In Woodward's typology, the only way to achieve such customized service is to deliver it in small batches, that would be small hospital wards specialized to very specific patients. This is in line with Porter's (1980) classification into differentiation, cost leadership and focus strategies. In this sense, differentiation strategies to meet additional customer needs are not compatible with mass production efficiency.

Although Woodward and Porter formulated useful theories, new developments occurred during the following years. Flexible manufacturing and mass customization deviate from the diagonal in Figure 28 and show high product flexibility is also possible in large batch sizes.

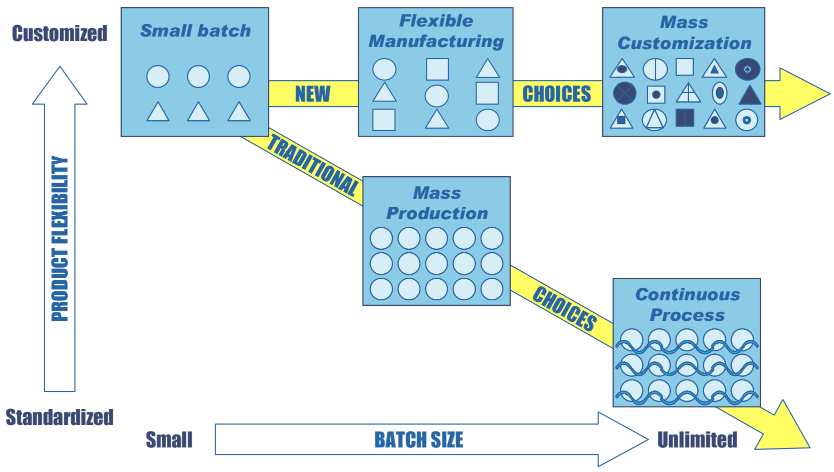

Figure 28: Relationship of flexible manufacturing technology to traditional technologies (source: Daft, 2004)

Mass customization is "the ability to produce products or services in high volume, yet vary their specification to the needs of individual customers or types of customer" (Slack, 2001). Exactly this possibility of mass customization provides major opportunities for the Erasmus MC to increase efficiency while maintaining differentiation and patient loyalty at a high level. Although parts of health care should be customized to patient's needs, some extent can be standardized. For example, many patients use similar resources, like supplementary diagnostics e.g. laboratory testing and radiology, infuses, catering etc.
The same holds for the hospital's bed capacity: day care patients of different themes can use a standardized bed, that should be customized to the individual patient's, for example by adding needed medical equipment and specialized physicians and nurses.

However, the question remains: how to determine what to standardize and what to customize? So can actually all day care patients be combined in one day care center or should some be excluded from it? This question will not be completely answered in this report, but we would like to hand some useful instruments.

11.2 Instruments for mass customization

Our quantitative analysis revealed the merging of departments causes improvements in both availability and efficiency. As described above, hospital managers currently think each patient category is different and therefore cannot be bundled with other themes. However, this resistance mainly occurs because managers do not actually know what kinds of patients are admitted at the departments that are subject of the merging. That is why more transparency about patient categories is required to evaluate whether day care patients of certain themes can be merged. Therefore, we used the DBC categorization (also for the alternative theme distribution in Section 10.2) to distinguish patient categories within each theme.

We see there are not many similarities in DBC description between the themes. However, this is logical, since the patients are allocated to the themes based on the DBC code. On the contrary, there is also a lot of variety within the themes: each theme has a great number of categories (some only treated once per year) and clinical and day care patients have only few categories in common. Appendix P displays the most occurring patient categories per theme for both clinical and day care patients. These lists can be helpful to decide if any (and if so: which?) themes should be excluded from a shared day care center. The themes' managers should discuss this topic in a special meeting regarding the organization of day care in the new building. Regarding the decision where to admit non-surgical day care patients, we conclude from Appendix P that there is not much similarity with neither surgical day care nor clinical patients.

11.3 Patient experience

Another important topic that should be considered in deciding to establish special day care center(s) or to admit day care patients at the regular clinical wards is patient satisfaction. A quick literature search revealed some studies that investigated patient satisfaction of day surgery (O'Connor, Gibberd & West, 1991. Bain, Kelly, Snadden & Staines, 1999. Moen, Kvaerner, Haugeto & Mair, 2000. Ghosh & Sallam, 2005). All report overall patient satisfaction with day care was high. Research regarding non-surgical day care report positive results as well (Hopkinson & Hallett, 2001. Kernohan, Hasson, Hutchinson & Cochrane, 2006). Another study however found palliative day care was not found to improve overall health-related quality of life (Goodwin, Higginson, Myers, Douglas & Normand, 2003).

The Erasmus MC also performed her own study of the surgical day care facility. Using a questionnaire among 100 patients (response rate 47%), a broad spectrum of aspects was studied. Patients appear to be very satisfied (score of 9 or higher) about the way nurses get on with them, about the help provided by nurses if the patient asked for it, nurses' personal attention and the nurses' expertise. Patients were however insufficiently satisfied (score between 6 and 7) about recreation possibilities at the department, facilities near their beds and route signing inside and outside the hospital. (Stoffer, 2008) Besides, nurses of the surgical day care department use the QuIS Quality Manager: a computer tool to administrate side effects and patient satisfaction. Nurses ask the patient during recovery and call the patient a day after dismissal. Results are merely used to improve anesthetic issues and will not be discussed here. Although these studies are useful, these are not comparisons between day care and clinical facilities, but evaluations of day care facilities only.

Initialized by the Dutch OR benchmarking project, Caljouw (2007) studied however the satisfaction of operated patients in the Dutch academic medical centers, for both clinical

and day care facilities. Patient satisfaction was measured using the OPTEL (Caljouw, Beuzekom, Boer, 2006) that distinguishes four aspects of patient satisfaction: information and communication, medical expertise, customer service and personal treatment (respect, privacy, trust and sincerity). For the Erasmus MC, we see the information and communication aspect scores higher (although not significantly) at the surgical day care facility than for clinical admissions. Regarding medical expertise, several characteristics are measured but the only one that is compared between surgical day care and clinical care is the anxiety patients experienced. The prevalence of anxiety is distinctly lower at the day care facility. Customer service is measured by waiting and service times and cancellations, which are more positively experienced by day care patients. Personal treatment aspects are also higher valued for the day care facility compared to clinical day care.
During an OR benchmarking conference, the following advantages of surgical day care facilities were mentioned as well by the participants: possibility to welcome patients in a more domestic atmosphere, close to the entrance and outpatient facilities and to organize a patient-centered surgical and nursing team so staff is familiar to the patient (Wendt, 2008).
Concluding, we state establishing a day care center can be advantageous based on several grounds: next to efficiency and availability, it can also improve medical effectiveness and patient satisfaction.

11.4 Organizational consequences

This section describes organizational consequences of the alternative configurations. We distinguish performance indicators (11.4.1), organization and staff flexibility (11.4.2) and logistics and locations aspects (11.4.3).

11.4.1 Performance indicators

As stated in Chapter 2, current performance indicators of hospital wards usually only involve efficiency. However, high efficiency does not automatically mean high availability (usually the opposite). Therefore, we advise the Erasmus MC to also incorporate a way to measure availability in their business activity monitoring system. There are several ways to do this. First, the number or percentage of refusals can be used to measure availability. Second, we explained there is a relation between bed capacity, availability and efficiency: departments with more beds are able to function at a higher efficiency, while achieving the same availability. For this reason, hospitals should abandon the norm efficiency of 85% for all departments. So we advise to formulate different efficiency standards among the themes. The tools described in Section 8.1 can be helpful in making the trade-off between efficiency and availability and formulating appropriate norms.

11.4.2 Organization and staff flexibility

As stated in the beginning of Chapter 9, we assume beds are mutually interchangeable when evaluating the effects of merging departments. Whether the Erasmus MC chooses to add non-surgical day care patients to the collective day care center or to hospitalize these patients in the clinical wards, sharing of beds will be unavoidable. This means beds must be homogeneous (an arriving patient can make use of any bed).

Whether this is possible depends (among others) on the size of the merged departments. For instance, a day care center of let’s say more than 50 beds will probably not consist of one but multiple rooms. Besides, the number of nurses supervised by one unit head is limited, so one day care center will need multiple unit heads. As a consequence of these developments, several departments arise within the center, although this might not be intended. If these departments disregard to collaborate and share beds, availability and efficiency advantages of merging will decline.

Because a bed is only available if there is staff to care for the patient, the Erasmus MC needs flexible workforce to actually benefit from efficiency advantages resulting from merging departments. So there is a need for skills flexibility (Hopp & Spearman, 2000): nurses can have a certain specialization, but should be employable to care for patients of all themes at the day care center. The implication of skills flexibility is that greater emphasis must be placed on training and knowledge management. Defining what knowledge and experience are required to perform particular tasks and translating these into training activities are clearly prerequisites for effective skills flexibility. For example, at the day care centers, nurses should rather be generalists instead of specialists. This might require a change in culture and/or attitude, since nurses are mostly proud of their specialization. However, a major part of the tasks are equal for all themes. Moreover, the day care center will attract a certain kind of nurses as well. At the clinical wards, specialization by patient group (theme) remains possible.

11.4.3 Logistics and location

As stated above, we advise to establish a surgical day care center for all themes together. This however does not mean this center is an autonomous department that can function without the help of other facilities in the hospital. To avoid rising material costs, the surgical day care center can share the warehouse with the regular OR complex. The recovery can also be shared to extend the opening hours of the operating rooms. There are different opinions about whether the operating rooms can be shared as well. (Wendt, 2008) In our opinion, the expensiveness of OR equipment causes a dedicated day care OR department to be unjustifiable. Therefore, we advise the Erasmus MC to only establish one OR complex for both clinical and day care patients. Doing so, the OR complex as well as the day care department can function as service suppliers to the clients (specialties/themes). In that way, coordination with e.g. radiology and the central sterilization department will also be easier.

For non-surgical day care treatments, no OR facilities are needed. However, it also needs scarce resource used by other users as well. One of the most important resources in that case is the medical specialist. The Erasmus MC should decide whether the day care center has dedicated specialists or that the specialist also works in the clinics or outpatient department at the same time and will be called in case he/she is needed.

In this view, it is also important to eliminate unnecessary transport times. First of all, the location of the surgical day care department should be close to the OR complex. Otherwise, times to transport patients and specialists to come over to dismiss the patient will increase. For non-surgical day care patients, the Erasmus MC should also think of the other hospital facilities needed and locate the day care department close to these facilities.

11.5 Further research

In this study, we investigated a way to optimize the usage of the hospital’s beds: merging day care patients of several themes into day care centers. However, there might also be other initiatives to increase efficiency while remaining appropriate availability levels. In other words, hospitals might be able to treat more patients without increasing capacity. We see opportunities regarding planning (11.5.1), an observatory (11.5.2) and reduction of length of stay (11.5.3).

11.5.1 Planning

As mentioned in Chapter 3, the majority of admitted patients are elective admissions. Planning can be used to smooth the admission of these patients. Chapter 6 revealed that the daily number of admissions is currently highly variable. However, since LOS is variable as well, deterministic admissions are not desirable either. Good planning is in our opinion to smooth the number of present patients (in this report referred to the offered load times the availability). In that way, peaks in bed occupancy are minimized. The question is: what planning balances the admission process with the departure process best? This question cannot be answered easily, so further research on this topic is required. The difficulty is increased because the admission process is not only dependent on ward capacity, but also for example on OR-planning.

Several studies on this scheduling topic were already performed. Roth and Dierdonk (1995) developed a so-called Hospital Resource Planning that functions as a hospital-wide planning and control system. However such ERP-like systems have trouble dealing with variability and stochasticity.
Studies regarding the Intensive Care and OR planning however can provide us with useful methods and lessons. For example Houdenhoven et al (2008) assessed the benefits of a cyclic case scheduling approach that exploits a Master Surgical Schedule (MSS). This MSS succeeded to reduce unused OR capacity by up-to 6.3% with simultaneous optimal leveling of the ICU bed occupancy. It is desirable such studies are also performed for the regular clinical wards.

11.5.2 Observatory

As mentioned in Section 4.3.3, an observatory at the ED might yield variability pooling effects by the phenomenon called queue sharing. We can view the observatory as a flexible facility for all patients arriving at the ED and awaiting hospital admission, no matter at which ward. In that way, the introduction of an observatory influences the arrival process to the wards by reducing the number of unplanned clinical ward admissions. The maximum LOS in such an observatory is usually 24 or 48 hours.
In 2007, the number of patients eligible for an observatory equaled approximately 4200. The LOS distribution of admitted emergency patients appears to be represented by a gamma distribution with α=0.70 en β=170.38 expressed in hours. (Visser, 2008)
Knowing this, we can use the Erlang loss model to calculate the appropriate capacity of an observatory and the effect on clinical bed capacities.

In case the observatory's maximum LOS is 24 hours, λ_{obs}=3.03 and $\frac{1}{\mu}_{obs}$=0.42 days. To ensure 95% availability, the observatory would need 4 beds and is able to achieve an efficiency of 30.8%. Assuming that patients who stayed at the observatory no longer need to be admitted at the clinical wards and the clinical ward admission process remains Poisson, we know the load of each ward will reduce by $\frac{\lambda_{obs}}{n \cdot \mu_{obs}}$, with n the number of wards. Because this ED does not serve the ward of theme 6 adult, the load reduction for each of the other themes equals $\frac{3.03}{6 \cdot 0.42} = 0.21$. Recalculating the clinical bed capacities of Section 8.1 reveals this only reduces required capacity with at most one bed per theme.

When maximum LOS equals 48 hours, λ=4.66 and $\frac{1}{\mu}$=0.79 days. A capacity of 7 observatory beds (with efficiency of 50.0%) is required to ensure 95% availability.

In this case, the load reduction for each of the other themes equals $\frac{4.66}{6 \cdot 0.79} = 0.61$.

Again, recalculating the clinical bed capacities of Section 8.1 reveals the reduction in required capacity is only one bed per theme.

So introducing an observatory does not significantly result in reduced demand at the hospital wards. This is because –although the arrival rate decreases- the average LOS increases (because some patients with short LOS no longer arrive at the wards), so the load does not change much.
Concluding, such an observatory is only interesting as a buffer capacity for the wards that can delay admissions until a bed is available. Doing so, it can make planning easier. This will not be studied here, but might be interesting for further research.

11.5.3 LOS reduction

As shown in Chapter 10, required bed capacity is determined by the load experienced by the department. This load consists of the arrival rate and the patients' length of stay.
Because of lost revenues it is generally speaking not advisable to decrease the arrival rate. With the introduction of the DBC finance system, it however will become profitable to decrease the LOS. At the same time, the load on the wards decreases and creates the ability to admit extra patients. Section 10.1 showed that as the LOS decreases with 1 day, the required capacity decreases with approximately $\lambda \cdot Availability$ beds, with λ the daily arrival rate and availability the desired probability to be able to admit an arriving patient. If both LOS decrease and arrival rate increase occur, the required bed capacity decreases as $\frac{\%\, LOS\ decrease}{100\% - \%\, LOS\ decrease} > \%\, Arrival\ rate\ increase$ and increases otherwise.
LOS reduction is however not to be expected to occur spontaneously. The Erasmus MC should undertake action herself. First, advanced medical treatment and close coordination with external step-down facilities like nursing homes and care hotels can decrease patient LOS at the wards. As a consequence, cured patients no longer have to needlessly stay in the hospital because there is no other place to go. Second, other unnecessary usage of hospital beds should be eliminated. Theories like lean thinking (Womack & Jones, 2003) can be helpful to distinguish waste of expensive resources. Examples are patients waiting for staff, CT scans and other resources, unnecessary transport and waiting for no-show patients. Third, we can think of collaborations with other hospitals: the patient might stay elsewhere, while a physician of the Erasmus MC still treats the patient. That is to say, the patient might need hospital care, but does not need academic care (mostly in case of chronic diseases) or the patients wish to stay elsewhere. Of course, it should be investigated whether this is financially rewarded and whether it is worth the physician's traveling.

11.6 Conclusion

As described in this chapter, one should realize that bed capacity and allocation decisions should not be based on quantitative results only. Such results always have organizational consequences that should be considered as well.
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Also, we advise to perform further research on planning, the introduction of an observatory and LOS reduction possibilities.

12. Conclusions and discussion

The aims of this project are to determine required ward capacity for current and future patient characteristics and study the effects on availability and/or efficiency of introducing day care centers in the new Erasmus MC.

12.1 Conclusions

For service operations that cannot store their output, capacity allocation is best considered using queuing theory. From former research using queuing models, we discovered the Erlang loss (or M/G/s/s) model evaluates the hospital's capacity level best. That is because this model is able to determine both availability and efficiency of a certain bed configuration. Also, it incorporates queues are finite and patients leave the hospital in case there is no free bed upon arrival.
Historical data of 2007 were used to analyze the arrival process and length of stay distribution. We distinguish between clinical patients and surgical and non-surgical day care patients.
In the M/G/s/s model the length of stays of arriving patients are independent and identically distributed with expectation $\frac{1}{\mu}$. Patients arrive according to a Poisson process with parameter λ. The arrival rate of clinical patients is the sum of the number of daily admissions and refusals. Validation revealed the method used to determine the clinical arrival rate is an accurate representation of reality. For day care patients, we assume the number of arrivals equal the number of daily admissions.
For both clinical and day care patients, the daily number of admissions is not deterministic and varies to a great extent, but is not a Poisson process. However, validation in terms of the number of occupied beds indicates that the Erlang loss model approximates reality quite well. For day care patients however, the outcomes using the Erlang loss model (which we call average situation) will provide an optimistic view of the availability. Therefore, we also provide the so-called peak situation, which assumes arrivals all occur at one moment of the day and gives a pessimistic availability view. In reality, the required bed capacity should be in between the average and peak situation. Section 12.2.1 will argue which of the two situations is most realistic.

We applied the validated Erlang loss model to the provisional bed configuration of the Erasmus MC to determine required ward capacity for current patient characteristics. Wards with higher bed capacity are able to function at a higher efficiency while maintaining the same availability level as smaller wards. These economies of scale can be understood by the concept called variability pooling, also known as the portfolio effect. This concept states combined processes' variability is less than the sum of the variability of the individual processes. As a result, larger wards need less buffer capacity to counterbalance variability.

The current provisional bed configuration is calculated using a standard average efficiency of 85%. This method is not capable of describing variable arrival rates and gives misleading results, which are often called 'flaws of averages'. However, because of the economies of scale explained above, relatively small wards should have a lower efficiency target to achieve the same availability level as larger wards. Therefore, the Erasmus MC should revise the provisional bed configuration among the themes and utilize different efficiency norms for departments of different sizes.

To determine the appropriate capacity level per theme, the Erasmus MC should view the decision as a trade-off between availability and efficiency. To be precise, as bed capacity increases, availability increases, while efficiency decreases. Both availability increase and efficiency decrease diminish as bed capacity increases. Hospital managers should question whether the increase in availability is worth the decrease in efficiency or not.

Because norms for neither availability nor efficiency are formulated, we designed a method to support making the trade-off between availability and efficiency. Using this method, the recommended capacity is the number of beds accompanying the maximum sum of weighted availability and weighted efficiency. This method is straightforward and (if availability and efficiency weights are equal) results in availability and efficiency that are very likely within tolerable ranges for clinical patients of the Erasmus MC. Varying the weights revealed that the required capacity is not given, but depends on the perceived mutual importance of availability and efficiency too a large extent.

Another shortage of former research is that it disregards the fact that total bed capacity is often limited in hospitals. Therefore, we developed a tool to allocate beds over the departments in this case. This tool incorporates two important facts:
- The hospital-wide expected number of refusals decreases as departments with higher arrival rates function at higher availability.
- The hospital-wide number of unused beds decreases as departments with more beds function at higher efficiency.
Doing so, the tool uses the trade-off as described above. Again, the weights assigned to availability and efficiency determine the exact allocation of beds over the departments.

For day care patients, arrival rates and length of stay are usually so low that in case separate departments for each theme are established, it is impossible to achieve both high availability and efficiency. This indicates it might be profitable to share day care bed capacity among the themes and brings us at the second part of the research question. Merging departments can increase operational efficiency to a great extent, as a consequence of the economies of scale that decrease the need for buffer capacity. We developed the department merging tool to evaluate the effects of this merging. We illustrated the usage of this tool by investigating the potential benefit of the following scenarios:
- Establishing a center for surgical day care for all themes
- Establishing a center for non-surgical day care for all themes
- Establishing a collective day care center for all themes together
- Hospitalizing all patients in the clinical wards
Besides, we showed the effects of excluding some themes from the center and establish their own day care department. Finally, the Erasmus MC can calculate consequences of other organizational alternatives herself quite easily using the department merging tool.

Compared to theme-based separate departments for surgical day care patients, establishing a center for surgical day care for all themes results in major reduction of required bed capacity. The same holds for a center for non-surgical day care for all themes. An extra capacity reduction can be achieved by a collective day care center for all themes together. Hospitalizing day care patients in the clinical wards decreases the availabilities of the merged departments compared to separate day care departments.
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Finally, we used sensitivity analysis to evaluate the robustness of the results. The majority of the differences in arrival rate and length of stay between 2007 and 2008 reveal to be not significant. Over a longer term, LOS does seem to decrease. As the LOS decreases with 1 day, the required capacity decreases with approximately $\lambda \cdot Availability$ beds, with λ the daily arrival rate and availability the desired probability to be able to admit an arriving patient. If LOS decreases and arrival rate increases, the required bed capacity decreases as $\frac{\%\,LOS\ decrease}{100\% - \%\,LOS\ decrease} > \%\,Arrival\ rate\ increase$ and increases otherwise. The tools described above are also developed to be able to determine required bed capacity for changing patient characteristics.

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12.2 Discussion

In this report, we showed how the Erlang loss model is helpful in determining the required capacity of a ward and the advantages of merging departments, especially when the load of each department is low. This section reflects on the performed research. We will discuss the results regarding day care patients (12.2.1), the limitations that come along with the methodology (12.2.2) and the main contributions of this study (12.2.3).

12.2.1 Discussion of the results regarding day care patients

This section determines whether the average or the peak situation is most realistic for day care patients. As described in Sections 8.2 and 8.3, it makes quite some difference whether the Erasmus MC uses the average or peak situation to decide upon the required bed capacities, especially for themes with relatively high arrival rates. This section will assist the Erasmus MC to decide upon which situation (average or peak) is most realistic.

The peak situation is a negative scenario, which assumes all admissions occur at 8:00 o'clock in the morning and does not take the LOS into account. On the other hand, the average situation is a positive scenario, which uses the correct total number of arrivals per day but underestimates the arrival rate per hour (see Section 7.2.2 for a more detailed explanation).

