MASTER

Integrated decision making with regard to capacity and patient planning

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Integrated decision making with regard to capacity and patient planning

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Abstract

This study follows an integrated approach to decision making with regard to capacity and patient planning over multiple departments in a hospital. Interactions between departments are analysed, and decoupling points revealed. A model is developed with the aim to optimize patient planning and capacity. The model is a mixed integer linear programming problem, which minimizes the over- and underutilization at different resources by obtaining an optimal tactical week plan for patient admission and including stochastic length of stay. To verify and validate the model in terms of minimizing over- and underutilization but also on quality and costs, a case study is conducted at Maasziekenhuis Pantein (MZH) in Beugen, the Netherlands, and a decision support tool is developed. Two main departments are considered: the Operating Theatres department and the wards, and one specialty is considered: surgery. In this study a valid decision support tool is developed to optimize patient planning and capacity for multiple departments. Furthermore, results have indicated that implementing the model has a positive effect on costs and quality.

Preface and Acknowledgements

A big gain in knowledge about healthcare, process improvement, and a further discovery about my interests. That's a summary of what this master thesis project has contributed to me in a nutshell.

I have always really liked the subject and after this project I feel I now have a better intuition what is possible in practice and what may be very difficult. Also, I better understand the structure of a company, in my case a hospital, and how it operates. Especially, because my research assignment was initially hospital-wide, and I cooperated with people from many units of the hospital and from the department of Finance & Control (F&C): a department not only covering the hospital but also for example home care. My skills developed during the courses have now been put into practice.

During the project, I was glad I could laugh with my colleagues at F&C, like the weeks after the yearly department activity, where each of us sketched another colleague in seven minutes. After finishing this outline, we coloured the paintings which ended up to be really nice pictures. The weeks after everyone could still laugh a few minutes by only looking at the paintings again. Nice, to think about something else but the master thesis project.

After a few months we switched from supervisor, mainly due to the available time for supervising. Gertjan, I am thankful for how you guided me in setting up the project. Rob, I am grateful for the time you had for me, and especially the way you helped me by really thinking along with me in giving the project a clear direction, but also by suggesting with who in the hospital I should have a talk and being very supportive in providing information and tips. I would also like to thank the other people in the hospital who answered all my questions.

Moreover, thanks to Henny van Ooijen, my supervisor from the TU/e. Despite the content, the length of the meeting, and how many questions I had, you always knew how to trigger me in such a way that after the meeting I felt full of inspiration and had new energy for my project. My second supervisor Ad Kleingeld, thanks for your comments and interest in my project. Emphasizing quality makes the project more useful and relevant.

During the master thesis, I enjoyed the time with my friends and family, to relax and talk about everything but my project in the evenings and weekends. However, I also liked the discussion with them about my project coming from an outsider: it gave me new insights. And last but not least, I would like to thank my boyfriend Tom for encouraging me to do what I like and aspire.

Thank you all!

Jacqueline Trommelen,

Eindhoven, The Netherlands

Management Summary

Problem introduction

This research is conducted at Maasziekenhuis Pantein (MZH) in Beugen, Noord-Brabant, The Netherlands. The management argues that performance can be increased by analysing what kind of resources its patients use at different departments, so that they can optimize their capacity in meeting the demand. Therefore, this study focuses on optimizing patient planning and capacity in hospitals over different departments. Integrated capacity management is increasingly important in scientific literature. However, actually implementing the strategies concerning integrated capacity management, and optimizing hospital-wide is little known about.

This led to the following research question:

How can a decision support tool be developed to optimize patient planning and capacity for multiple departments in a hospital?

Methodology

To answer the research question the following method was used (based on the model developed by Sagasti & Mitroff (1973):

<u>Conceptualization</u>

- A detailed analysis of the current situation in MZH was performed.
- A literature review was conducted to summarize the current methods of optimizing patient demand and capacity over different departments.
- The interactions between departments in the hospital were modelled

<u>Building the scientific model</u>

A Mixed Integer Linear Programming model was developed to optimize patient planning and capacity over multiple departments, and implemented in a decision support tool. The model is built in MS Excel, by using an add-in of AIMMS.

<u>Solving the scientific model</u>

To verify and validate the decision support tool, a case study at MZH was conducted.

- Patients were assigned to groups having mostly the same resource requirements.
- Capacity of departments was determined.
- Scenarios were evaluated to find the impact of decisions at strategic level.
- The effects of the model on quality was analysed for MZH
- The results of the model were analysed to conclude about the possible costs savings when implementing the model

<u>Implementing the results of the model</u>

The way the decision support tool should be used at the operational level was examined.

Case study at Maasziekenhuis Pantein

MZH can be classified as a ‘basic hospital’ (basisziekenhuis) which indicates a hospital with 150-300 beds (Boot & Knapen, 2005). This study focused on surgery patients undergoing an operation and included the OT department and the wards. Elective patients were classified according their subspecialty and their expected length of stay (LOS). This resulted in 10 patient groups as specified in the table below.

Patient group	Subspecialty surgery	LOS	Average number per week in 2014	Percentage total (%)	Surgery duration + changing time	
					Mean	Standard deviation
1	General surgery and surgery for children	0-1	10	33	61	21
2		2-5	3	10	75	33
3		>5	1	3	115	42
4	Traumatology and emergency	0-1	3	10	64	31
5		2-5	2	7	96	47
6		>5	1	3	123	55
7	Oncology, lungs, gastrointestinal surgery	0-1	2	7	75	26
8		2-5	5	17	97	30
9		>5	2	7	161	67
10	Vascular surgery	>0	1	3	84	46

Results

The decision support tool correctly captures the objective to optimize patient planning and capacity over different departments. The model has provided an optimal admission scheme for elective surgery patients in MZH. Therefore, the decision support tool is able to support the management of MZH in optimizing patient and capacity planning at the tactical level. An optimal admission profile is generated for patients per patient group to be admitted at which day of the week. This means a profile that results in the smallest possible deviation between the realised and the target resource utilisation, while the total available capacity of the different resource is exceeded as little as possible, the target patient throughput is met and the given restrictions are not violated. Besides this, the tool gives an overview of the use of resources.

Scenarios

Three different scenarios are tested to review on three decisions that could be made at the strategic level, in comparison to the basic scenario presented. These scenarios are: expanding operating room capacity to 7 PM, lower capacity in the weekends to avoid costs, and no restrictions of patient groups per day. It has been concluded that applying the basic situation works best in terms of minimizing over- and underutilization for MZH. Besides this, the optimal patient admission scheme is determined for 2015.

Quality

The effects of the model have also been expressed in terms of quality. Different elements of quality, developed by the Institute of Medicine (2001), increase by applying the model. More specifically safety, patient-centeredness, timeliness, and efficiency increase, effectiveness and equity are indifferent.

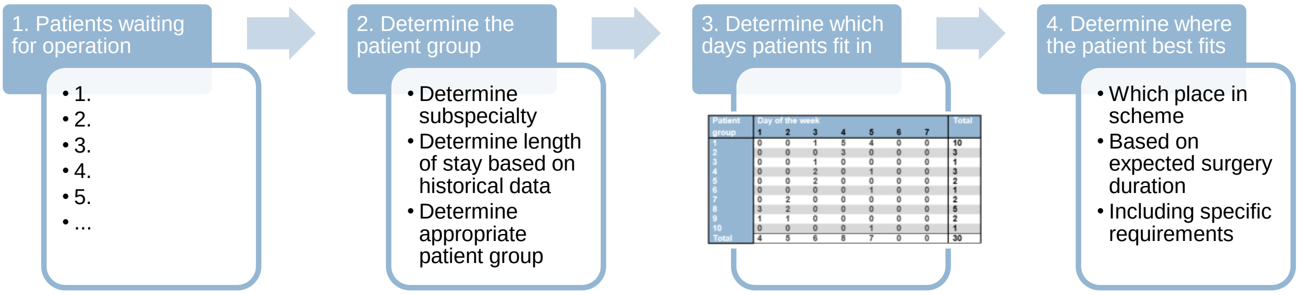
Costs

By implementing the decision support tool, cost savings could be over €100.000. The costs are expressed as reduces in misplacements and number of nurses due to stabilizing processes.