Interviewing Erasmus MC's managers and observing the care process of the surgical day treatment department reveals flaws in the registration of day care patients. In reality, patients do not arrive during the entire day, but only during opening times of the day care facilities. Also, the fraction of patients arriving in the beginning of the day is lower than registered: patients' arrivals are more smoothened over the day and the average length of stay is shorter than approximately 9 hours (see Section 6.1), but rather 4 to 5 hours. As a consequence, the average number of present patients is $2\lambda \cdot 0.5\frac{1}{\mu} = \frac{\lambda}{\mu}$. This means the average situation described above is a more adequate representation of reality than the peak situation.

One can also argue that the number of daily day care arrivals can be planned. This means the number of daily arrivals is deterministic and uniformly distributed over the day: variability of arrival rate is eliminated and arrivals are equal to λ every day. In case half of the patients arrive in the morning and the other half in the afternoon and ALOS would be 4 to 5 hours, the hospital would decide capacity to be equal to $0.5 \cdot \lambda$ beds. As a result, P_{loss} is always zero, so availability and efficiency both equal 100%.
In case of separate theme-based surgical and separate theme-based non-surgical departments, capacity will be almost two beds per theme lower than advised by the trade-off method used in Sections 8.2 and 8.3. In the absence of variability in arrival rates, presence of patients will be more uniform as well and economies of scale no longer occur.
Note that waiting times can increase extremely under these conditions. Also, planning of day care patients is not an isolated activity, but depends on for example OR-planning as well. These however are scheduling problems and involve completely different studies, so have not be considered in this study.

12.2.2 Discussion of the method

This section discusses the limitations that come along with the used methodology. First, we argue whether the use of an analytic model is justified. Second, we review the validity of the collected data.

Use of an analytic model

The Erlang loss model is a type of queuing analytic model. Analytical models can give a good understanding of the system they represent. Furthermore analytical models can be accurate and give concrete solutions. However, analytical models are not without drawbacks.

An often stated drawback is the lack of the possibility to model complex systems. An alternative and commonly used method to deal with this complexity is discrete-event simulation. However, simulation models demonstrate the behavior of the system rather than that they give exact solutions. For example, they can demonstrate the patient flows of an Emergency Department and create a better understanding of the process. Because the objective of this study was not at operational level, but to actually calculate availability and efficiency at strategic level, analytic models serve this purpose better.

Another drawback of analytic models is the danger of applying the wrong model (Weber, 2006). Therefore, the assumptions of the model should be verified with reality. This is exactly what we did in the validation section of this report (7.3). Although admissions are not exactly Poisson, this validation revealed the Erlang loss model is adequate enough to represent the bed occupancy. The validation could also be done using a simulation model. There are however some other disadvantages of such models that made the researcher decide not to use simulation in this study. First, simulation models are often time-consuming to develop. Second, the persuasive impact of an animation often creates tendency to place greater confidence in a study's result than justified. Third, a simulation model cannot easily be adapted to changes in the system. (Law & Kelton, 2000)
The data regarding the observed presence of patients could be easily derived from the hospital's information system and gives the same results as a simulation study would provide. Therefore, the researcher preferred to use these data over the time-consuming development of a simulation model.

Analytic models are also criticized because people not familiar with Operations Research are not able to use them. In general, this is a valid remark. We however succeeded to fix this by developing several very user-friendly tools. In this way, people without any OR knowledge are able to calculate scenarios themselves (see contributions in Section 12.2.3).

Data validity

As described in Chapter 5, we made some simplifications that might not correspond to reality. Most have to do with the accuracy of collected data. This section describes the most important uncertainties.

First, we derived data regarding moments of admission and dismissal from historical records: the Erasmus MC's database Business Objects (BO). The accuracy of the used input data therefore depends on the accuracy of registration in BO. For example, Section 13.1 revealed the registration of day care patients is biased. For clinical patients, moments of admission and dismissal are not clustered as much as for day care patients, so registration is most probably better. Similar prudence should be taken into account regarding registration of the admission type. Section 10.4 already revealed the group of day care admissions might be actually larger than registered.

Second, the results presented in the Chapters 8 and 9 are based on data of the year 2007. It is not guaranteed these figures are similar in the future. However, the sensitivity analyses in Chapter 10 revealed the data is more or less the same for the year 2008. The chapter also presents a trend analysis that supports decision-making for the future.

Third, we experienced some difficulties to allocate current patients to the future themes. We developed our own allocation method based on specialty. This method gives similar results as an alternative allocation method based on DBC code. However, for some admissions it is not entirely clear to which DBC they belong, because the DBC is missing or there are multiple parallel DBCs. So the latter method is also not unbiased.

12.2.3 Contributions of the study

As described in Chapters 2 and 4, other researchers already showed the Erlang loss model can be used to evaluate the size of wards and the advantages of merging wards in another Dutch medical center than the Erasmus MC. The study reported in this thesis can therefore be seen as a confirmation of the adequacy and applicability of the Erlang loss model in such kind of strategic decisions. So although a limitation of our study is that it was conducted at the Erasmus MC only, the indications that results can be generalized become stronger.

Moreover, this study extended the current research in various ways. First, it provides a methodology to actually make the trade-off between availability and efficiency. Second, it presents a way hospitals should allocate beds over their departments in case total bed capacity is restricted. We calculated what these two extensions mean for the Erasmus MC. Additionally, we constructed two user-friendly tools that can be used by other hospitals without major adjustments. Third, the Erlang loss model was applied to clinical patients only until now. We reasoned this model is also applicable to day care patients. For determining appropriate bed capacities however, the resulting capacities from this model are presumably a bit low. It is suggested to also determine a more negative scenario, as proposed in Section 7.2.2.

This study does not give the Erasmus MC a clear-cut answer to the question whether it should introduce one center for all day care patients or should admit day care patients at the clinical wards. This is for example because -as Chapter 11 described- other considerations than quantitative results also play a part when making strategic management decisions. However, we clearly showed the benefits in terms of availability and efficiency of merging day care into theme-combined centers. The department merging tool showed these benefits also apply in case availability norms are not equal for each theme. The same benefits apply for admitted day care patients in the clinics: required bed capacity to achieve 95% availability decreases even more. However, the 95% availability norm is not fixed and should be seen in hospital-wide perspective: beds should be allocated so that overall availability and efficiency are maximized.
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Moreover, the application of the Erlang loss model makes the hospital's managers aware of economies of scale and merging benefits. Especially the developed tools enable managers to compute effects of certain choices themselves. These tools therefore make analytical models more accessible, flexible and generally applicable.

Definitions

Arrivals	Patients arriving to the hospital. If there is a free bed available, an arrival is admitted. If all beds are occupied, the arriving patient is refused (see: "Refusals" below). So the number of arrivals is the sum of both admissions and refusals. The average arrival rate is the number of arrivals per unit time and denoted by λ. $\frac{1}{\lambda}$ is the mean interarrival time.
Admissions	Arriving patients who find at least one bed available. Hospitals keep record of the number of admissions. Every admission is registered as one of the four following admission types: 1. Out-patient childbirth 2. Screening admission (preceding surgery) 3. Day care admission 4. Clinical admission Each admission type has its own requirements and financial reimbursement.
Refusals	Arriving patients who find all beds occupied are blocked and counted as a refusal (or refused admission) in this report. In practice, refusals might be diverted to another hospital, a so-called over-bed is put into use, a planned operation is postponed and/or other patients released earlier. These solutions have serious drawbacks for the quality of care. The number of refusals can be interpreted as a service level to indicate quality of care. Unfortunately, hospitals usually do not keep record of this number.
Length of stay (LOS)	The time spent at a hospital's ward. After this time, the patient is discharged or transferred to another ward. In this study, the LOS is derived from the hospital's information system, by subtracting each patient's time of discharge from his/her admission time. If going through multiple wards within one admission, the patient's LOS equals the sum of the LOSs at these wards. The average LOS (ALOS) in units time is denoted by $\frac{1}{\mu}$, where μ is the service rate in case of exponentially distributed service times.

The relation between the previously mentioned definitions can be graphically displayed by the following figure:

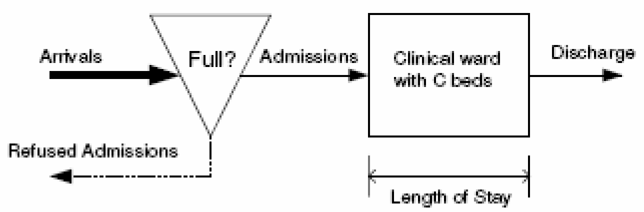

Figure 29: Patient flow through a clinical ward (de Bruin et al, 2008)

Availability — The fraction of arriving patients that is admitted in the hospital (so not blocked/refused). In the long run, this equals the probability of being able to admit an arriving patient. Note that the fraction of blocked arrivals is usually called P_{loss}, so availability can be expressed as $1-P_{loss}$.

Capacity — The capacity of the hospital is measured by the number of beds. Note that there is a difference between design and effective capacity. Design capacity is the maximum capacity level available under ideal conditions. This level is attained only by using many temporary measures, like overtime and overstaffing.
Effective capacity is the maximum number of beds available under normal conditions. These conditions include realistic work schedules and regular staff levels.
In this report, we take the number of physical beds as a measure for design capacity, while effective capacity is the number of operational beds.
Unless mentioned otherwise, this study takes the effective capacity of operational beds as a measure of capacity.

Efficiency — The ratio of total productive time divided by the time capacity is available, given as a percentage. Note that efficiency is calculated with effective capacity as a starting point (see "Capacity" above).

$$Efficiency = \frac{productive\ time}{effective\ capacity \cdot time\ capacity\ is\ available}$$

Deterministic models — System models with no randomness, so assumes the activity duration is known with certainty.

Stochastic models — Models that explicitly include random phenomena. This means these models account for the fact that some figures (for example LOS, number of daily arrivals, etc.) are not always equal.

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Appendices

Appendix A: Variability

Chapter 4 mentions variability as important cause for realized utilization below 100%.

Variability can occur in both process times (LOS) and arrival rates. This section gives an explanation of the term variability.

The formal definition of variability is the "quality of nonuniformity of a class of entities". Variability occurs from controllable variation (as a direct result of decisions) and from random variation (as a consequence of events beyond our immediate control). (Hopp & Spearman, 2000)

Variance σ^2 and standard deviation σ are measures of absolute variability.
Since relative variability is often more important than absolute measures, the coefficient of variation (CV) and its squared (SCV) can be used:

$CV = c = \frac{\sigma}{t}$ and $SCV = c^2 = \frac{\sigma^2}{t^2}$

with t is the mean (usually a time).

Variability occurs in various cases, for example in process times, but also in arrival rates:

Process time CV = $c_e = \frac{\sigma_e}{t_e}$

Arrival CV = $c_a = \frac{\sigma_a}{t_a}$

Appendix B: Kendall's notation

Kendall (1951) developed the standard notation used to describe queuing systems by six characteristics: A/B/S/K/N/D.
- A: describes the arrival process;
- B: the service time distribution;
- S: the number of parallel servers (in our case: beds);
- K: the maximum allowable number of customers (patients) in the system – both waiting and in service;
- N: the size of the calling population and
- D: represents the queue discipline (service order)

All six characteristics can adopt various values (see below). Simplified notations consist of for example only four (A/B/S/K) or even three characteristics (A/B/S). In this case, the service order is a general queue discipline (D=GD) and the size of both the calling population and the maximum allowable number of customers is infinite (N=∞ and K=∞). (Winston, 2004).

A: Arrival process

Interarrival times are independent, identically distributed (iid) and distributed:

M	Exponentially
D	Deterministic
E_k	Erlangs with shape parameter k
GI	Some general distribution

B: Service time distribution

Service times are iid and distributed:

M	Exponentially
H_k	Hyperexpontially, into k different groups
D	Deterministic
E_k	Erlangs with shape parameter k
GI	Some general distribution

S: number of parallel servers

The number of parallel servers can be any integer number or ∞.

K: Maximum number of customers in system

The maximum allowable number of customers in the system can be each integer number or ∞. This parameter is sometimes denoted C+k where k is the buffer size, the number of places in the queue above the number of servers C.

N: Population size

The size of the population from which customers are drawn can be each integer number or ∞.

D: Queue discipline

The discipline or priority order that jobs in the queue are served:

FCFS	First come, first served
LCFS	Last come, first served
SIRO	Service in random order
GD	General queue discipline

Appendix C: Specialty-theme conversion table

Section 5.3 describes the way we executed data collection. We make distinction between patient categories based on their specialty to determine the needed number of beds per theme. The following conversion table displays the theme for each specialty.

Specialty abbreviation	Specialty description	Theme
ADO	Adolescent Psychiatry	-
ALL	Allergology	3
ANE	Anesthesiology	4
BEA	Artificial respiration	-
BEH	Treatment center	2
BEV	Obstetrics: childbirth	6 adult
BYT	Foundation De Bijter	6 child
CAR	Cardiology	5
CAS	Cardiology	6 child
CHI	General surgery	3
CRC	Cardio surgery	5
CYT	Cytostatica	2
DER	Dermatology	3
DIS	Diabetes	6 child
END	Endocrinology	6 child
GAS	Gastroenterology	6 child
GER	Geriatrics	3
GYN	Gynecology	6 adult
HAE	Hematology	2
HAS	Hematology	6 child
HHS	Complex surgery Sophia	6 child
HLK	Pediatric surgery	6 child
ICP	Intensive Care Pediatrics	6 child
IMM	Immunology Sophia	6 child
IN1	Internal medicine	3
IN2	Internal medicine	3
IN3	Internal medicine	3
INT	Endo-oncology	2
IVF	In vitro fertilisation	6 adult
KAA	Oral surgery	4
KGA	Pediatrics	6 child
KNO	ENT (Ear-nose-throat)	1
LON	Pulmonary diseases	5
LOS	Pulmonary diseases	5
MDL	Gastroenterology	3
MET	Genetics	6 child
NCL	Nuclear Medicine	2
NEC	Neurosurgery	1
NEU	Neurology	1
NIE	Kidney diseases	6 child
NKG	High care pediatrics	6 child
NTR	Kidney transplantation	3
OBS	Obstetrics	6 adult
ONG	Traumatology	4
ONC	Endo-oncology	2
ONS	Pediatric oncology	6 child
OOG	Ophthalmology	1

ORT	Orthopedics	4
PAS	Neonatology	6 child
PIJ	Pain reduction	1
PLC	Plastic surgery	4
PSK	Child and youth psychiatry	-
PSY	Psychiatry	-
RES	Rheumatology	6 child
REU	Rheumatology	3
RON	Radiology	6 child
RTH	Radiotherapy	2
THC	Thorax surgery	5
THK	Dental surgery	4
URO	Urology	6 adult
ZWA	Obstetrics: pregnancy	6 adult

As mentioned in section 5.3, admissions at the Intensive Care (IC) and Post Anesthesia Care Unit (PACU) are excluded because these will not be part of the six themes mentioned in chapter 3. The excluded departments are:

3ZBE C. I.C. Inw.Gen./Beademing(3z)
6ZPA C. Post Anesthesia Care Unit
16CD C. Kliniek Cardiologie Iccu
16TH C. Kliniek Ic Thoraxchirurgie
AZIC C. Kliniek I.C.Chirurgie (10z)
B3IC H. Intensive Care
ICC1 S. Kc Kliniek Ic-1
ICC2 S. Kc Kliniek Ic-2
ICC3 S. Kc Kliniek Ic-3
ICK2 S. Ic Kinderen - 2
ICK4 S. Ic Kinderen - 4
ICK3 S. Ic Kinderen - 3
ICP1 S. Ic Pediatrie - 1
ICP2 S. Ic Pediatrie - 2

Appendix D: Chi-square goodness-of-fit test for clinical admissions

We use Pearson's chi-square goodness-of-fit test to conclude whether the Poisson distribution with mean λ is rightly chosen to represent the daily number of admitted clinical patients per theme.
We do this by comparing the amount of admissions per day that we would expect to fall into category j under the Poisson distribution ($n \cdot p_j$) with the amount of observed data that actually falls into category j (N_j) for j = 1, 2, …, k.
The chi-square test is approximately valid if $k \geq 3$, $n \cdot p_j \geq 5$ and p_j's should be equal (Law & Kelton, 2000).

The test statistic is $X^2 = \sum_{j=1}^{j=k} \frac{(Observed_j - Expected_j)^2}{Expected_j} = \sum_{j=1}^{j=k} \frac{(N_j - n \cdot p_j)^2}{n \cdot p_j}$

For large n, a test with approximate level α is obtained by rejecting H_0 if $X^2 > \chi^2_{k-1,1-\alpha}$, where $\chi^2_{k-1,1-\alpha}$ is the upper 1-α critical point for a chi-square distribution with k-1 degrees of freedom. If we have to estimate m parameters (m≥1) from the data to specify the fitted distribution, the critical value equals $\chi^2_{k-m-1,1-\alpha}$.

To illustrate the methodology, we consider the clinical admissions during weekdays for theme 1.
We test whether the Poisson distribution λ = 12.73 fits observed data.
As is usually the case for discrete distributions, we cannot make the p_j's exactly equal, but by grouping adjacent points, we can define intervals that make the p_j's roughly the same.
The following table shows the observed and expected counts and the components of chi-square test statistic.
Note that the first adjacent points are grouped together so that the minimum expected count ($n \cdot p_j$) is at least equal to 5.

Category j	{0, 6}	{7}	{8}	{9}	{10}	{11}	{12}	{13}	{14}	{15}	{16}	{17}	{18}	{19}	{20,...}
Observed	19	6	17	17	23	24	29	23	19	13	17	18	13	8	15
Expected	7.90	8.30	13.21	18.69	23.79	27.54	29.22	28.61	26.02	22.09	17.58	13.16	9.31	6.24	9.35
X2 component	15.61	0.64	1.09	0.15	0.03	0.45	0.00	1.10	1.89	3.74	0.02	1.78	1.46	0.50	3.41

Table A.1: Calculating the chi-square test statistic for clinical admissions during weekdays (theme 1)

The chi-square statistic is equal to 31.87.
Since the number of categories is (k) is 15 and the parameter λ is estimated from the data (so m=1), the number of degrees of freedom is 13.
For α=0.005, the critical area of $\chi^2_{13,0.995}$ is $[29.82, \infty\rangle$ so the p-value is less than 0.005 and we should reject the hypothesis that the Poisson distribution with λ = 12.73 fits the observed data.

If we execute this test for all days (weekdays and weekends) together, the test statistics always exceed their critical value. This means the Poisson distribution with λ (see most right column of table 7 in section 6.2.1) is not a good representation for the observed clinical admissions for all days.

		Themes						
		1	2	3	4	5	6 adult	6 child
Weekdays (n=261)	**Critical value**	29.819	35.718	35.718	28.300	32.801	32.801	34.267
	Test statistic	31.874	505.417	161.339	144.291	128.600	50.510	36.843
Weekends (n=104)	**Critical value**	20.278	***18.548***	***20.278***	18.548	18.548	***21.955***	***21.955***
	Test statistic	39.437	***15.676***	***5.527***	47.729	43.943	***10.678***	***7.531***
All days (n=365)	**Critical value**	29.819	32.801	34.267	28.300	32.801	32.801	34.267
	Test statistic	227.7474	2001.723	1159.856	518.2605	1367.395	425.2481	838.0642

Table A.2: Chi-square test statistics and critical values per theme

However, splitting weekdays from weekends results in a different conclusion. The test statistics printed in Italic do not exceed the critical values if alpha is 0.005 or less. This means the Poisson distributions for weekends with their own λ (see most left two columns of table 7 in section 6.2.1) are a good representation for the observed clinical admissions of the themes 2, 3, 6 adult and 6 child.

Test statistics are a lot closer to the critical values if weekdays are considered apart from weekends. So –although a Poisson distribution is also rejected sometimes-, we can conclude a Poisson distribution can much better represent the clinical admissions if weekdays and weekends are considered apart from each other for each theme.

We see the model does not succeed to fit for all themes. It is instructive to find out why: so which cells make large contributions to the test values?
The greatest contributions to the test value most come from the first and last intervals: so in those cases, there are too many small counts and too many large counts relative to what is expected for a Poisson distribution.

Appendix E: Kolmogorov-Smirnov and Anderson-Darling tests for clinical admissions

A drawback of chi-square tests is the difficulty of deciding how to specify the intervals. There are some other goodness-of-fit tests available that do not encounter this drawback, for example the Kolmogorov-Smirnov test and the Anderson-Darling test.

This appendix gives an overview of the results when these two tests are applied to the question whether the Poisson distribution with mean λ is rightly chosen to represent the daily number of arriving clinical patients per theme.

Kolmorogov-Smirnov
Rejecting or not rejecting the hypothesis occurs in a similar manner as for the chi-square test: in case the test statistic is within the interval $[\text{critical value}, \infty\rangle$ the hypothesis is rejected.

	Alpha				
	0.2	**0.1**	**0.05**	**0.02**	**0.01**
Weekdays (n=261)	0.06642	0.0757	0.08406	0.09396	0.10083
Weekends (n=104)	0.10522	0.11993	0.13316	0.14885	0.15974
All days (n=365)	0.05616	0.06401	0.07108	0.07946	0.08527

Table A.3: Critical values for Kolmorogov-Smirnov test

Comparing the tables A.3 and A.4, results in the conclusion that the hypothesis should not be rejected for the weekends of the themes 1, 3 and 6 adult (if $\alpha \leq 0.05$). So the Poisson distribution with mean of λ is a good representative for these categories.

	Themes						
	1	2	3	4	5	6 adult	6 child
Weekdays (n=261)	0.12620	0.18977	0.11699	0.16349	0.14329	0.11122	0.11689
Weekends (n=104)	***0.15640***	0.20083	***0.13057***	0.18889	0.18186	***0.14842***	0.16839
All days (n=365)	0.15474	0.31781	0.23389	0.17993	0.25411	0.18470	0.19542

Table A.4: Test statistics for Kolmorogov-Smirnov test per theme

The majority of weekdays and weekends are rejected to be a Poisson process. However, the test values are not that far above the critical values and at least closer than when we consider all days together.

Anderson-Darling
Rejecting or not rejecting the hypothesis again occurs in a similar manner as for the chi-square test: in case the test statistic is within the interval $[\text{critical value}, \infty\rangle$ the hypothesis is rejected.
For the Anderson-Darling test, critical values do not depend on the sample size:

	Alpha				
	0.2	**0.1**	**0.05**	**0.02**	**0.01**
Critical value	1.3749	1.9286	2.5018	3.2892	3.9074

Table A.5: Critical values for the Anderson-Darling test

Comparing the tables A.5 and A.6, results in the conclusion that the hypothesis should not be rejected for the weekends of theme 3, theme 6 adult and theme 6 child. So the Poisson distribution with mean of λ is a good representative.

	Themes						
	1	2	3	4	5	6 adult	6 child
Weekdays (n=261)	5.393	50.818	14.889	19.166	16.539	5.495	5.730
Weekends (n=104)	6.469	4.365	***2.309***	10.836	7.713	***2.211***	***2.227***
All days (n=365)	30.023	275.330	133.060	48.532	144.110	44.079	70.648

Table A.6: Test statistics for the Anderson-Darling test per theme

The majority of weekdays and weekends are rejected to be a Poisson process. However, the test statistics are not that far above the critical values and at least closer than when we consider all days together.

Appendix F: Poisson dispersion test for clinical admissions

Under the null hypothesis, the test statistic $T = n \cdot \frac{\text{variance}}{\text{mean}}$ has a chi-squared distribution with n-1 degrees of freedom (with n = the number of observations).

From Rice (2007) we find:
"Since a chi-square random variable with m degrees of freedom is the sum of the squares of m independent N(0,1) random variables, the central limit theorem implies that for large values of m the chi-square distribution with m degrees of freedom is approximately normal. For a chi-square distribution, the mean equals the number of degrees of freedom and variance equals twice the number of degrees of freedom. The p-value can thus be found by standardizing the statistic."

So, $P(T \geq n \cdot \frac{\text{variance}}{\text{mean}}) = P\left(\frac{T-(n-1)}{\sqrt{2\cdot(n-1)}} \geq \frac{n \cdot \frac{\text{variance}}{\text{mean}} - (n-1)}{\sqrt{2\cdot(n-1)}} \right)$

$$\approx 1 - \Phi\left(\frac{n \cdot \frac{\text{variance}}{\text{mean}} - (n-1)}{\sqrt{2\cdot(n-1)}} \right)$$

The p-values per theme are:

	1	2	3	4	5	6 adult	6 child	Average
Weekdays (n=261)	4.058E-09	0	0	0	0	2.45E-09	2.71E-09	0
Weekends (n=104)	0	0.009476	0.084688	0	0	0.002975	0.286042	7.04E-11
All days (n=365)	0	0	0	0	0	0	0	0

If we would use a critical p-value of 0.0025, this means the null hypothesis is only not rejected for weekend admissions of the themes 2, 3, 6 adult and 6 child, but rejected for weekend admissions of the themes 1, 4 and 5. Also the null hypothesis is rejected for weekday admissions of all themes.

Appendix G: Goodness-of-fit tests for day care arrivals

Just like with clinical admissions, we assess whether a Poisson process can represent day care arrivals. This assessment consists of several tests: Pearson's chi-square test, Kolmogorov-Smirnov test, Anderson-Darling test and the Poisson dispersion test.
Because the methodologies are the same as for clinical admissions, we only discuss the results and conclusions of these tests in this appendix.

Pearson's chi-square test
If we compare the test statistics with the critical values, we see the test values for both surgical and non-surgical patients always exceed these critical values. This means the Poisson distribution is a not very good representation for the observed day care arrivals.

		Themes						
		1	2	3	4	5	6 adult	6 child
Surgical	Critical value	14.06714	9.487729	7.814728	14.06714		12.59159	19.67514
	Test statistic	1002.332	29.63333	505.2937	1283.098		352.5035	83.39061
Non-surgical	Critical value	18.30704	30.14353	32.67057		11.0705	16.91898	23.68479
	Test statistic	217.9812	73.55659	155.7541		141.9673	57.59028	58.55274

Table A.7: Chi-square test statistics and critical values per theme

Kolmogorov-Smirnov test
The critical values for day care patients are the same as for clinical patients during weekdays (n=261, see appendix E). Test statistics per theme are as follows:

	Themes						
	1	2	3	4	5	6 adult	6 child
Surgical	0.28593	0.25532	0.50164	0.31256		0.2519	0.17897
Non-surgical	0.19097	0.15321	0.16589		0.23551	0.18169	0.1806

Table A.8: Test statistics for Kolmorogov-Smirnov test per theme

This means test statistics of all themes exceed the critical values.

Anderson-Darling test
The critical values for day care patients are again independent of the sample size and the same as for clinical patients (see appendix E). Test statistics per theme are as follows:

	Themes						
	1	2	3	4	5	6 adult	6 child
Surgical	83.133	22.372	96.992	92.839		39.021	17.081
Non-surgical	26.202	17.433	25.696		26.917	11.072	14.7

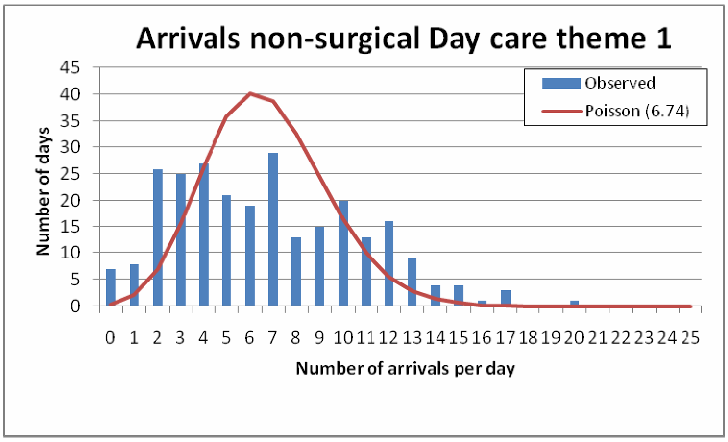
Table A.8: Test statistics for the Anderson-Darling test per theme

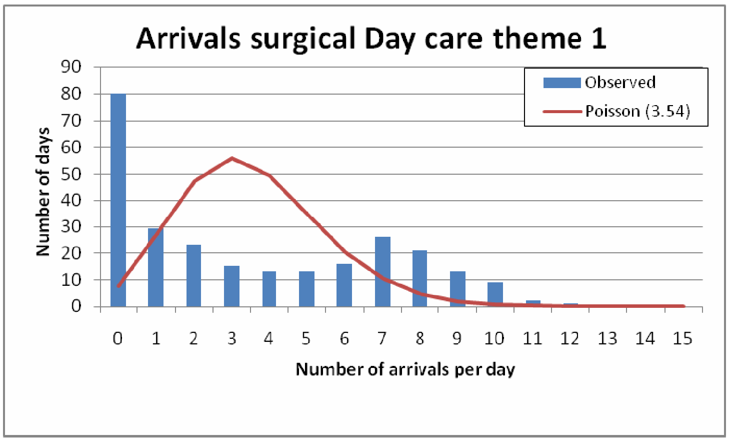
Again test statistics of all themes exceed the critical values.

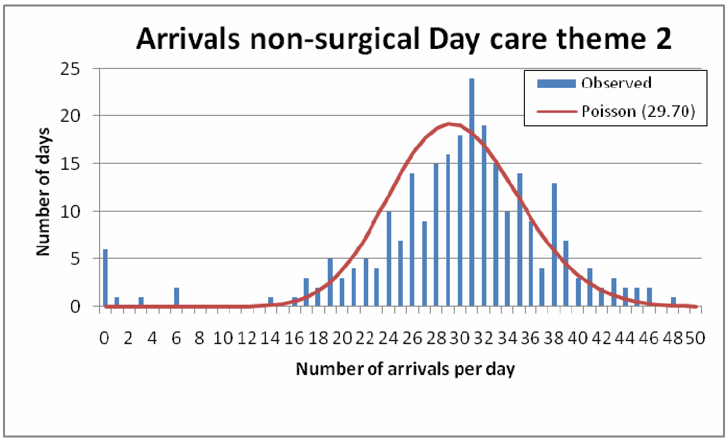
Poisson dispersion test
The p-values per theme are:

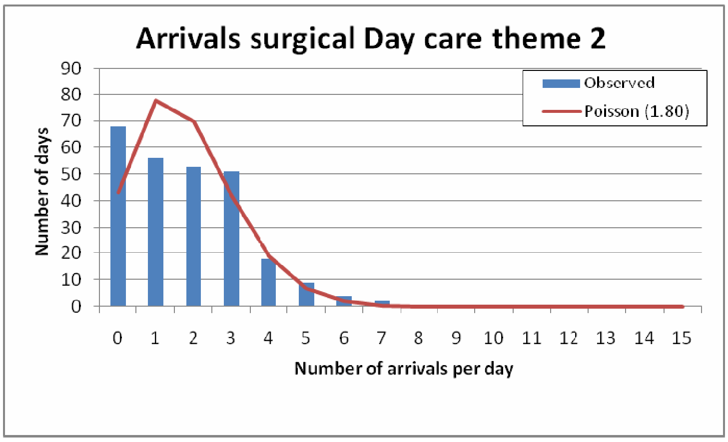
	1	2	3	4	5	6 adult	6 child
Surgical	0	1.76E-05	0	0		0	0
Non-surgical	0	0	0		0	3.38E-12	0

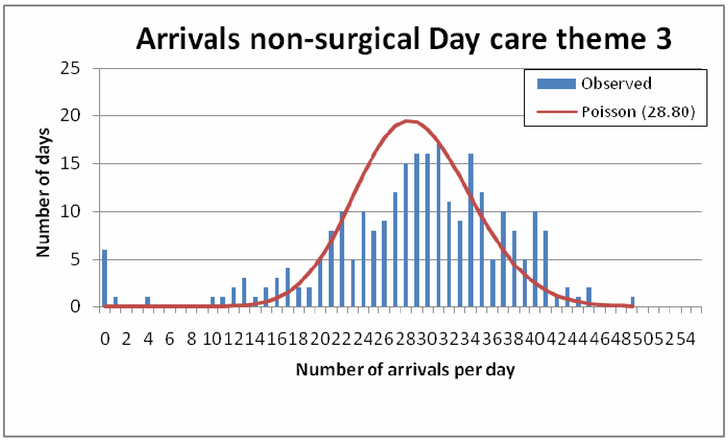
If we would use a critical p-value of 0.0025, this means the null hypothesis is rejected for both surgical and non-surgical day care arrivals of all themes.
To show where the Poisson distribution deviates from the observed arrivals, we constructed the graphs shown at the next pages.

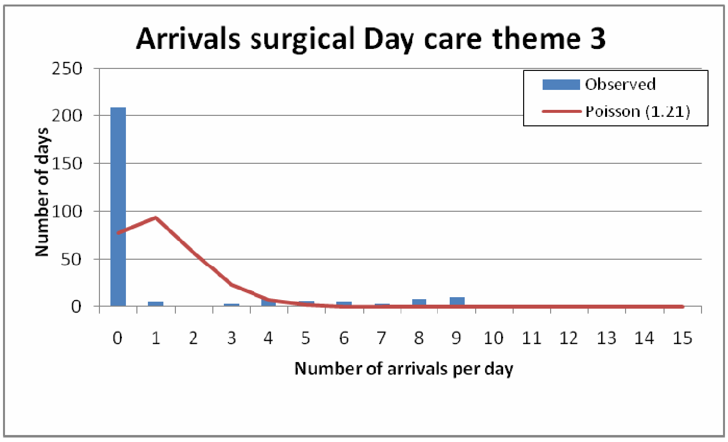

Arrivals non-surgical Day care theme 1
Observed
Poisson (6.74)
Number of days
Number of arrivals per day

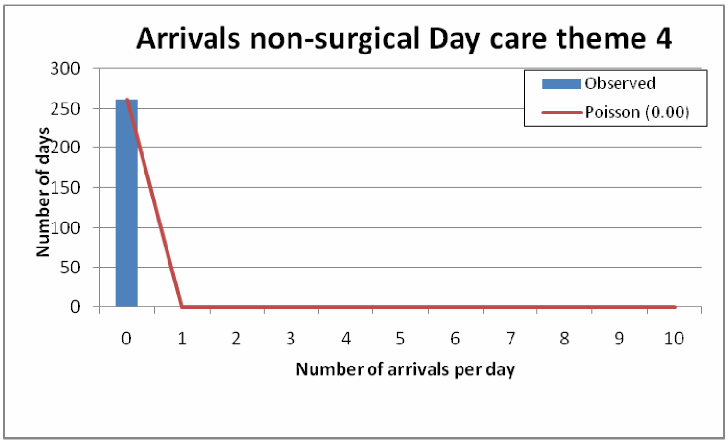

Arrivals surgical Day care theme 1
Observed
Poisson (3.54)
Number of days
Number of arrivals per day

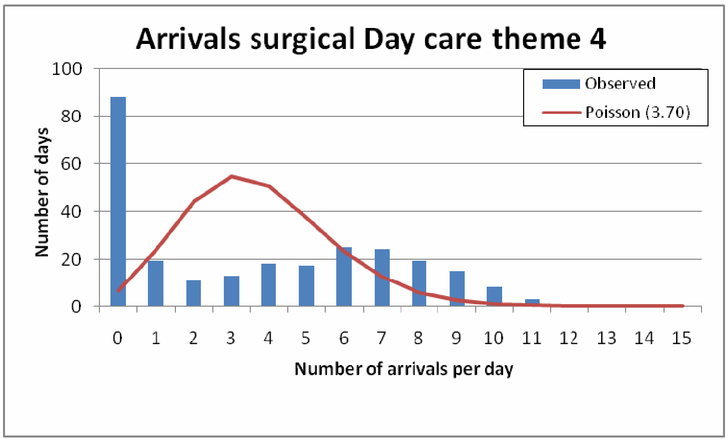

Arrivals non-surgical Day care theme 2
Observed
Poisson (29.70)
Number of days
Number of arrivals per day

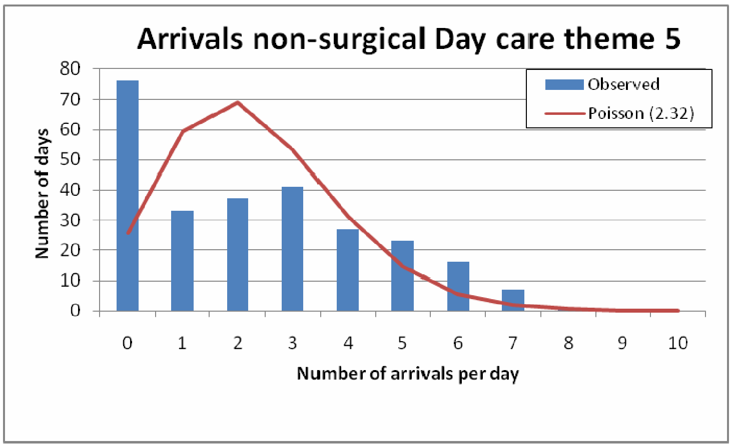

Arrivals surgical Day care theme 2
Observed
Poisson (1.80)
Number of days
Number of arrivals per day

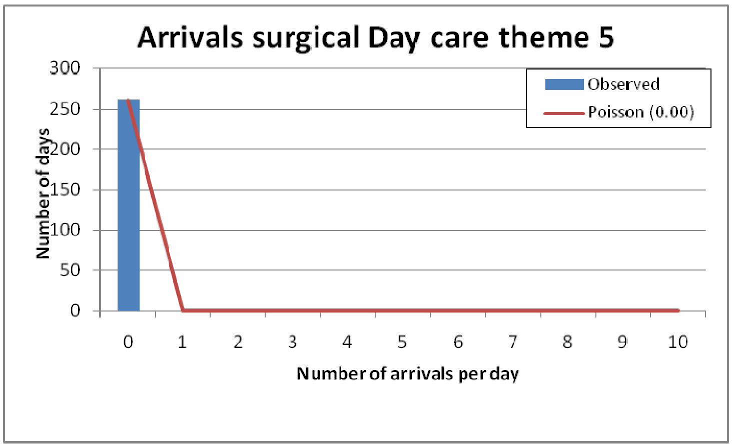

Arrivals non-surgical Day care theme 3
Observed
Poisson (28.80)
Number of days
Number of arrivals per day

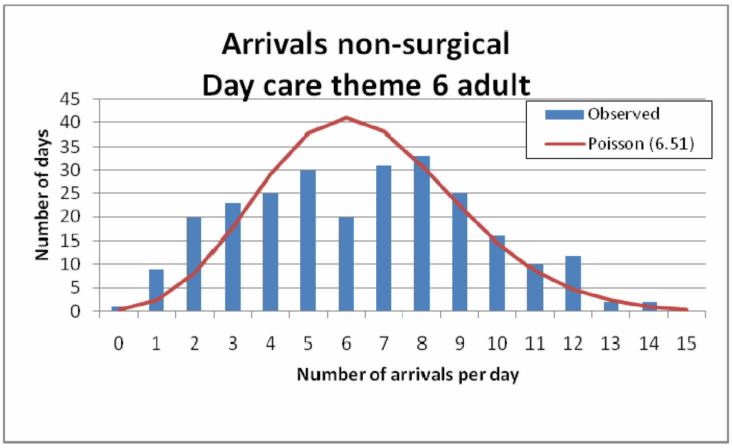

Arrivals surgical Day care theme 3
Observed
Poisson (1.21)
Number of days
Number of arrivals per day

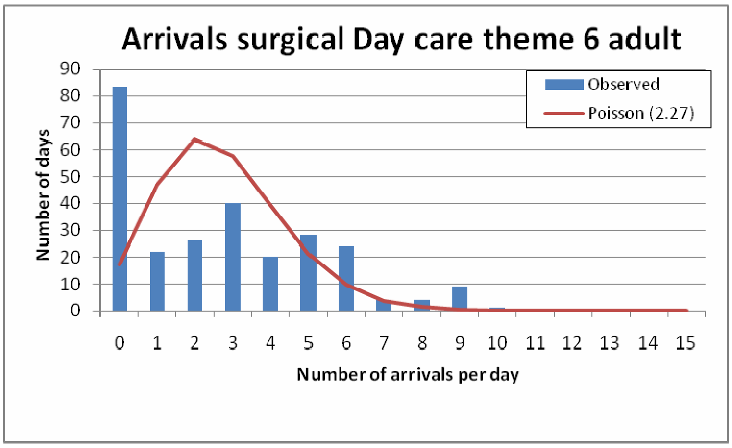

Arrivals non-surgical Day care theme 4
Observed
Poisson (0.00)
Number of days
Number of arrivals per day

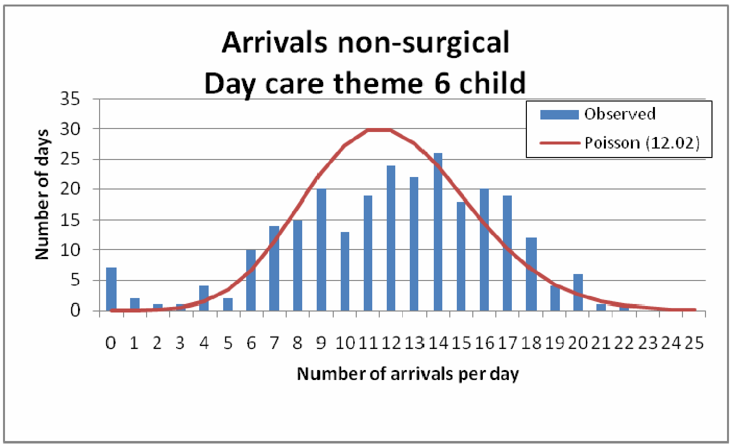

Arrivals surgical Day care theme 4
Observed
Poisson (3.70)
Number of days
Number of arrivals per day

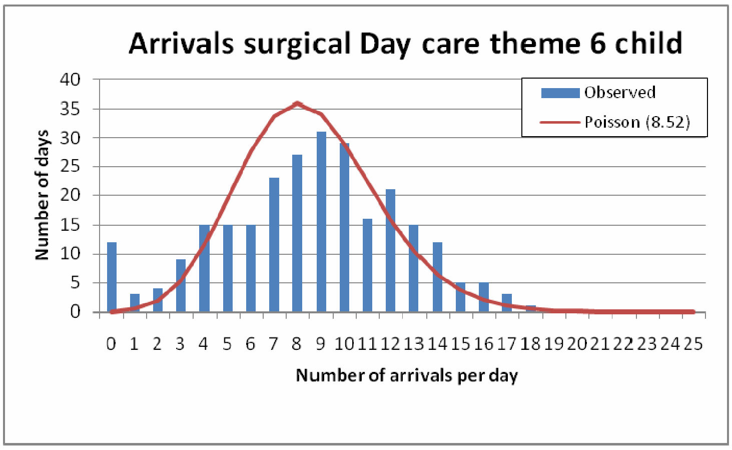

Arrivals non-surgical Day care theme 5
Observed
Poisson (2.32)
Number of days
0 10 20 30 40 50 60 70 80
0 1 2 3 4 5 6 7 8 9 10
Number of arrivals per day

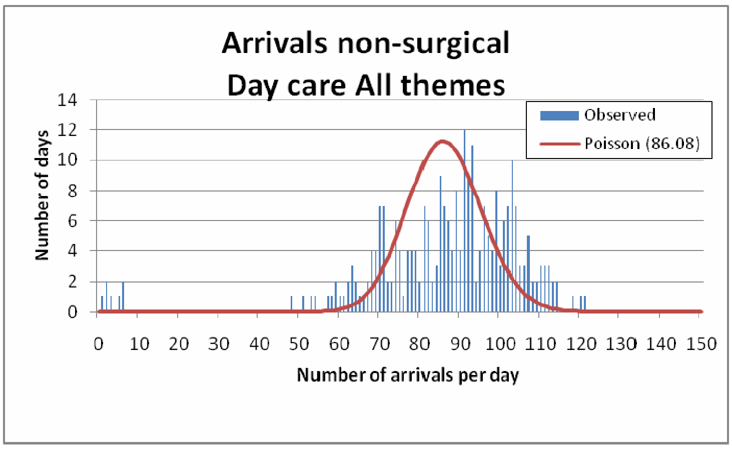

Arrivals surgical Day care theme 5
Observed
Poisson (0.00)
Number of days
0 50 100 150 200 250 300
0 1 2 3 4 5 6 7 8 9 10
Number of arrivals per day