Operationalization of the model

If nothing changes during the year, managers should normally use the tool once a year to set the appropriate capacity and find an optimal admission scheme. The figure below, shows the method to plan patients according to the optimal patient admission scheme.

Action plan for planners



Conclusion and recommendations

Conclusions

This study has developed a valid decision support tool which optimizes patient planning and capacity over different departments. The decision support tool is general and therefore applicable to all hospitals. Finally the impact of the model on costs and quality is analysed, which seems to be positive. This study has therefore analysed to what extent implementing the model contributes to saving costs and improving quality. The information provided by the decision support tool can be used in discussions about capacity and patient demand in decision making.

Theoretical contributions

The mathematical model which minimizes over- and underutilization is applicable to each department of the hospital. A case study is performed to test this model, which lead to insights of the associated aspects of the model meaning costs, quality, and operational implementation.

Practical recommendations

For MZH, this study has given insight in the current processes, how much patients are arriving at the hospital for surgery and what resources they need. It is recommended that MZH should firstly implement the optimal planning for admission of patients as it has many benefits. After testing and evaluating on the performance of the new planning, further implementation should be about the calculations of other specialisms. When the OT department and wards are optimized, the demand and supply in other departments can be stabilized, using the model.

List of Abbreviations

IC	Intensive Care
LOS	Length Of Stay
MILP	Mixed Integer Linear Programming
MSS	Master Surgery Schedule
MZH	Maasziekenhuis Pantein
N-P ratio	Nurse-patient ratio
OR	Operating Room
OT Department	Operating Theatres Department

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1. Introduction

This master thesis contains the results of a research on decision making with regard to capacity and patient planning within the Maasziekenhuis Pantein (MZH) in Beugen, The Netherlands.

As the population ages, and competition rises, hospitals face the pressure to revise their processes to save costs and improve quality. Therefore, the last decennia hospitals focus increasingly on efficiency, and try emphasize this to their employees, to eventually use resources more intensively. To gain more efficiency literature focuses increasingly on integrated decision making (Adan et al., 2011; Hulshof, 2013; Drupsteen, van der Vaart, & van Donk, 2013; Helm and Van Oyen, 2014).

This study focuses on improving the use of capacity across all resources in a hospital, which is also integrated decision making. As most healthcare institutes, MZH faces also an increasing pressure to reduce costs, and sees that one way of realizing that is by managing processes more efficiently, and gain productivity, resulting in an increasing performance.

1.1 Research environment

This research is conducted at Maasziekenhuis Pantein (MZH), located in Beugen and supervised by F&C (Finance & Control). The MZH is part of a larger organisation Stichting Pantein. Stichting Pantein consists of care organisations including Maasziekenhuis Pantein, Zorgcentra Pantein, Thuiszorg Pantein, and the organisation Servicebedrijf Pantein (Appendix 1). Thuiszorg includes also maternity care. With a hospital, care centers, maternity care and home care, it has one of the broadest portfolios of care in the Netherlands. It is a collection of independently operating companies, but led by the general management of Pantein (Pantein, 2015). Pantein is a foundation and aims to offer customized care, to everyone with needs in the fields of health, housing, welfare, and care. Their strategy for 2013-2017 is:

“To provide excellent care close to the customer in all of our thinking and doing.”

In 2014, MZH had 619 employees (410 FTE), excluding the specialists. In 2014, 72 specialists (55 FTE) were working at MZH. The working area of MZH is a rural area and includes the muncipalities: Mook&Middelaar, Gennep, Cuijk, Grave, Mill, Sint Anthonis, Boxmeer and Bergen. MZH can be classified as a ‘basic hospital’ (basisziekenhuis) which indicates a hospital with 150-300 beds (Boot & Knapen, 2005), because the number of beds available for clinical capacity and day treatment was 167 in 2013 and 2014. Furthermore, MZH positions itself as a network hospital within a construction with the Radboudumc and the St. Maartenskliniek. Some departments of MZH are vulnerable in terms of volume and quality, since it is a small hospital. Cooperating can therefore be beneficial. MZH has moved to a new building in April 2011. Therefore, the hospital itself is relatively new. While designing the new hospital, how to manage people and goods efficiently through the hospital was one of the major concerns. The hospital is divided in three centres, which are managed by three centre managers. These three centres are split up in departments which are led by team managers. The organizational structure of MZH is presented in Appendix 1.