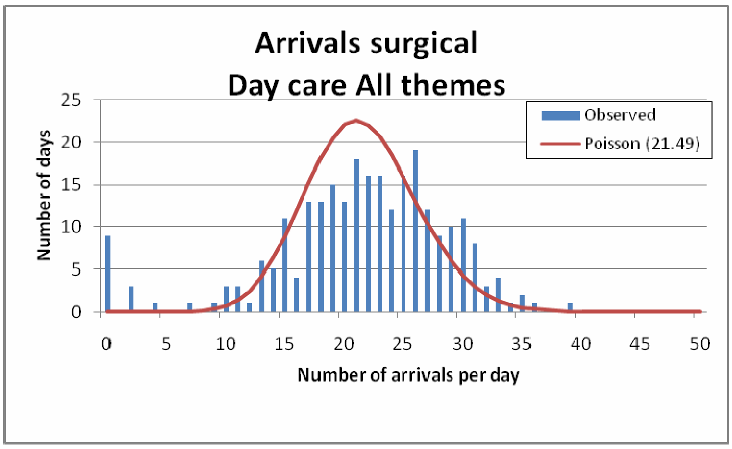

Arrivals non-surgical
Day care theme 6 adult
Observed
Poisson (6.51)
Number of days
0 5 10 15 20 25 30 35 40 45
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Number of arrivals per day


Arrivals surgical Day care theme 6 adult
Observed
Poisson (2.27)
Number of days
0 10 20 30 40 50 60 70 80 90
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Number of arrivals per day


Arrivals non-surgical
Day care theme 6 child
Observed
Poisson (12.02)
Number of days
0 5 10 15 20 25 30 35
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Number of arrivals per day

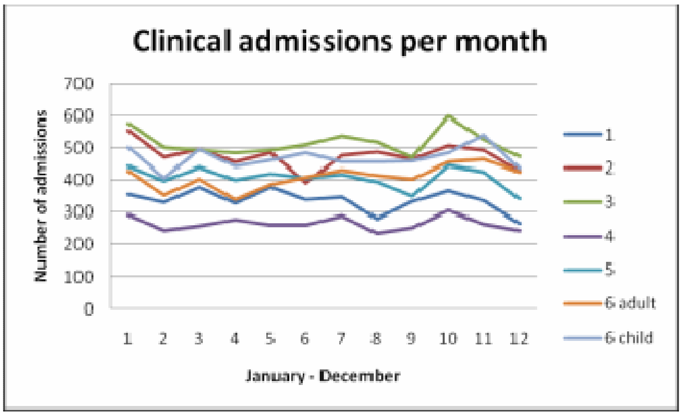

Arrivals surgical Day care theme 6 child
Observed
Poisson (8.52)
Number of days
0 5 10 15 20 25 30 35 40
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Number of arrivals per day

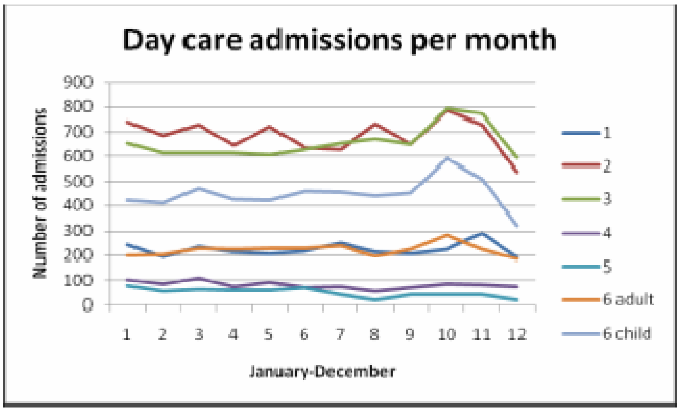

Arrivals non-surgical
Day care All themes
Observed
Poisson (86.08)
Number of days
0 2 4 6 8 10 12 14
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
Number of arrivals per day

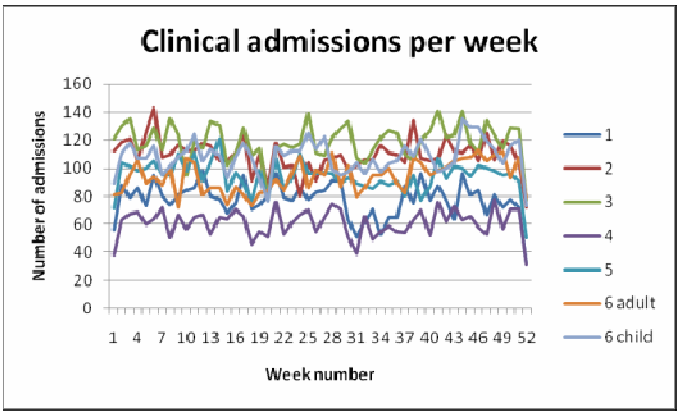

Arrivals surgical
Day care All themes
Observed
Poisson (21.49)
Number of days
0 5 10 15 20 25
0 5 10 15 20 25 30 35 40 45 50
Number of arrivals per day

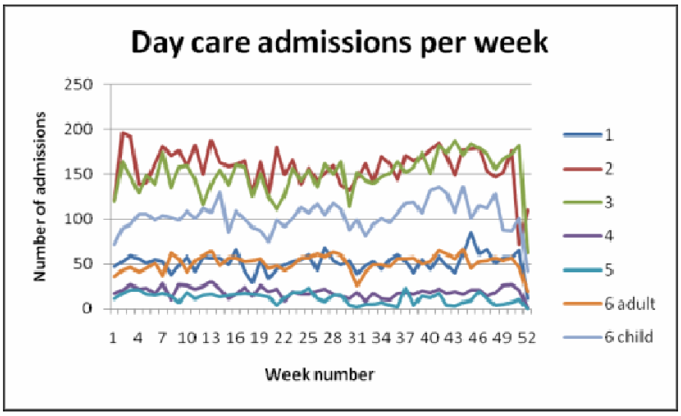
Appendix H: Time-dependency of admissions

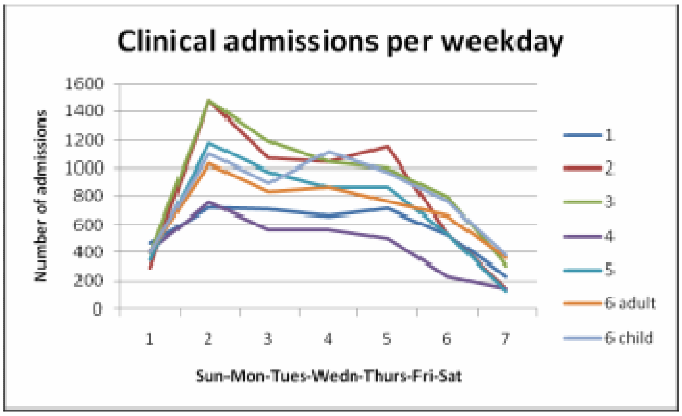
In chapter 7 is stated the Erlang loss model is accurate to base hospital capacity decisions upon. This model declares admissions are Poisson distributed. However, in reality this is not completely true: admissions are dependent of time. This appendix shows whether admissions vary per month, week, day and hour, both for clinical and day care admissions.

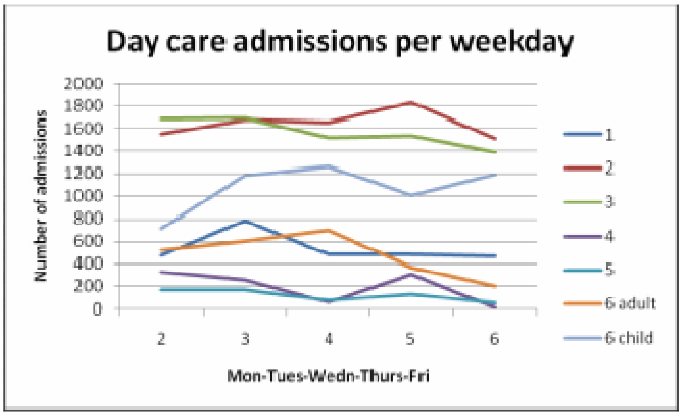


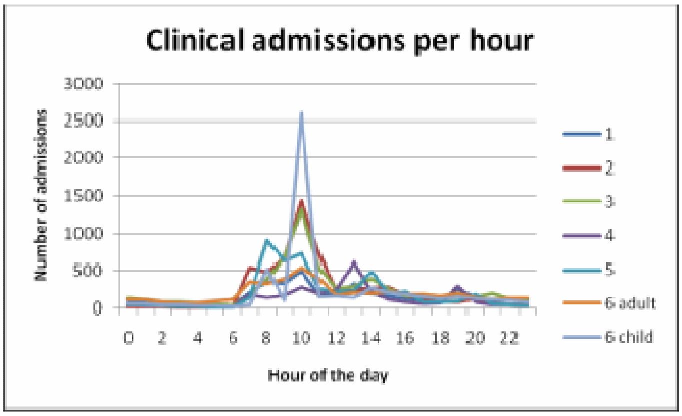


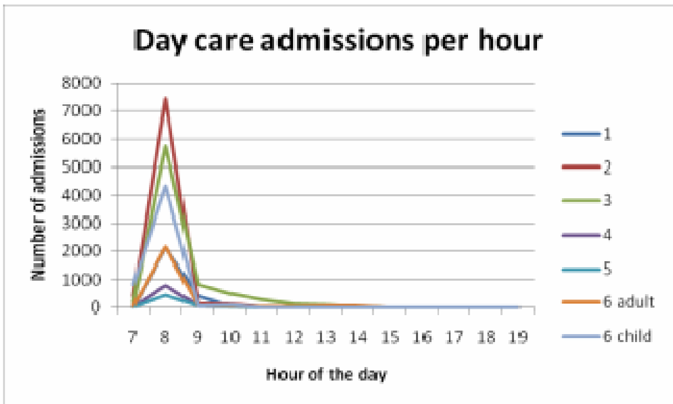






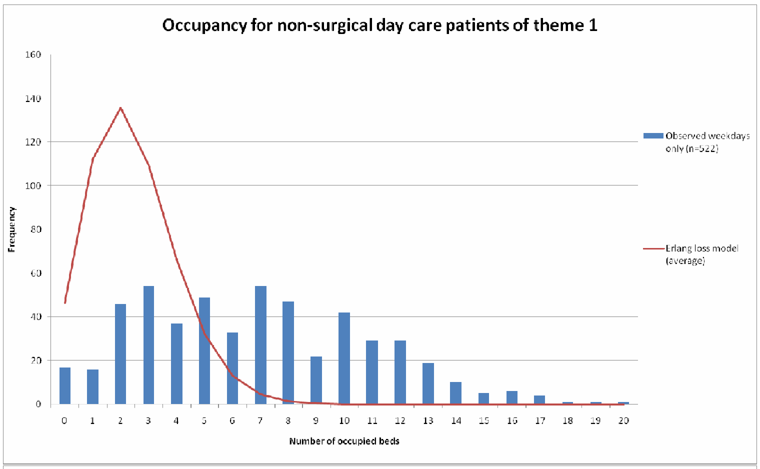


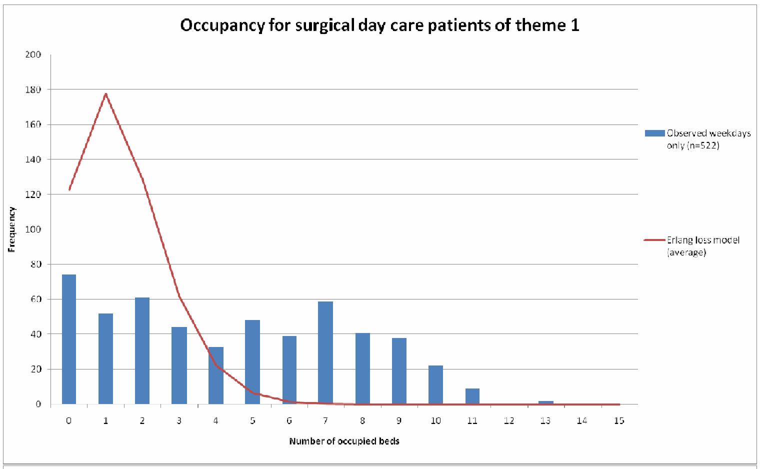


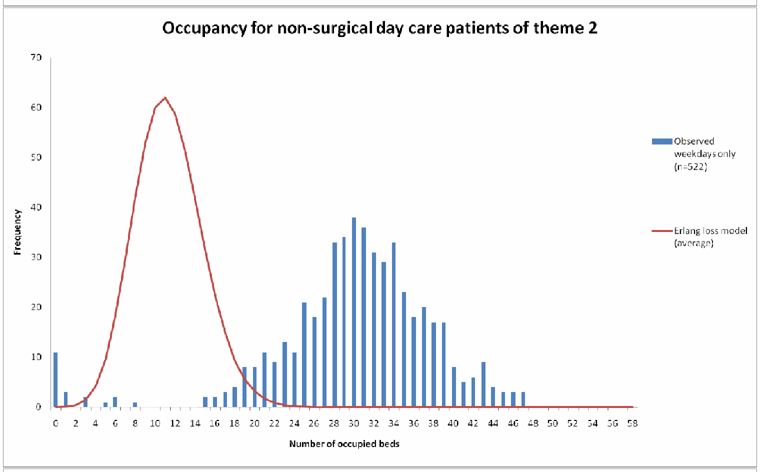


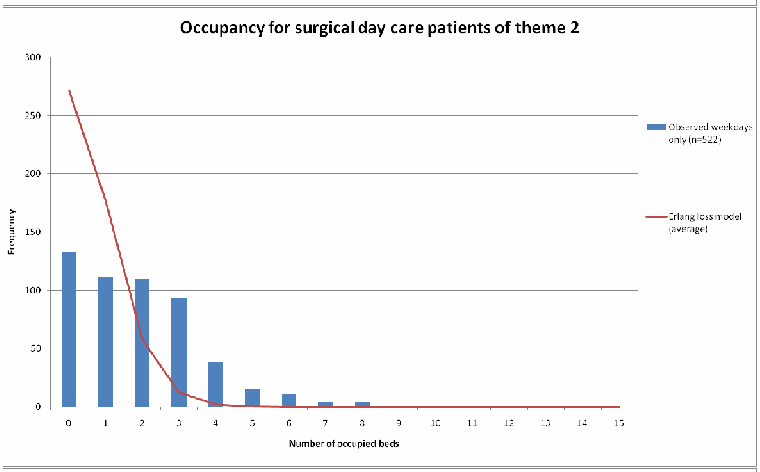
Appendix I: Presence of day care patients

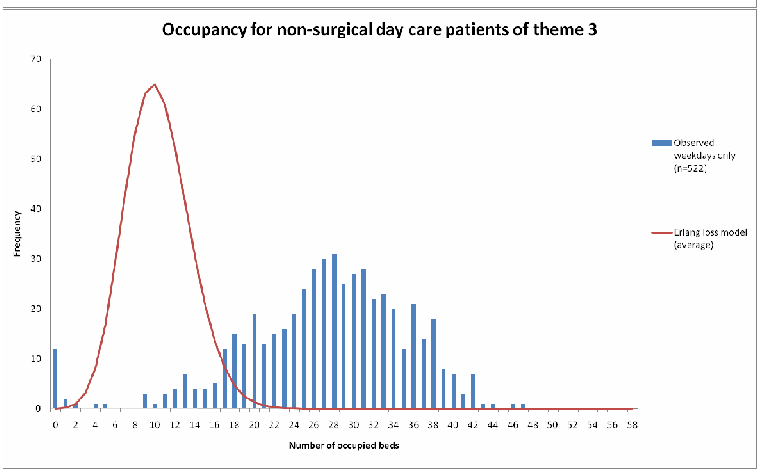
In section 7.2.2 we explain formulas used for clinical patients to calculate availability and efficiency underestimate the observed number of present day care patients. This appendix supports this statement.

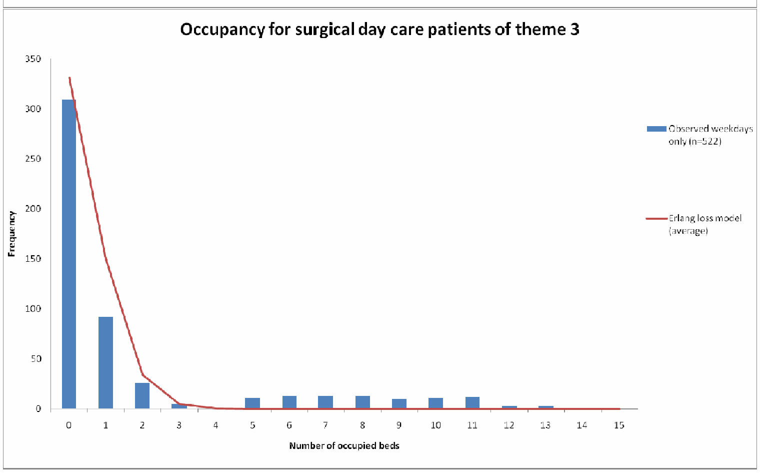




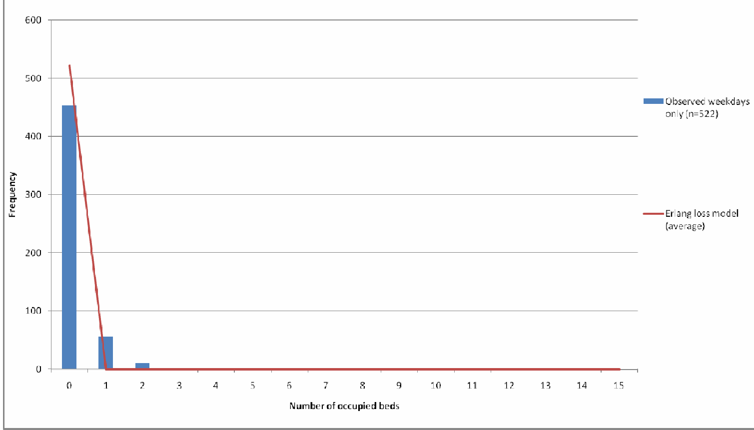




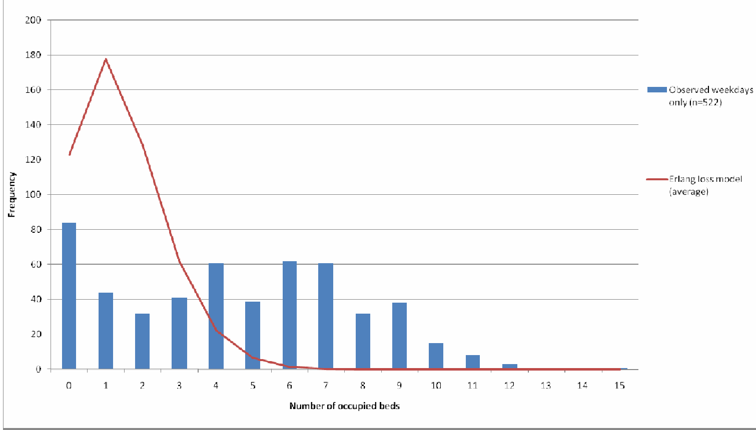




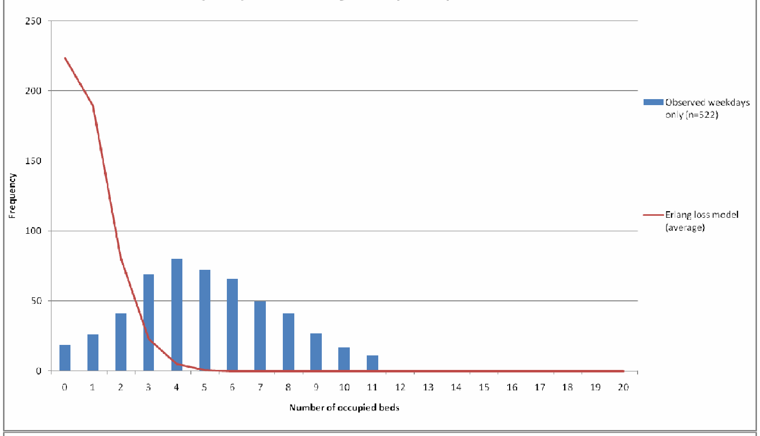
Occupancy for non-surgical day care patients of theme 4



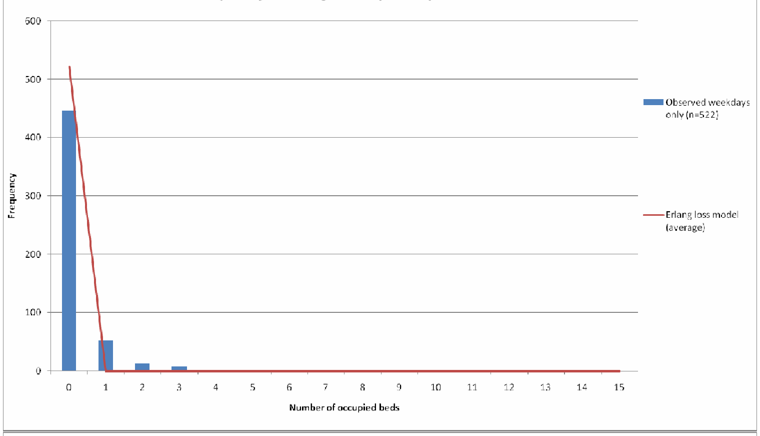
Occupancy for surgical day care patients of theme 4



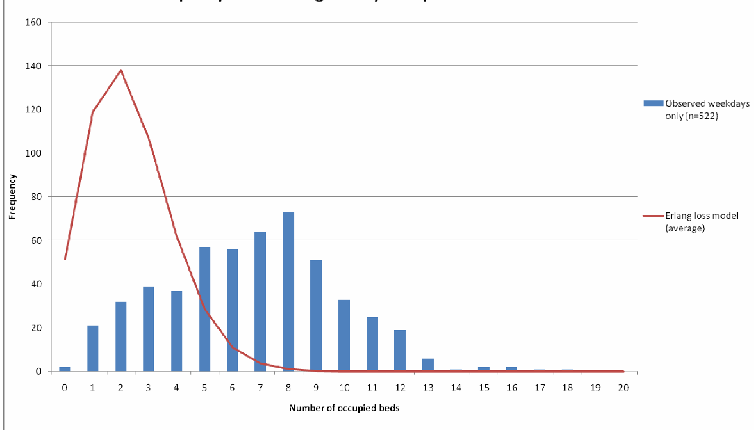
Occupancy for non-surgical day care patients of theme 5



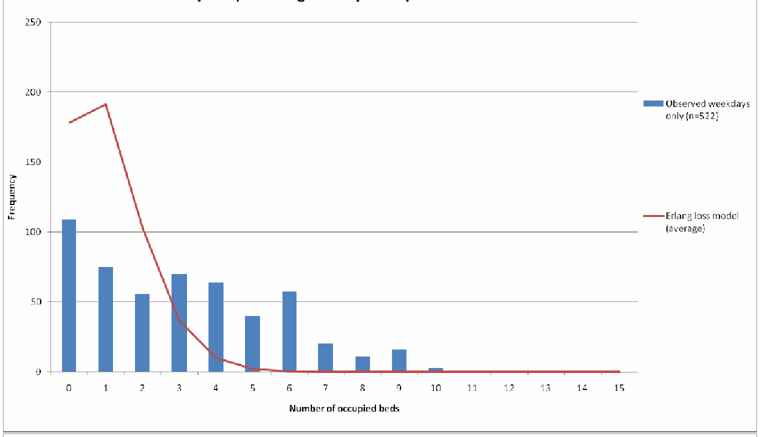
Occupancy for surgical day care patients of theme 5



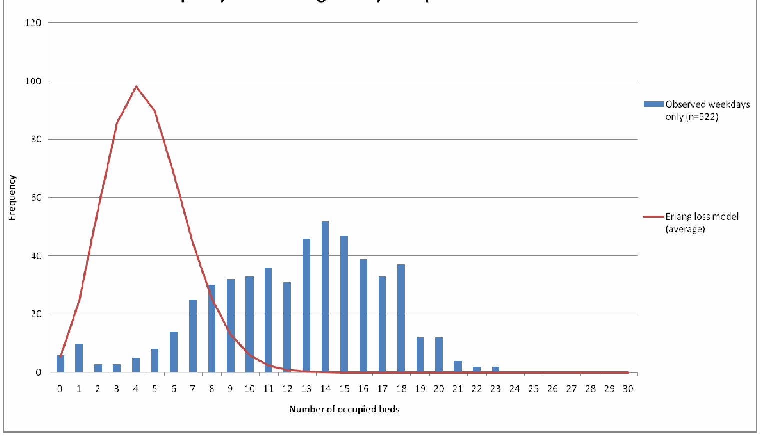
Occupancy for non-surgical day care patients of theme 6 adult



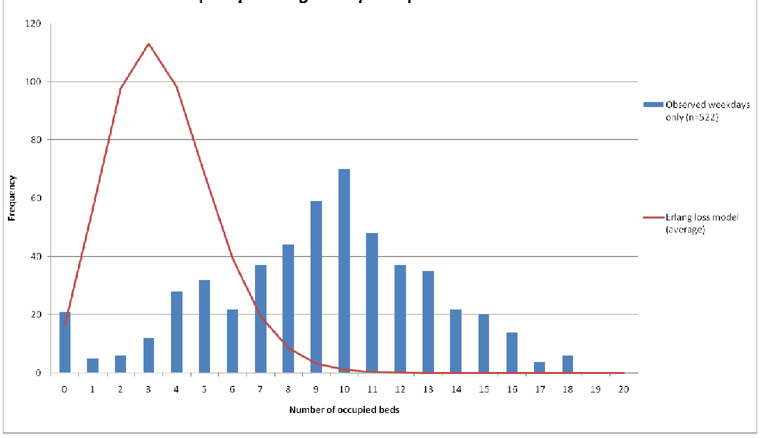
Occupancy for surgical day care patients of theme 6 adult



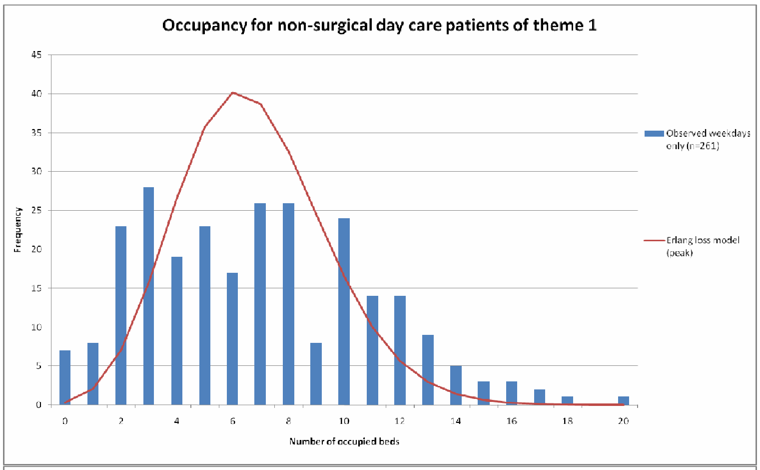
Occupancy for non-surgical day care patients of theme 6 child

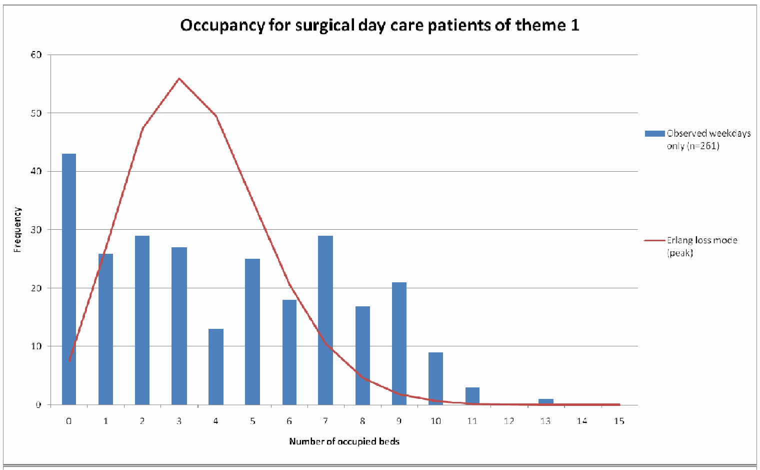


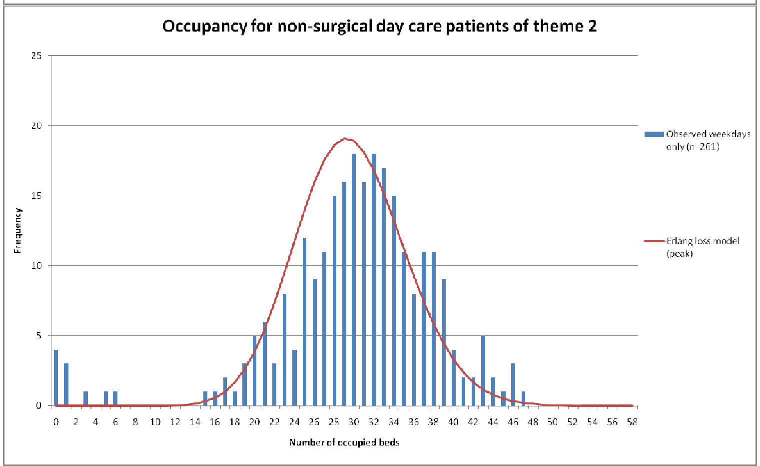
Occupancy for surgical day care patients of theme 6 child

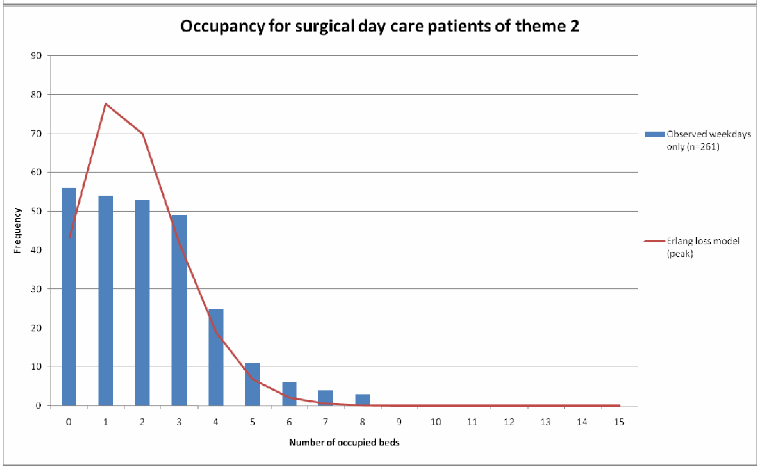


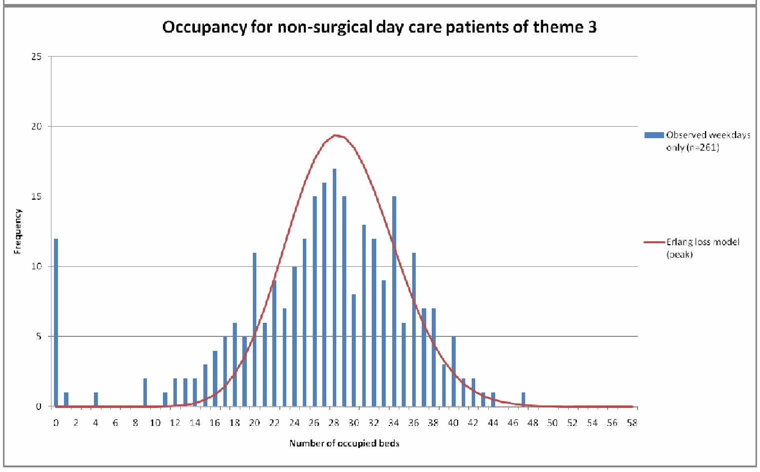
Besides the average situation per day, we also distinguished the busy period in the morning. During this period, availability is one in case the number of arrivals is equal to or smaller than the bed capacity. In case the number of arrivals exceeds bed capacity, peak availability is the bed capacity as a part of the number of arrivals.
Efficiency is the number of arrivals as a part of the bed capacity (with a maximum of 100%).
The figures below compare the observed number of occupied beds at 11:00 of each day with the expectation using Poisson arrivals.

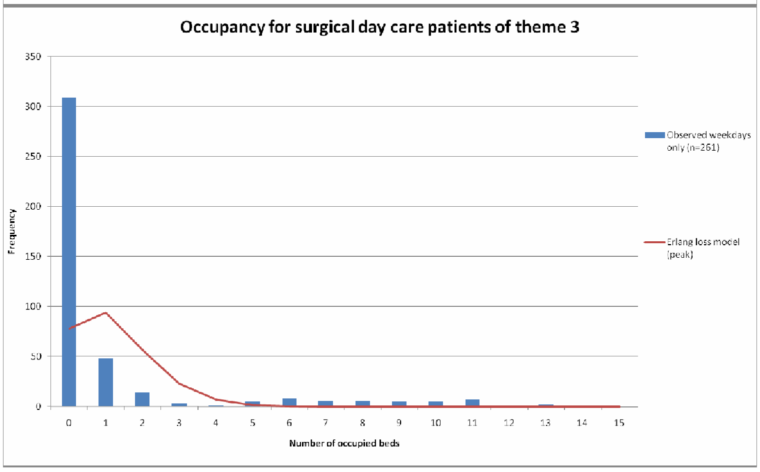


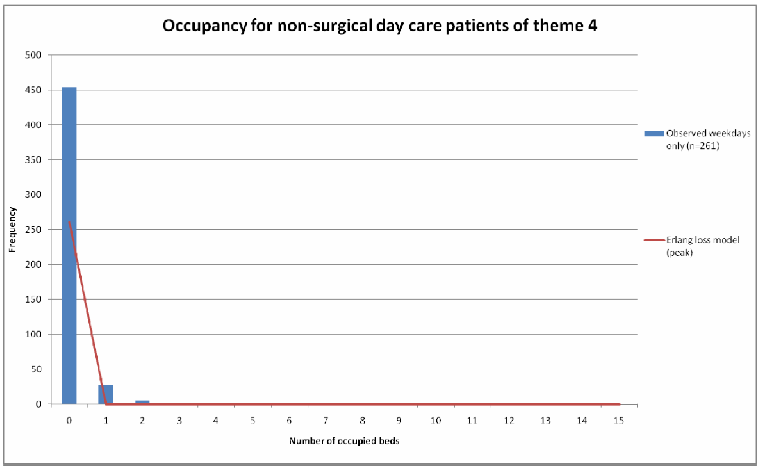


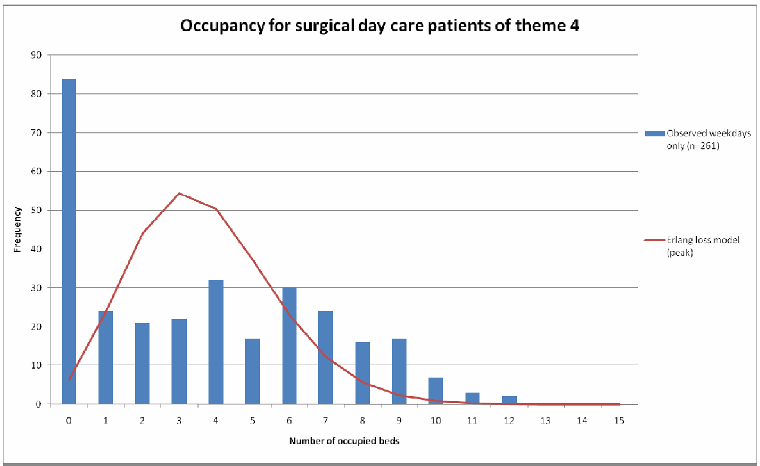


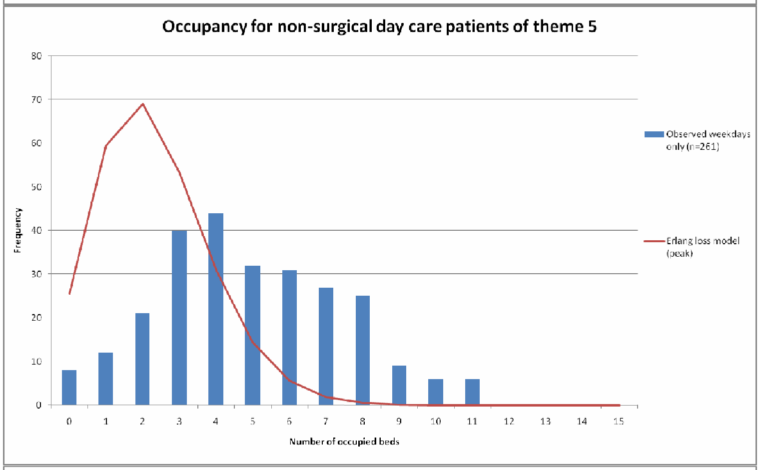


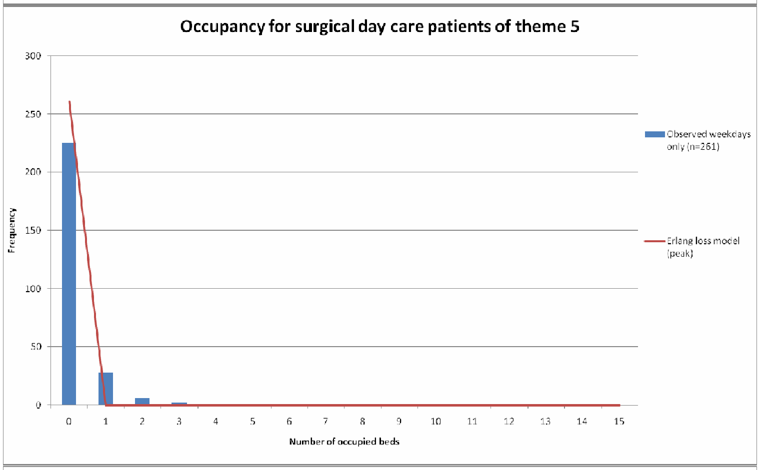


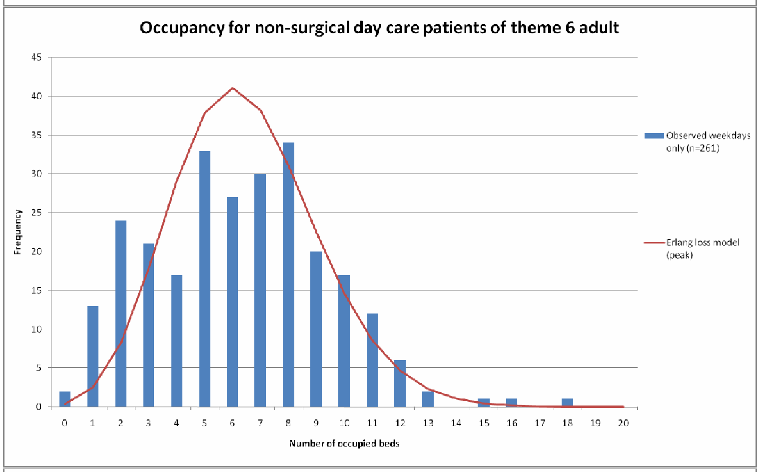


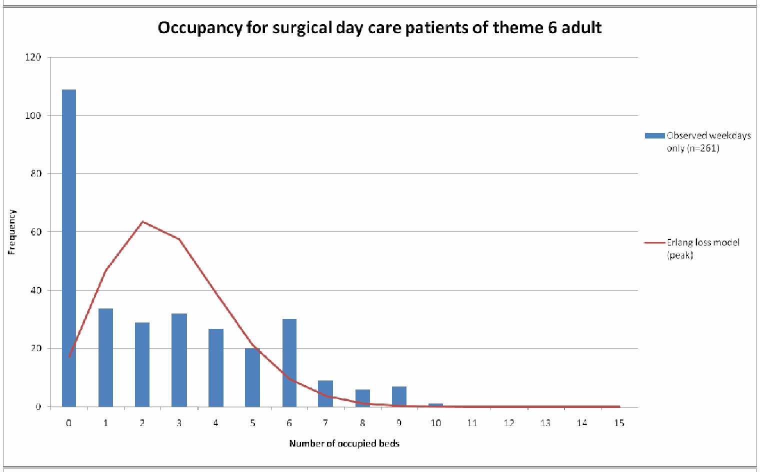

Occupancy for non-surgical day care patients of theme 4
Observed weekdays only (n=261)
Erlang loss model (peak)
Frequency
Number of occupied beds
0 50 100 150 200 250 300 350 400 450 500
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

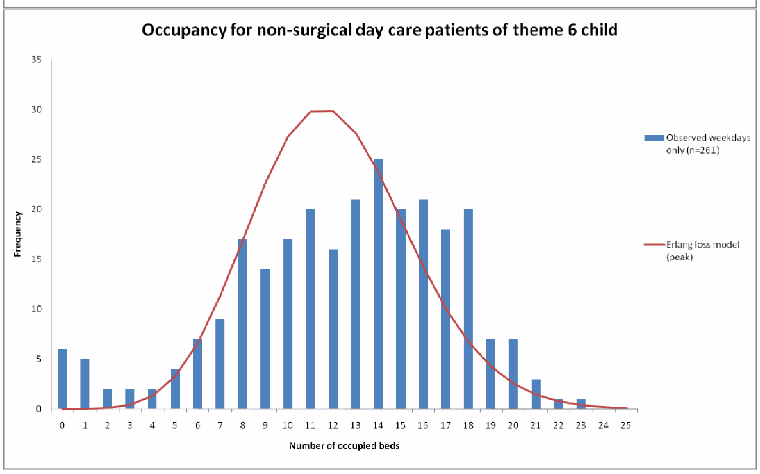

Occupancy for surgical day care patients of theme 4
Observed weekdays only (n=261)
Erlang loss model (peak)
Frequency
Number of occupied beds
0 10 20 30 40 50 60 70 80 90
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

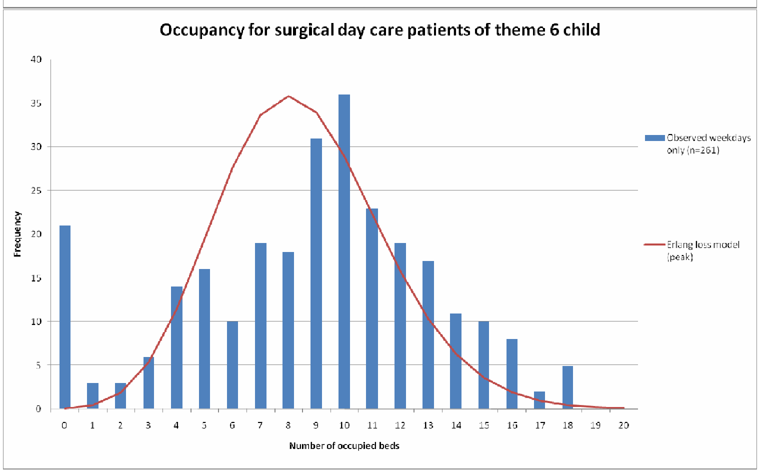

Occupancy for non-surgical day care patients of theme 5
Observed weekdays only (n=261)
Erlang loss model (peak)
Frequency
Number of occupied beds
0 10 20 30 40 50 60 70 80
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15


Occupancy for surgical day care patients of theme 5
Observed weekdays only (n=261)
Erlang loss model (peak)
Frequency
Number of occupied beds
0 50 100 150 200 250 300
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15


Occupancy for non-surgical day care patients of theme 6 adult
Observed weekdays only (n=261)
Erlang loss model (peak)
Frequency
Number of occupied beds
0 5 10 15 20 25 30 35 40 45
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20


Occupancy for surgical day care patients of theme 6 adult
Observed weekdays only (n=261)
Erlang loss model (peak)
Frequency
Number of occupied beds
0 20 40 60 80 100 120
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15


Occupancy for non-surgical day care patients of theme 6 child
Observed weekdays only (n=261)
Erlang loss model (peak)
Frequency
Number of occupied beds
0 5 10 15 20 25 30 35
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

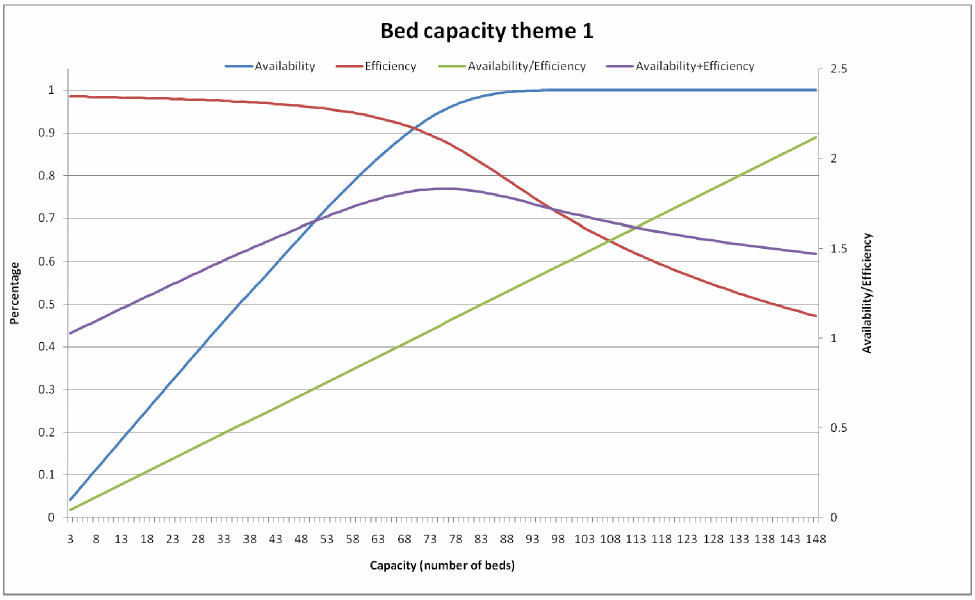

Occupancy for surgical day care patients of theme 6 child
Observed weekdays only (n=261)
Erlang loss model (peak)
Frequency
Number of occupied beds
0 5 10 15 20 25 30 35 40
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