MZH provides the following specialties:

- Cardiology
- Dermatology
- Gynaecology
- Internal Medicine
- Oral Surgery
- Ear, Nose and Throat
- Paediatrics
- Clinical Chemistry
- Clinical Pathology[1]
- Clinical Pharmacology[2]
- Medical Microbiology [2]
- Medical psychology
- Neurology
- Ophthalmology
- Orthopaedics[3]
- Psychiatry[4]
- Pulmonology
- Radio Diagnostics
- Rheumatology[4]
- Rehabilitation[4]
- Surgery
- Urology
- Obstetrics

The annual report of Pantein gives number about the longest waiting time in MZH, which is registered for the specialism Oral Surgery for both outpatient and inpatient, with in 2014 respectively 10 and 12 weeks. The rest of the specialties varies between 1 and 4 for inpatient and 1-8 for inpatient.

The growth potential concerning customer satisfaction of MZH in 2013 was +12[5], while the national average was -12, which indicates that the customer satisfaction of MZH is good compared to the national average (Pantein, 2014). Table 1 shows numbers about the staff of the MZH (Pantein, 2014; Pantein, 2015).

Finally, the building hospital is structured like Figure 1.1, with five floors and the wings A-D for the first four floors. Floor five has only wing B and C. MZH has four ORs and two Outpatient ORs, for small surgery.

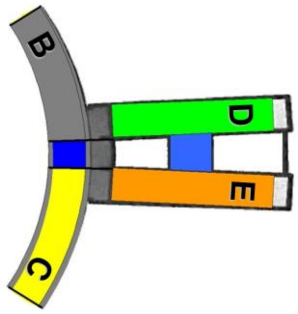

Figure 1.1: Building structure of MZH

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[1] Clinical Pathology and Medical Microbiology are outsourced to UMC St Radboud in Nijmegen in 2009.

[2] Brocacef Ziekenhuisfarmacie provides the hospital pharmacy

[3] Cooperation with St. Maartenskliniek in Nijmegen.

[4] Pantein and GGZ Brabant Noord-Oost form GGZ Center Land van Cuijk and Noord-Limburg, which provides the specialty psychiatry.

[5] Net Promotor Score (NPS) is a management tool to get a clear measure of the company's performance through the customers' eyes, by asking one question: 'How likely is it that you would recommend [the company] to a friend or colleague?'. The customers respond on a 0-10 point rating scale (The Net Promoter Community, 2015). The measure +12 shows the grow potential concerning customer satisfaction. This measure can vary between -100 and +100.

1.2 Trends hospital care

Figure 1.2 compares the trend of healthcare costs with the national income. It demonstrates that in 30 years the healthcare costs are tripled, while the income only slightly increases (Bos, Koevoets, & Oosterwaal, 2011). This fact indicates the necessity of reorganizing and restructuring healthcare. Healthcare processes need to be organized more efficiently to keep healthcare payable.

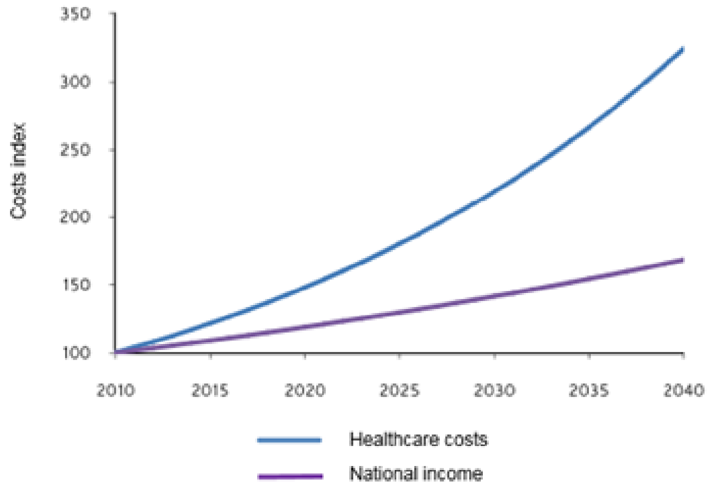

Figure 1.2: Trend healthcare costs in the Netherlands on a 100 point scale (Source: CBS, 2011)