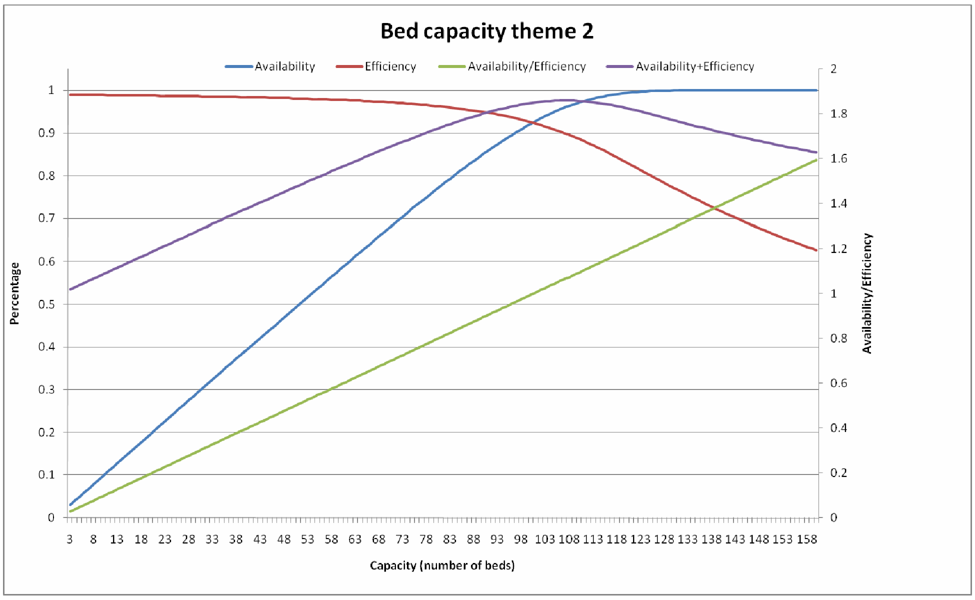
Appendix J: Capacity for clinical care

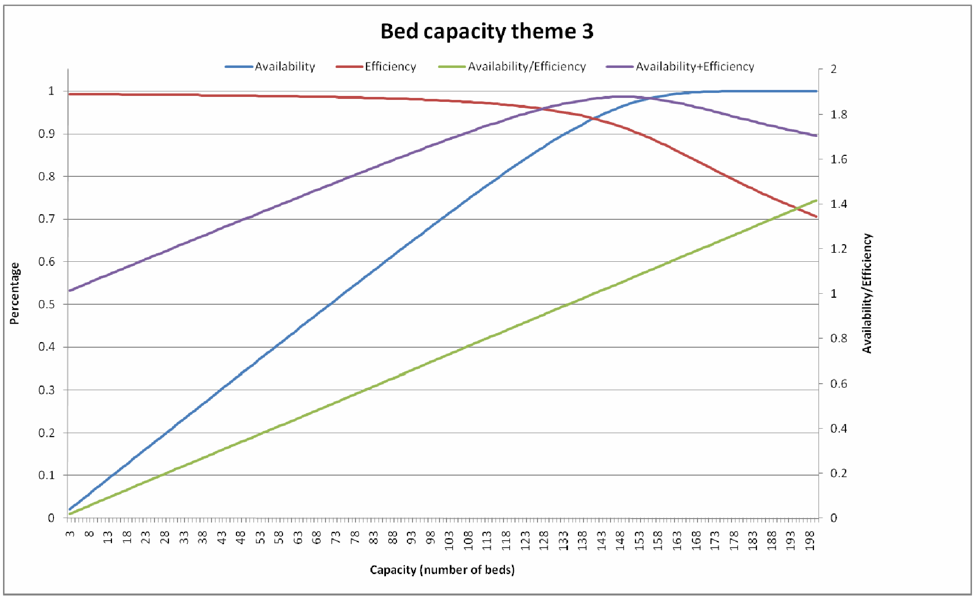
In section 8.1 we determine required capacity for clinical care, based on the trade-off between availability and efficiency. This appendix shows the relation between these three variables for clinical patients per theme. These graphs display the possibilities to optimize the variables and support the Erasmus MC's management in determining the required capacity.

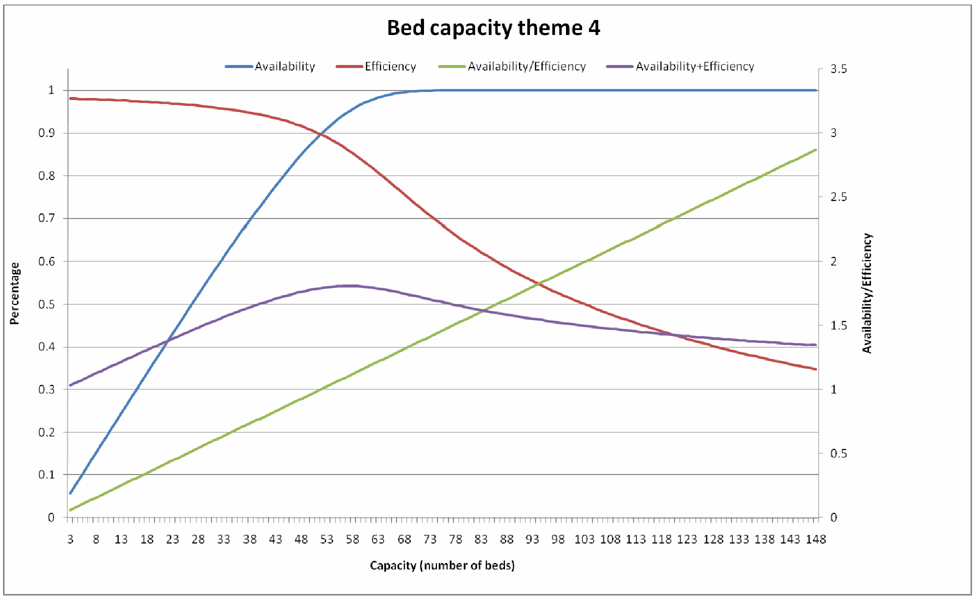
We also show the ratio $\frac{Availability}{Efficiency}$ as a function of the bed capacity to show is not a constant, but increases linearly with bed capacity.

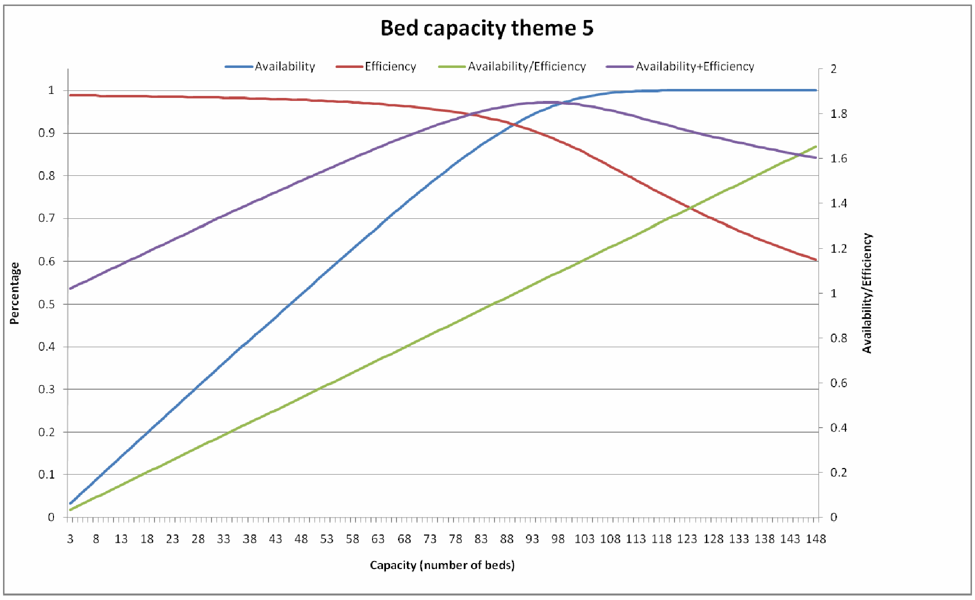
Finally, we display the sum of availability and efficiency, which can be helpful in making the trade-off between availability and efficiency (8.1.3).

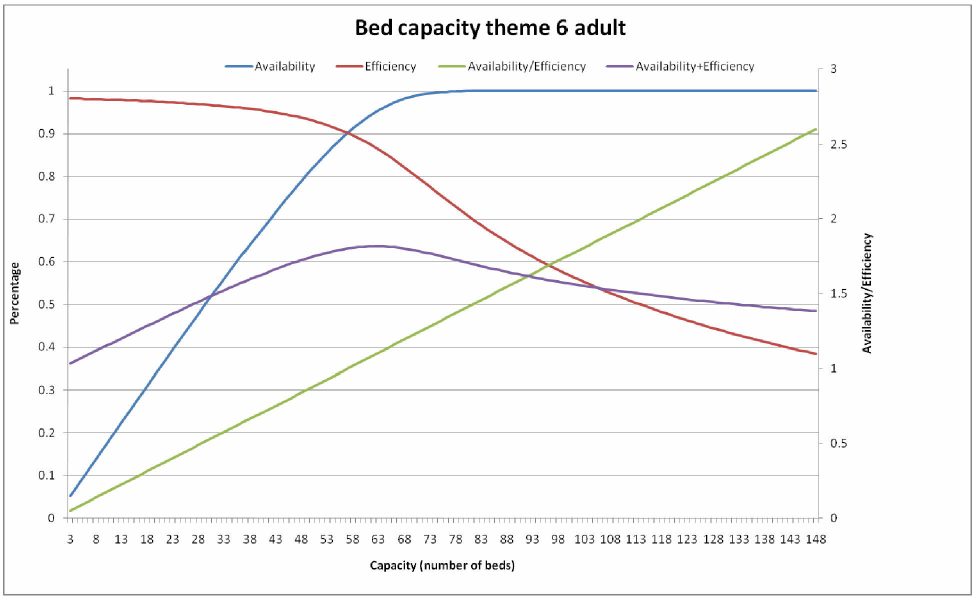


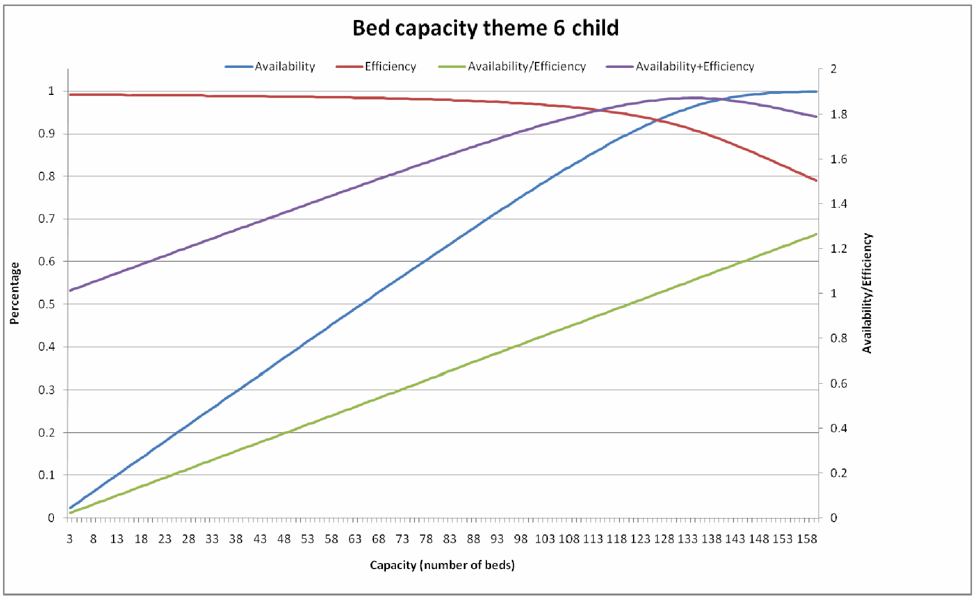



Bed capacity theme 3
Availability
Efficiency
Availability/Efficiency
Availability+Efficiency
Percentage
Availability/Efficiency
Capacity (number of beds)


Bed capacity theme 4
Availability
Efficiency
Availability/Efficiency
Availability+Efficiency
Percentage
Availability/Efficiency
Capacity (number of beds)

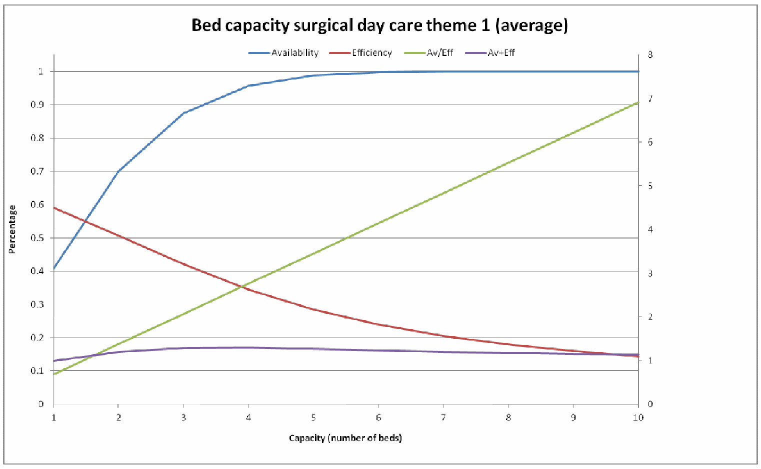

Bed capacity theme 5
Availability
Efficiency
Availability/Efficiency
Availability+Efficiency
Percentage
Availability/Efficiency
Capacity (number of beds)

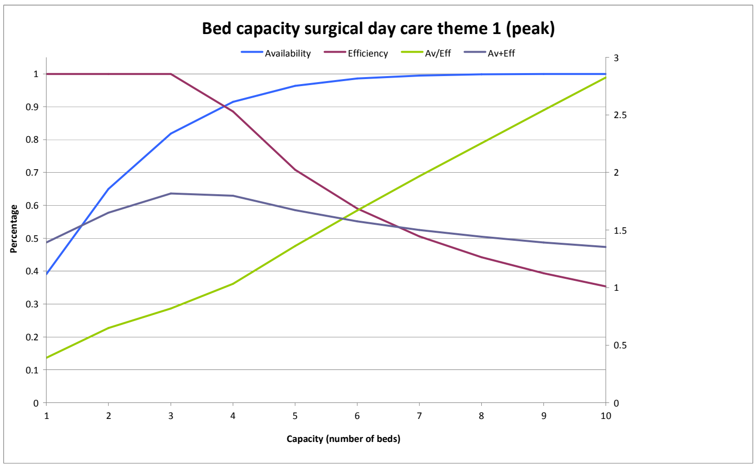

Bed capacity theme 6 adult
Availability
Efficiency
Availability/Efficiency
Availability+Efficiency
Percentage
Availability/Efficiency
Capacity (number of beds)

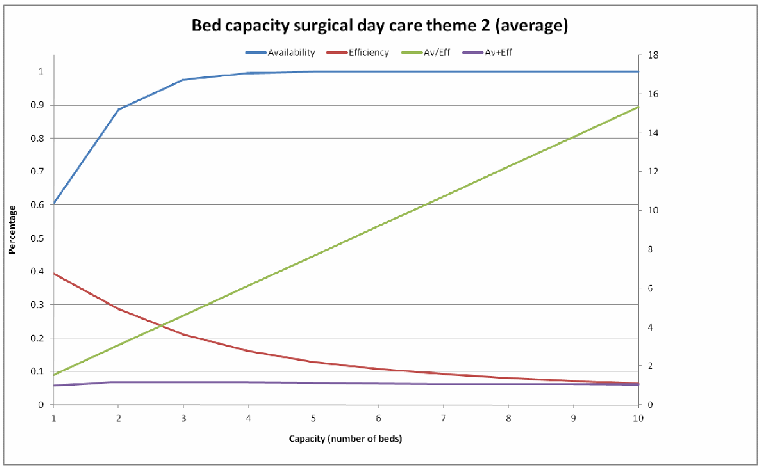

Bed capacity theme 6 child
Availability
Efficiency
Availability/Efficiency
Availability+Efficiency
Percentage
Availability/Efficiency
Capacity (number of beds)

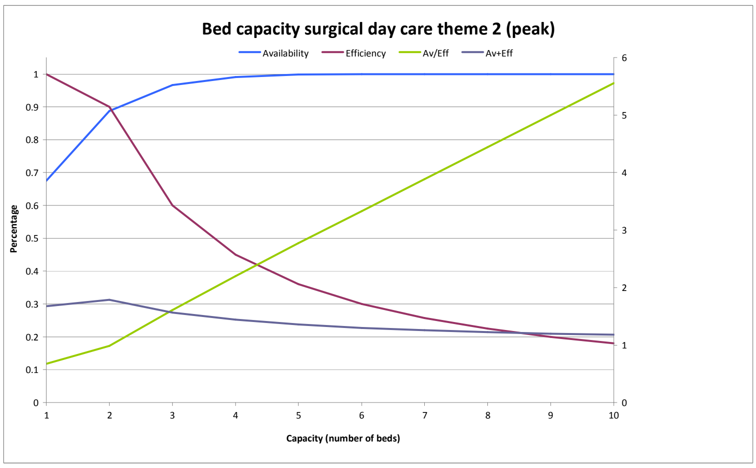
Appendix K: Capacity for surgical day care, separated per theme

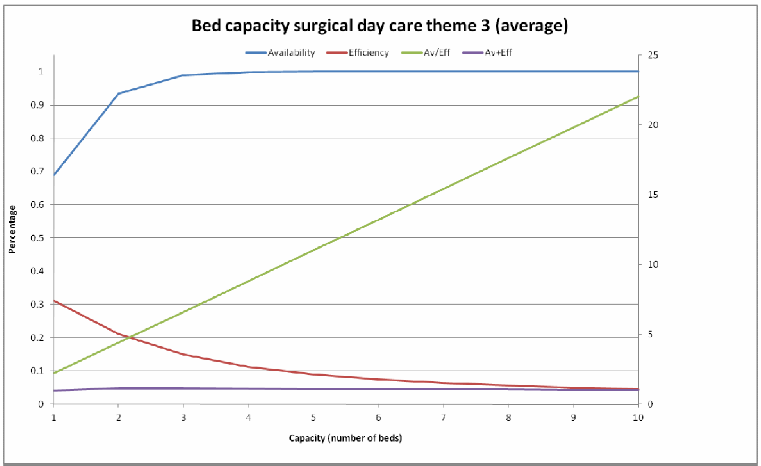
In section 8.2 we determine required capacity for surgical day care, based on the trade-off between availability and efficiency. This appendix shows the relation between these three variables for clinical patients per theme. These graphs display the possibilities to optimize the variables and support the Erasmus MC's management in determining the required capacity.
We distinguish the average situation and the busy period of the day with maximal P_{loss} and efficiency (so minimal availability). The first situation is displayed left and the latter at the right side (and is also called peak situation).
To ease making the trade-off between availability and efficiency, it also displays the ratio of availability and efficiency, as well as the sum.

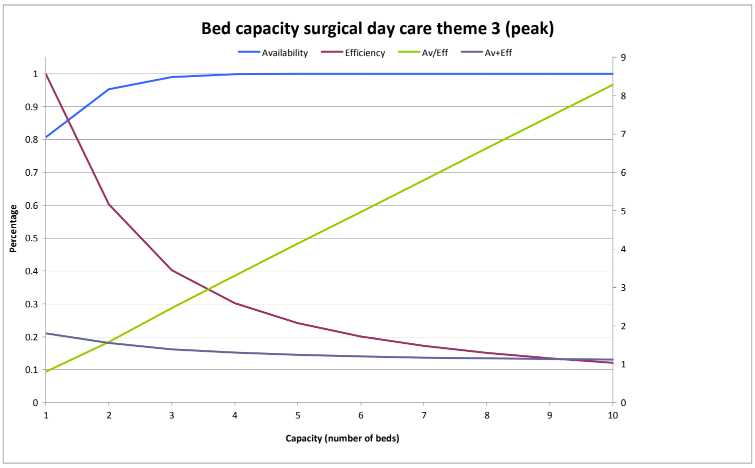


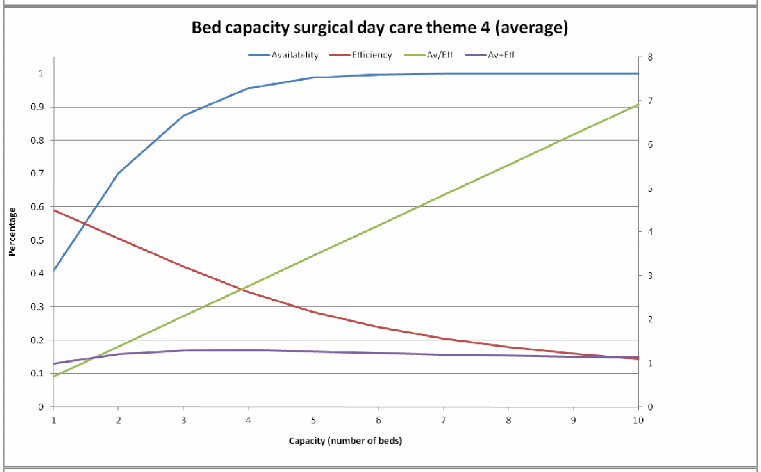


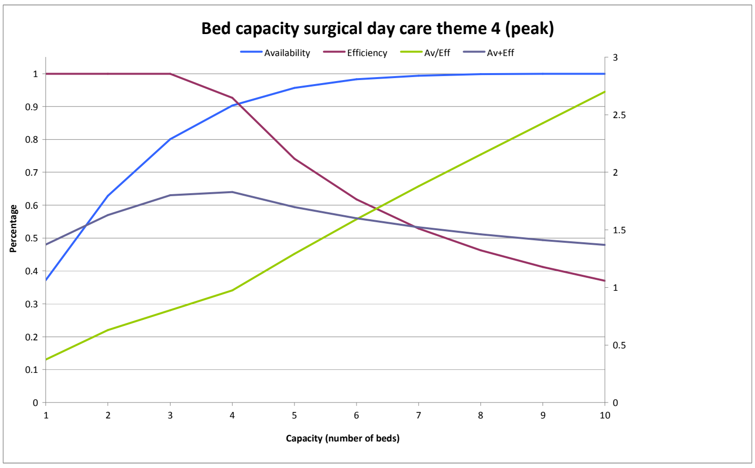


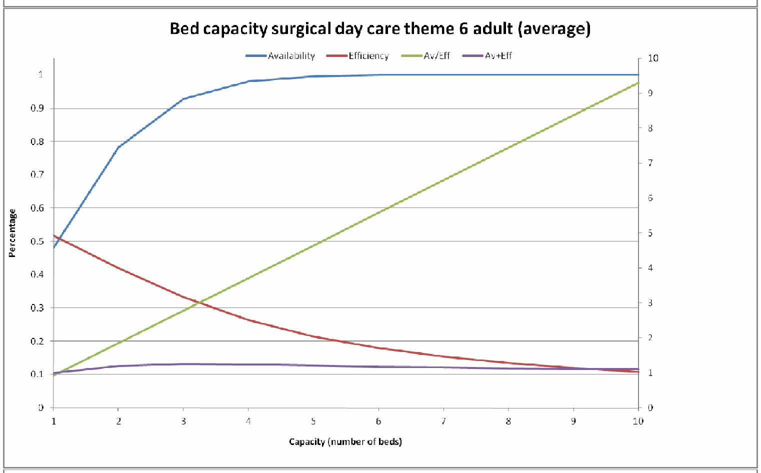


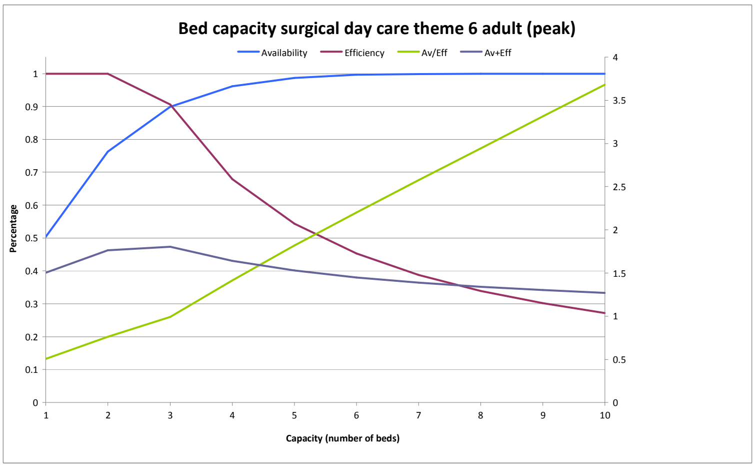

Bed capacity surgical day care theme 3 (average)
Availability
Efficiency
Av/Eff
Av+Eff
Percentage
Capacity (number of beds)

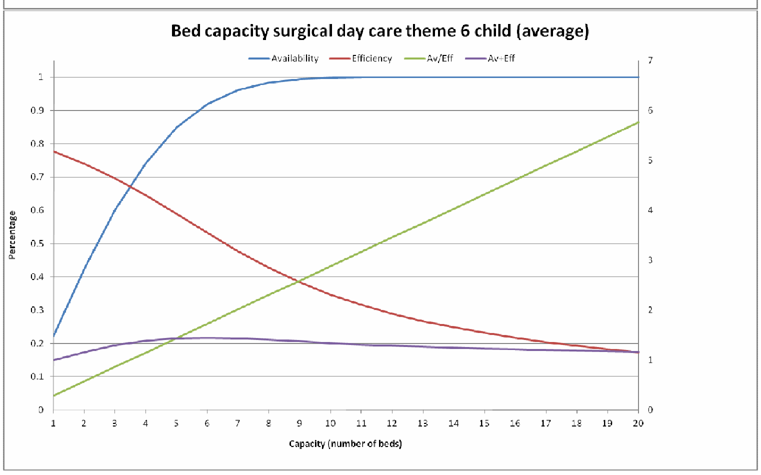

Bed capacity surgical day care theme 3 (peak)
Availability
Efficiency
Av/Eff
Av+Eff
Percentage
Capacity (number of beds)

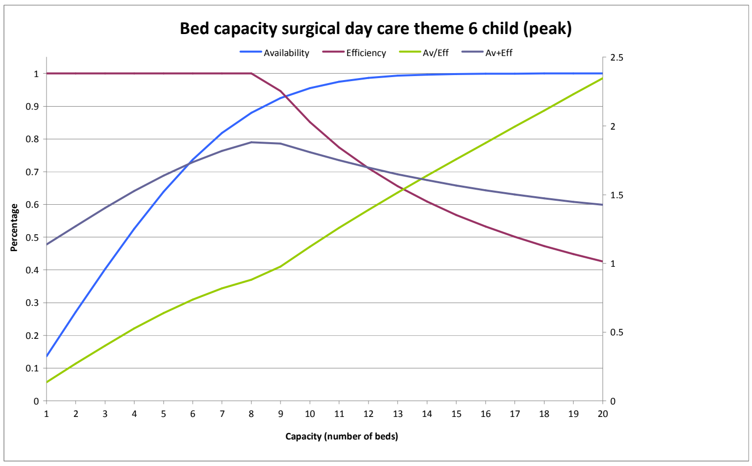

Bed capacity surgical day care theme 4 (average)
Availability
Efficiency
Av/Eff
Av+Eff
Percentage
Capacity (number of beds)


Bed capacity surgical day care theme 4 (peak)
Availability
Efficiency
Av/Eff
Av+Eff
Percentage
Capacity (number of beds)


Bed capacity surgical day care theme 6 adult (average)
Availability
Efficiency
Av/Eff
Av+Eff
Percentage
Capacity (number of beds)

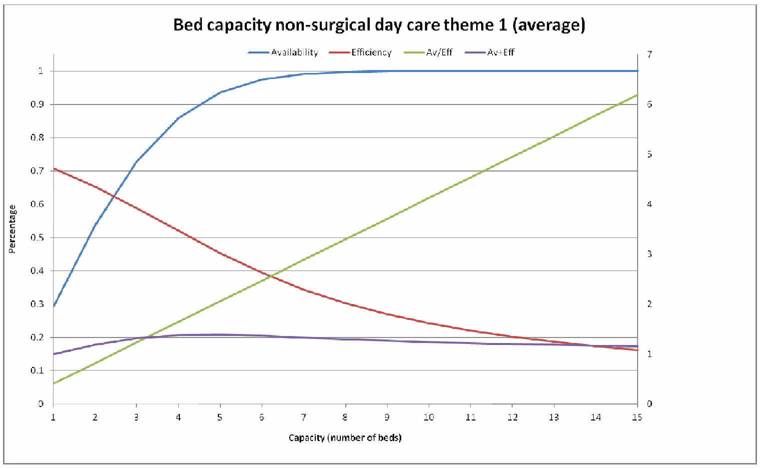

Bed capacity surgical day care theme 6 adult (peak)
Availability
Efficiency
Av/Eff
Av+Eff
Percentage
Capacity (number of beds)

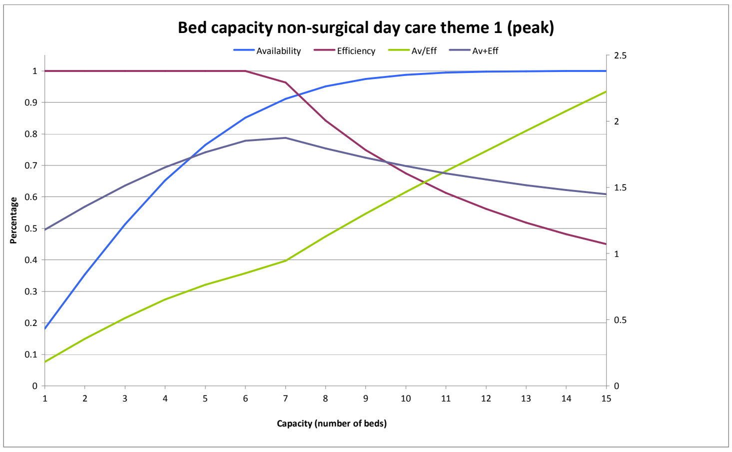

Bed capacity surgical day care theme 6 child (average)
Availability
Efficiency
Av/Eff
Av+Eff
Percentage
Capacity (number of beds)

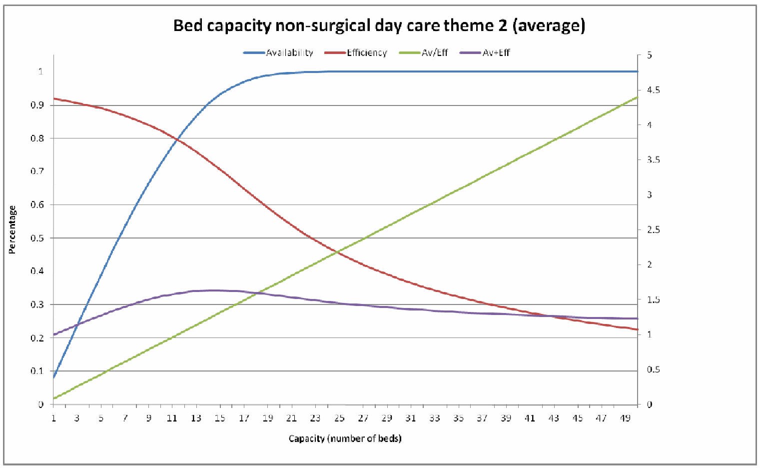

Bed capacity surgical day care theme 6 child (peak)
Availability
Efficiency
Av/Eff
Av+Eff
Percentage
Capacity (number of beds)

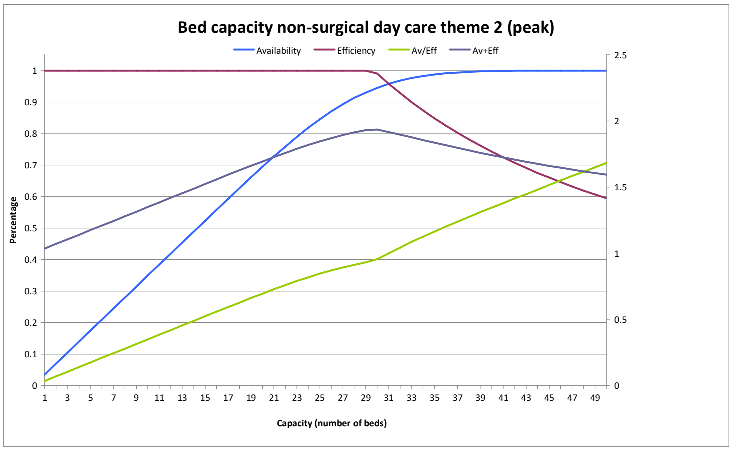
Appendix L: Capacity for non-surgical day care, separated per theme

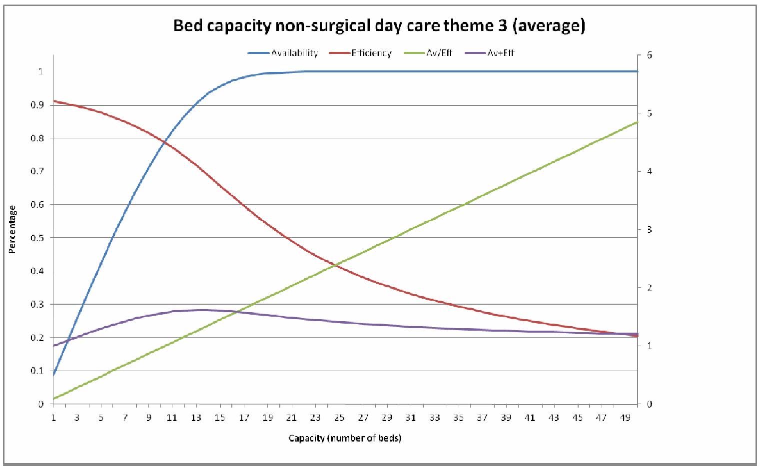
In section 8.3 we determine required capacity for non-surgical day care, based on the trade-off between availability and efficiency. This appendix shows the relation between these three variables for clinical patients per theme. These graphs display the possibilities to optimize the variables and support the Erasmus MC's management in determining the required capacity. Just as for surgical day care, we distinguish the average situation (displayed left) and the peak situation (displayed right).
To ease making the trade-off between availability and efficiency, it also displays the ratio of availability and efficiency, as well as the sum.

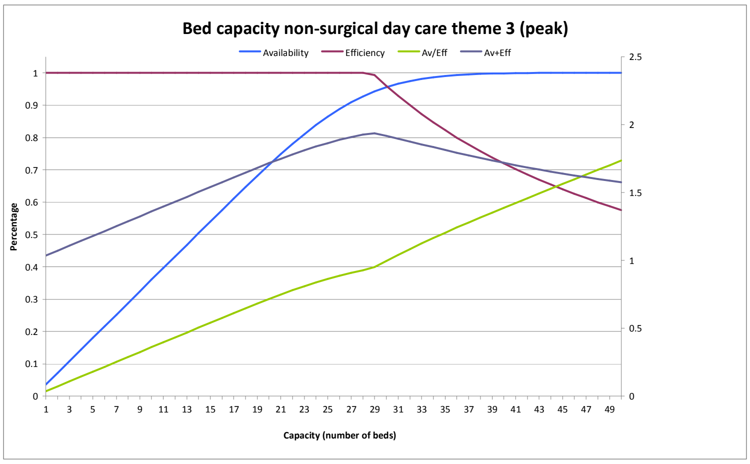


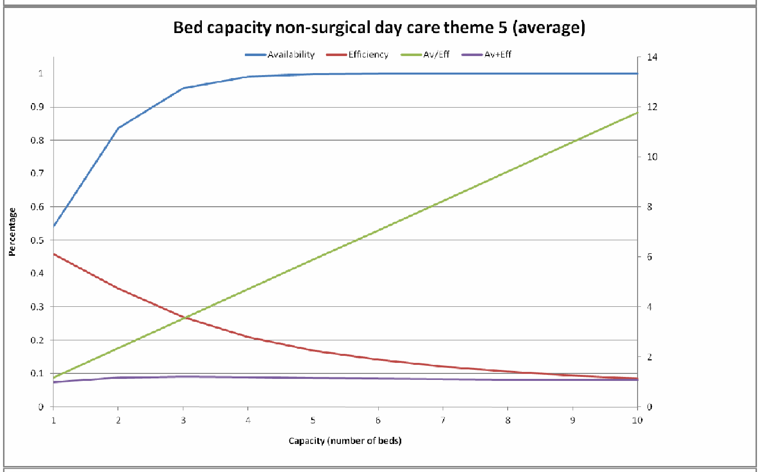


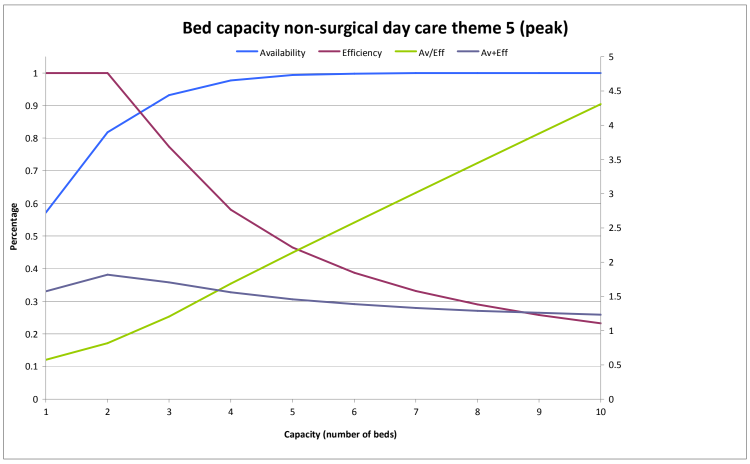


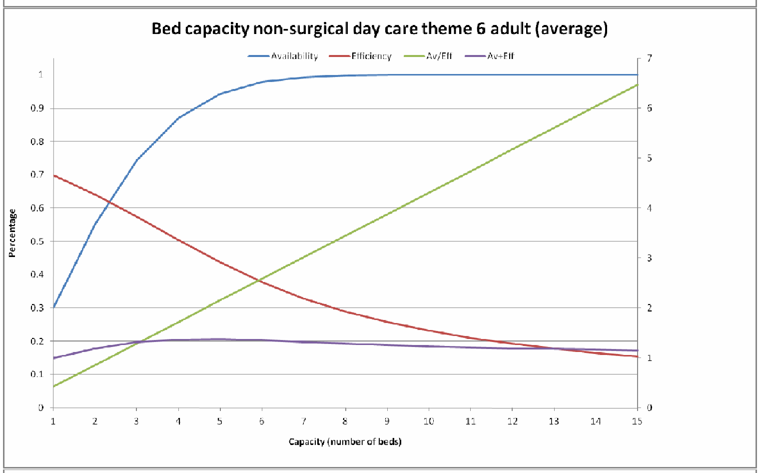


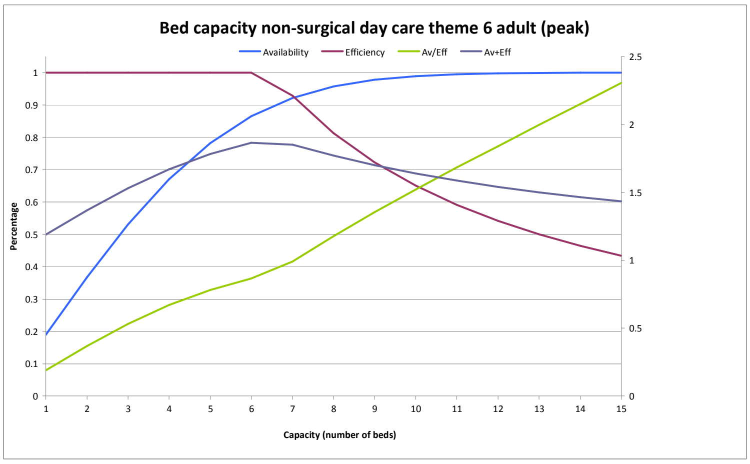

Bed capacity non-surgical day care theme 3 (average)
Availability
Efficiency
Av/Eff
Av+Eff
Percentage
Capacity (number of beds)

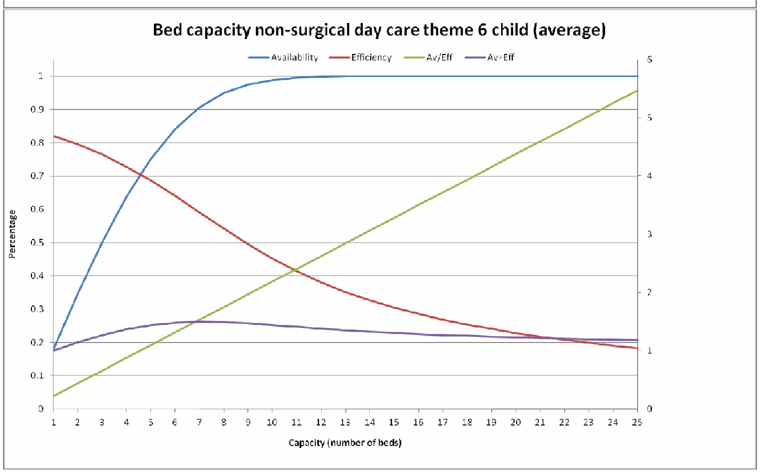

Bed capacity non-surgical day care theme 3 (peak)
Availability
Efficiency
Av/Eff
Av+Eff
Percentage
Capacity (number of beds)

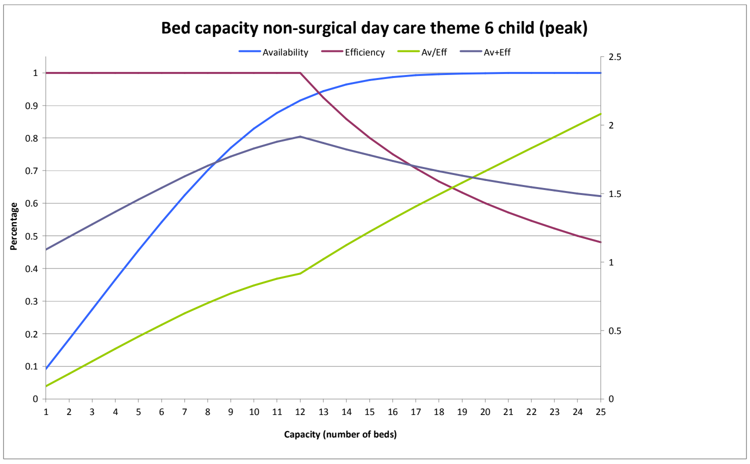

Bed capacity non-surgical day care theme 5 (average)
Availability
Efficiency
Av/Eff
Av+Eff
Percentage
Capacity (number of beds)


Bed capacity non-surgical day care theme 5 (peak)
Availability
Efficiency
Av/Eff
Av+Eff
Percentage
Capacity (number of beds)


Bed capacity non-surgical day care theme 6 adult (average)
Availability
Efficiency
Av/Eff
Av+Eff
Percentage
Capacity (number of beds)


Bed capacity non-surgical day care theme 6 adult (peak)
Availability
Efficiency
Av/Eff
Av+Eff
Percentage
Capacity (number of beds)


Bed capacity non-surgical day care theme 6 child (average)
Availability
Efficiency
Av/Eff
Av+Eff
Percentage
Capacity (number of beds)


Bed capacity non-surgical day care theme 6 child (peak)
Availability
Efficiency
Av/Eff
Av+Eff
Percentage
Capacity (number of beds)

Appendix M: Day care capacity theme distribution

In chapter 10, we execute several sensitivity analyses. Section 10.2 focuses on the consequences of an alternative theme distribution. The consequences for clinical care are displayed in section 10.2.1 itself. In section 10.2.2, we see the new $\frac{1}{\mu}$'s and λ's of day care patients change only slightly. This appendix shows the new required capacities to achieve certain availability levels (and the corresponding efficiency rates) in case each theme would establish a separate department for surgical day care patients and one for non-surgical day care.

Surgical day care patients

Required number of beds for several availabilities levels:

			Average situation				Peak situation			
Theme	1/μ	λ	99%	98%	95%	90%	99%	98%	95%	90%
1	0.40	3.80	6	5	5	4	7	6	5	5
2	0.36	1.52	4	3	3	2	4	4	3	2
3	0.38	1.35	4	3	3	2	4	3	3	2
4	0.39	3.77	6	5	4	4	7	6	5	5
5	0.00	0.00								
6 adult	0.40	2.53	5	4	4	3	5	5	4	3
Total			**25**	**20**	**19**	**15**	**27**	**24**	**20**	**17**

Corresponding efficiencies:

			Average situation				Peak situation			
Theme	1/μ	λ	99%	98%	95%	90%	99%	98%	95%	90%
1	0.40	3.80	25.5%	30.3%	30.3%	36.5%	54.4%	63.4%	76.1%	76.1%
2	0.36	1.52	13.7%	18.1%	18.1%	25.1%	37.9%	37.9%	50.6%	75.9%
3	0.38	1.35	12.8%	16.9%	16.9%	23.7%	33.7%	45.0%	45.0%	67.4%
4	0.39	3.77	24.4%	29.0%	35.0%	35.0%	53.9%	62.8%	75.4%	75.4%
5	0.00	0.00								
6 adult	0.40	2.53	19.9%	24.6%	24.6%	31.3%	50.6%	50.6%	63.2%	84.3%

Also, we determined the recommended capacity when we make the trade-off between availability and efficiency, by optimizing the sum of availability and efficiency:

	Average situation			Peak situation		
Theme	Capacity	Availability	Efficiency	Capacity	Availability	Efficiency
1	4	94.9%	36.5%	4	89.6%	95.1%
2	3	98.4%	18.1%	1	73.7%	100.0%
3	2	92.0%	23.7%	1	77.4%	100.0%
4	4	95.5%	35.0%	4	89.8%	94.3%
5						
6 adult	3	93.7%	31.3%	2	78.9%	100.0%
Total	**16**			**12**		

Non-surgical day care patients

Required number of beds for several availabilities levels:

			Average situation				Peak situation			
Theme	$1/\mu$	λ	99%	98%	95%	90%	99%	98%	95%	90%
1	0.34	4.34	6	5	4	4	8	7	6	5
2	0.38	28.25	19	18	16	14	35	33	30	27
3	0.36	29.33	19	17	15	13	36	34	31	28
4	0.40	2.36	5	4	4	3	5	5	4	3
5	0.37	2.85	5	4	4	3	6	5	4	4
6 adult	0.36	6.95	7	7	6	5	11	10	9	7
Total			**61**	**55**	**49**	**42**	**101**	**94**	**84**	**74**

Corresponding efficiencies:

			Average situation				Peak situation			
Theme	$1/\mu$	λ	99%	98%	95%	90%	99%	98%	95%	90%
1	0.34	4.34	24.2%	28.8%	34.8%	34.8%	54.2%	62.0%	72.3%	86.7%
2	0.38	28.25	56.6%	59.4%	65.3%	71.2%	80.7%	85.6%	94.2%	100.0%
3	0.36	29.33	54.6%	60.3%	66.4%	72.4%	81.5%	86.3%	94.6%	100.0%
4	0.40	2.36	29.3%	36.2%	36.2%	46.2%	47.1%	47.1%	58.9%	78.5%
5	0.37	2.85	21.1%	26.0%	26.0%	32.9%	47.4%	56.9%	71.2%	71.2%
6 adult	0.36	6.95	35.2%	35.2%	40.3%	46.3%	63.2%	69.5%	77.2%	99.3%

The recommended capacity when we make the trade-off between availability and efficiency (by optimizing the sum of availability and efficiency) is as follows:

	Average situation			Peak situation		
Theme	Capacity	Availability	Efficiency	Capacity	Availability	Efficiency
1	4	95.5%	34.8%	4	85.5%	100.0%
2	14	92.0%	71.2%	28	93.6%	100.0%
3	14	93.1%	69.4%	29	93.5%	100.0%
4	2	81.5%	59.8%	2	81.3%	100.0%
5	3	93.0%	32.9%	3	88.7%	94.9%
6 adult	5	93.1%	46.3%	7	90.2%	99.3%
Total	**42**			**73**		

Appendix N: Day care capacity 2008

This appendix focuses on the consequences of using patient admission data of 2008 instead of 2007, for day care patients. Namely, using this data results in deviated $1/\lambda$'s and μ's (shown in section 10.3.2).
We display the new required capacities to achieve certain availability levels (and the corresponding efficiency rates) in case each theme would establish a separate department for surgical day care patients and one for non-surgical day care.

Surgical day care patients

Required number of beds for several availabilities levels:

			Average situation				Peak situation			
Theme	$1/\mu$	λ	99%	98%	95%	90%	99%	98%	95%	90%
1	0.41	5.85	7	7	6	5	10	9	8	6
2	0.37	1.98	4	4	3	3	5	4	3	3
3	0.40	1.66	4	4	3	3	4	4	3	2
4	0.39	3.73	6	5	4	4	7	6	5	4
5	0.00	0.00								
6 adult	0.40	2.81	5	5	4	3	6	5	4	4
6 child	0.41	8.97	9	9	7	6	13	12	11	9
Total			35	34	27	24	45	40	34	28

Corresponding efficiencies:

			Average situation				Peak situation			
Theme	$1/\mu$	λ	99%	98%	95%	90%	99%	98%	95%	90%
1	0.41	5.85	33.6%	33.6%	38.6%	44.6%	58.5%	65.0%	73.1%	97.5%
2	0.37	1.98	18.0%	18.0%	23.4%	23.4%	39.5%	49.4%	65.9%	65.9%
3	0.40	1.66	16.5%	16.5%	21.5%	21.5%	41.6%	41.6%	55.4%	83.1%
4	0.39	3.73	23.9%	28.4%	34.4%	34.4%	53.3%	62.1%	74.6%	93.2%
5	0.00	0.00								
6 adult	0.40	2.81	22.1%	22.1%	27.2%	34.2%	46.8%	56.2%	70.2%	70.2%
6 child	0.41	8.97	40.9%	40.9%	50.4%	55.9%	69.0%	74.7%	81.5%	99.7%

Also, we determined the recommended capacity when we make the trade-off between availability and efficiency, by optimizing the sum of availability and efficiency:

	Average situation			Peak situation		
Theme	Capacity	Availability	Efficiency	Capacity	Availability	Efficiency
1	5	94.0%	44.6%	6	97.7%	38.6%
2	3	96.9%	23.4%	2	86.8%	31.5%
3	3	97.5%	21.5%	2	88.3%	29.2%
4	4	95.7%	34.4%	4	95.7%	34.4%
5						
6 adult	3	92.3%	34.2%	3	92.3%	34.2%
6 child	6	90.3%	55.9%	9	99.1%	40.9%
Total	24			26		

Non-surgical day care patients

Required number of beds for several availabilities levels:

			Average situation				Peak situation			
Theme	1/μ	λ	99%	98%	95%	90%	99%	98%	95%	90%
1	0.31	8.87	8	7	6	5	13	12	11	9
2	0.47	28.43	22	21	18	16	35	33	30	27
3	0.35	28.84	18	17	15	13	35	33	30	27
4	0.00	0.00								
5	0.31	3.05	5	4	4	3	6	6	5	4
6 adult	0.36	6.79	7	7	6	5	11	10	9	7
6 child	0.39	11.83	11	10	9	7	17	15	14	12
Total			**71**	**66**	**58**	**49**	**117**	**109**	**99**	**86**

Corresponding efficiencies:

			Average situation				Peak situation			
Theme	1/μ	λ	99%	98%	95%	90%	99%	98%	95%	90%
1	0.31	8.87	34.3%	38.8%	44.1%	50.2%	68.3%	73.9%	80.7%	98.6%
2	0.47	28.43	60.1%	62.6%	70.4%	75.3%	81.2%	86.1%	94.8%	100.0%
3	0.35	28.84	56.0%	58.9%	65.1%	71.2%	82.4%	87.4%	96.1%	100.0%
4	0.00	0.00								
5	0.31	3.05	19.1%	23.6%	23.6%	30.1%	50.8%	50.8%	61.0%	76.2%
6 adult	0.36	6.79	35.0%	35.0%	40.1%	46.1%	61.7%	67.9%	75.4%	96.9%
6 child	0.39	11.83	41.7%	45.5%	49.8%	59.5%	69.6%	78.9%	84.5%	98.6%

The recommended capacity when we make the trade-off between availability and efficiency (by optimizing the sum of availability and efficiency) is as follows:

	Average situation			Peak situation		
Theme	Capacity	Availability	Efficiency	Capacity	Availability	Efficiency
1	5	91.0%	50.2%	9	99.8%	30.6%
2	17	93.1%	72.9%	28	100.0%	47.6%
3	13	91.0%	71.2%	29	100.0%	35.1%
4						
5	3	94.3%	30.1%	3	94.3%	30.1%
6 adult	5	93.2%	46.1%	7	99.0%	35.0%
6 child	7	90.4%	59.5%	12	99.8%	38.3%
Total	**50**			**88**		

Appendix O: Two Sample t-test to compare LOS and arrival rate of 2007 and 2008

Section 10.5 evaluates whether this data of 2007 also represents the future situation.
To support this analysis, this appendix determines if the patients average LOSs and average arrival rates of 2008 significantly differ from those in 2007.
We execute of independent groups t-tests to compare the means of two groups (2007 and 2008), where each group consists of non-related observations. In this case, sample sizes between groups do not have to be equal.

The hypotheses for the comparison of the means from the two independent groups are:
H0: $\mu 1 = \mu 2$ means of the two groups are equal
H1: $\mu 1 \neq \mu 2$ means are not equal

The test statistic is a student's t-test with N-2 degrees of freedom, where N is the total number of observations. A low p-value indicates evidence to reject the null hypothesis in favor of the alternative. In other words, there is evidence that the means are not equal.

There are two kinds of t-tests: one that assumes equal variances and the other that that assumes unequal variances. We perform an F-test to determine equality of variance and subsequently execute the appropriate t-test.
In case the one-tail p-value of the F-test exceeds 0.05, we conclude the variances are not equal and proceed with the t-test that assumes non-equal variances.

For both types of t-tests, we evaluate whether the p-value is less or more than 0.05. In case the p-value is less than 0.05, this provides evidence to reject the null hypothesis of equal means. If the p-value exceeds 0.05, there is no reason to reject the null hypothesis and differences are not significant.

Below, we display the results of all t-tests performed. For both clinical and day care patients, we determined whether differences in LOS and number of daily arrivals are significant.
The numbers are printed in red if the p-value of the t-test is below 0.05, which indicate it concern a significant difference.

Clinical patients

Length of stay

	2007			2008			F-test 2 Sample for variance			T-test		
Theme	mean	SD	n	mean	SD	n	F	p-value	Variances	df	t Stat	p-value
1	5.77	9.13	4032	5.61	9.41	4080	0.94	0.03	Unequal	8108	0.77	0.44
2	6.42	10.32	5702	6.16	9.26	5649	1.24	0.00	Unequal	11241	1.43	0.15
3	8.32	12.18	6198	7.55	10.81	6380	1.27	0.00	Unequal	12308	3.72	0.00
4	5.91	10.09	3183	5.75	8.68	3054	1.35	0.00	Unequal	6162	0.66	0.51
5	6.22	12.57	4887	4.86	9.02	5798	1.94	0.00	Unequal	8668	6.28	0.00
6a	4.15	5.52	4911	3.91	5.54	5310	0.99	0.42	Equal	10219	2.14	0.03
6c	7.22	15.14	5630	6.61	13.67	5889	1.23	0.00	Unequal	11275	2.26	0.02

Number of daily admissions

	2007			2008			F-test 2 Sample for variance			T-test		
Theme	mean	SD	n	mean	SD	n	F	p-value	Variances	df	t Stat	p-value
1	11.05	5.00	365	11.15	5.51	366	0.82	0.03	Unequal	723	-0.26	0.80
2	15.62	10.13	365	15.43	9.77	366	1.08	0.25	Equal	729	0.25	0.80
3	16.98	8.87	365	17.43	8.62	366	1.06	0.29	Equal	729	-0.70	0.49
4	8.72	4.85	365	8.34	4.84	366	1.00	0.49	Equal	729	1.05	0.29
5	13.39	7.68	365	15.84	7.71	366	0.99	0.47	Equal	729	-4.31	0.00
6a	13.45	5.92	365	14.51	5.82	366	1.03	0.38	Equal	729	-2.43	0.02
6c	15.42	6.85	365	16.09	7.22	366	0.90	0.16	Equal	729	-1.28	0.20

Surgical day care patients

Length of stay

	2007			2008			F-test 2 Sample for variance			T-test		
Theme	mean	SD	n	mean	SD	n	F	p-value	Variances	df	t Stat	p-value
1	0.41	0.04	924	0.41	0.05	1533	0.55	0.00	Unequal	2352	1.74	0.08
2	0.36	0.08	470	0.37	0.09	516	0.83	0.02	Unequal	984	-0.85	0.40
3	0.38	0.04	315	0.40	0.04	434	1.41	0.00	Unequal	604	-7.65	0.00
4	0.39	0.06	968	0.39	0.06	976	0.98	0.37	Equal	1942	0.00	0.06
5												
6a	0.40	0.05	709	0.40	0.05	733	0.92	0.12	Equal	1440	-0.14	0.89
6c	0.41	0.04	2244	0.41	0.08	2341	0.33	0.00	Unequal	3779	-3.76	0.00

Number of daily arrivals

	2007			2008			F-test 2 Sample for variance			T-test		
Theme	mean	SD	n	mean	SD	n	F	p-value	Variances	df	t Stat	p-value
1	3.54	3.43	261	5.85	4.24	261	0.65	0.00	Unequal	498	-6.85	0.00
2	1.80	1.56	261	1.98	1.72	261	0.82	0.06	Equal	520	0.00	0.11
3	1.21	2.72	261	1.66	3.67	261	0.55	0.00	Unequal	480	-1.61	0.11
4	3.70	3.47	261	3.73	3.36	261	1.06	0.31	Equal	520	0.00	0.47
5												
6a	2.72	2.58	261	2.81	2.68	261	0.92	0.26	Equal	520	-0.40	0.69
6c	8.52	3.93	261	8.97	3.81	261	1.06	0.31	Equal	520	0.00	0.09

Non-surgical day care patients

Length of stay

	2007			2008			F-test 2 Sample for variance			T-test		
Theme	mean	SD	n	mean	SD	n	F	p-value	Variances	df	t Stat	p-value
1	0.36	0.07	1766	0.31	0.12	2321	0.37	0.00	Unequal	3906	16.28	0.00
2	0.38	0.05	7760	0.47	4.21	7434	0.00	0.00	Unequal	7435	-1.76	0.08
3	0.36	0.08	7532	0.35	0.10	7546	0.60	0.00	Unequal	14192	3.62	0.00
4												
5	0.36	0.07	615	0.31	0.10	796	0.40	0.00	Unequal	1362	10.95	0.00
6a	0.36	0.10	1961	0.36	0.11	2091	0.91	0.02	Unequal	-2.42	0.01	1.96
6c	0.38	0.05	3153	0.39	0.07	3097	0.54	0.00	Unequal	5683	-5.71	0.00

Number of daily arrivals

	2007			2008			F-test 2 Sample for variance			T-test		
Theme	mean	SD	n	mean	SD	n	F	p-value	Variances	df	t Stat	p-value
1	6.74	4.02	261	8.87	4.62	261	0.76	0.01	Unequal	510	-5.63	0.00
2	29.70	8.30	261	28.43	9.39	261	0.78	0.02	Unequal	512	1.63	0.10
3	28.80	8.77	261	28.84	10.36	261	0.72	0.00	Unequal	506	-0.05	0.96
4												
5	2.32	2.09	261	3.05	2.33	261	0.80	0.04	Unequal	514	-3.76	0.00
6a	6.51	3.22	261	6.79	3.66	261	0.77	0.02	Unequal	512	-0.93	0.35
6c	12.02	4.50	261	11.83	4.71	261	0.91	0.23	Equal	520	0.46	1.96

Appendix P: Patient categories

In section 12.2, we evaluate whether day care patients of certain themes can be merged. To distinguish patient categories within each theme, we sort the patient according to their DBC description.
Striking is that the number of DBC categories is extensive for each theme. Below, we only display the top-10 for both clinical and day care patients for each theme. We also distinguish surgical from non-surgical day care, to see whether non-surgical day care has more in common with clinical care or with surgical day care. We conclude the similarities with both clinical care and surgical day care are rare.

Theme 1

Clinical care

Patient category	Amount
Unknown	393
neurologie, niet elders classificeerbaar*	385
onbekend	191
eenmalig poli(kl)consult muv second opinion	132
commotio | contusio cerebri*	109
multiple sclerose	94
Chronische otitis media	94
epilepsie gegeneraliseerd	91
cataract	87
onbloedige beroerte	87

Surgical day care

Patient category	Amount
cataract	428
Unknown	74
eenvoudige neurolyse van een perifere zenuw	61
incomitant scheelzien	58
onbekend	48
overige pathologie lens	25
Septumafwijkingen	23
primair glaucoom	20
Benigne tumor speekselklieren	16
Dysfonie	15

Non-surgical day care

Patient category	Amount
multiple sclerose	177
TIA (incl. amaurosis fugax)	144
spierziekten | myopathie	143
polyneuropathie infectieus (GBS | CIDP)	140
onbloedige beroerte	78
n. medianus (incl. CTS)	48
Unknown	35
polyneuropathie anderszins	34
myasthenia gravis + myasthene syndr.	33
leptomeningeale maligniteit	28

Theme 2

Clinical care

Patient category	Amount
maligniteit nno	486
maligniteit cervix	287
Unknown	267
maligniteit hoofd-hals	214
AML/RAEB-t	210
maligniteit colorectaal	208
maligniteit mamma	174
maligne neoplasma mamma	146
maligniteit weke delen	144
maligniteit ovarium | tuba	135

Surgical day care

Patient category	Amount
Maligne larynxtumoren stadium I en II	50
maligne melanoom huid	38
blaas/RIP maligne/papillair	36
maligne neoplasma mamma	35
maligne neoplasma weke delen	33
Maligne larynxtumoren stadium III en IV	30
Maligne oropharynx tumor stadium III en IV	26
Maligne hypopharynxtumor stadium III en IV	22
benigne neoplasma mamma	17
Maligne oropharynx tumor stadium I en II	15

Non-surgical day care

Patient category	Amount
maligniteit mamma	1599
AML/RAEB-t	619
multipel myeloom	528
maligniteit slokdarm | cardia	501
maligniteit ovarium	338
maligniteit colorectaal	310
NHL SLL/imcyt.-Wald.str/foll.centr.grl-II/MAL	306
Hodgkin lymfoom klassiek	285
aplastische anemie	191
ALL	189

Theme 3

Clinical care

Patient category	Amount
Unknown	821
analyse klacht nno zonder diagnose	313
niertransplantatie	310
maligne neoplasma oesophagus	125
nacontrole levertransplantatie	124
voorbereiding levertransplantatie	124
maligne neoplasma lever secundair	109
onbekend	104
overige nierziekten nno	100
overige endocriene en metabole aandoeningen	85

Surgical day care

Patient category	Amount
hernia inguinalis	64
Unknown	55
varices van onderste extremiteiten	28
cholelithiasis	26
hernia umbilicalis	10
ganglion, groot lipoom, unguis incarn.	10
sinus pilonidalis	10
hemorrhoiden	10
hernia inguinalis recidief	7
huid en subcutis aspecifiek	6

Non-surgical day care

Patient category	Amount
Unknown	1532
m. Crohn	765
overige endocriene en metabole aandoeningen	639
carcinoma basocellulare	505
varicosis nno	388
nacontrole levertransplantatie	244
adenomateuze poliepen*	228
colitis ulcerosa*	197
onbekend	176
prikkelbaar darmsyndroom +- diverticulose*	149

Theme 4

Clinical care

Patient category	Amount
Unknown	392
arthrosis	240
post-traumatische afwijking	96
traumascreening n.n.o.	86
multitrauma n.n.o.	85
h def wo FG>3%/sl def ax lap	69
loslating | infectie | malpositie prothese	60
voorste kruisbandlesie	59
tibia (+- fibula) n.n.o. (excl. enkel)	42
enkel: Weber B/C	41

Surgical day care

Patient category	Amount
Unknown	101
meniscuslaesie	44
post-traumatische afwijking	36
Hallux valgus	30
arthrosis	29
te verwijderen osteosynthesemateriaal	27
bleph.plast,onder/bov enk/dubz	27
tenolyse	23
behandeling neuroom, zenuw tumor	22
sel fasciectomie,tr/tr 1straal	19

Non-surgical day care

Patient category	Amount
Perifere zenuwpijn (incl. PHN)	139
Complex regionaal pijn syndroom	115
Unknown	66
Mechanisch|discogene lage rugklacht	55
(Chronisch) degeneratieve lage rugklacht	51
Neurogene lage rugklacht	33
Overig	28
Myofasciaal pijnsyndroom | tendinitis	25
(Chronisch) degeneratief cervicaal	18
Sacraal pijnsyndroom	15

Theme 5

Clinical care

Patient category	Amount
Unknown	982
CABG, vene grafts en max. 1 arteriele graft	305
angina pectoris, stabiel	192
atrium fibrilleren | flutter	180
onbekend	168
COPD	165
ventriculaire hartritmestoornissen	151
chronisch hartfalen	148
Interstitiele aandoeningen	124
overige supraventriculaire hartritmestoorniss	122

Non-surgical day care

Patient category	Amount
Unknown	252
Tumoren NSCLC	69
geen aanwijzingen voor cardiale afwijkingen	43
hartklepafwijkingen	42
angina pectoris, stabiel	37
Pleurale aandoeningen	30
atrium fibrilleren | flutter	25
onbekend	22
chronisch hartfalen	21
thoracale klachten eci	17

Theme 6 adult

Clinical care

Patient category	Amount
Unknown	2959
overigen, gezond geen pathologie	474
nier/stenen/overig	109
cyclusstoornis	88
orienterend fertiliteitsond.| basale beh.vrou	86
incontinentie | prolaps	74
onbekend	61
uterus myomatosus	60
prostaat&ves.sem./RIP maligne/NUnknownMUnknown	59
benigne adnexafwijking	58

Surgical day care

Patient category	Amount
nier/stenen/overig	246
ureter/stenen/nno	120
testis&epid./infertiliteit/na vas.	58
Unknown	49
onbekend	27
testis&epid./infertiliteit/testiculaire	15
testis&epid./infertiliteit/primair	15
testis&epid./infertiliteit/obstructie	12
scrotum/varicocele/nno	11
nier/stenen/infectie	10

Non-surgical day care

Patient category	Amount
gespecialiseerde technieken	728
cervixafwijking incl. afw. cervixcytologie	219
orienterend fertiliteitsond.| basale beh.vrou	178
begeleiding graviditeit in tweede lijn	160
cyclusstoornis	116
abortus missed	77
vulvaire en vaginale afwijkingen	53
begeleiding partus met nazorg en nacontrole	50
begeleiding graviditeit in derde lijn	48
Unknown	48