1.3 Thesis outline

The structure of this report is as follows: first the research assignment is determined (Chapter 2), then a detailed analysis of the problem is given which includes an analysis of the current situation, interdependencies within a hospital and a description of the conceptual model is (Chapter 3). This is followed by the mathematical formulation of the model developed in this study (Chapter 4). As the model is found to be correct, several scenarios are applied for MZH, which they can use to decide upon capacity usage. Then, a case study is conducted to validate and verify the model (Chapter 5). In addition to this, this is followed by chapters about the effects on quality, the costs involved, and how to use the model at operational level (Chapter 7, 8 & 9). The conclusion and recommendations end the master thesis (Chapter 10). Finally, the references are listed (Chapter 11).

2. Research assignment

This chapter discusses the content of the research assignment. Section 2.1 gives the problem statement, which includes a further background of the problem MZH faces. In Section 2.2 related literature to this problem is discussed. Then, the objectives of the research are presented in Section 2.3, including the research question and the research assignment. Section 2.4 gives the methodology used in this study. Finally, Section 2.5 gives an overview of the scope.

2.1 Problem statement

MZH feels pressure to organize its processes more efficiently to save costs. The management argues that performance can be increased by analysing what kind of resources its patients use, so that they can optimize their capacity in meeting the demand. In interviews in MZH, people indicate surprises in demand, and lack of information about where to start improving. Currently, patients are flowing through the hospital but no clear information exists about numbers and routes. When the amounts and routes are known, better decisions about for example the occupancy rates, admission of patients, and scheduling staff could be made. The main goal of this project is therefore to help the management in decision making concerning capacity and patient planning over multiple departments.

It is also important how the hospital is currently managing and monitoring the performance. Moreover, we need to identify to what extent the departments are already organizing processes with improving performance as a goal and where might be room for improvement. The processes in the hospital seem to be mostly managed by an ad hoc work approach and this leads to no insight into the consequences of the measures taken. One cause of this problem is that the departments in the hospital operate independently of each other. Probably, optimizing resources between the different departments might raise performance.

2.2 Related literature

In this section, first the definitions of the concepts productivity, efficiency, effectiveness, and performance are clarified (Section 2.2.1). Secondly, unit, chain and network logistics are discussed (Section 2.2.2). Then, the resource interactions are discussed, followed by literature discussing model encompassing multiple departments (Section 2.2.4). Finally the research gaps are identified, related to the problem in MZH (Section 2.2.5).

2.2.1 Defining productivity, efficiency, effectiveness and performance

This study is concerned with optimizing patient admission and capacity over multiple departments in a hospital. Considering this topic, it is interesting to know how related performance measures are defined, because optimizing the patient admission and capacity is done to improve performance. The terms productivity, efficiency, effectiveness and performance are often mixed. In 't Veld & Slatius (2010) give a clear overview of the different definitions. Table 2.1 shows the formulas.

Table 2.1: Definitions of productivity, efficiency, effectiveness, and performance

Concept	*Definition*
Productivity	$\frac{R_{real}}{O_{real}} = P_{real}$
Efficiency	$\frac{O_{norm}}{O_{real}}$
Effectiveness	$\frac{R_{real}}{R_{norm}}$
Performance	$\frac{P_{real}}{P_{norm}}$

Note: R = Result, O = Offer

$Real$ stands for the actual result, so not what is expected before. So, R_{real} represents the actual result of the output. For example, the amount of cookies baked in a factory per day. O_{real} represents the actual offer, which means everything we need to get something done. Examples are: money, effort, manpower, materials, resources, time et cetera. In the cookies factory, this could be the number of people working per day. $Norm$ represents the expected value. So, O_{norm} represents the expected or preferred amount of offers needed and R_{norm} the expected or preferred result. P_{norm} represents the expected or preferred performance.

The concepts are strongly related, as a gain in productivity, could give a gain in efficiency, effectiveness and performance as well. This can be seen in the formulas as all parameters of productivity come back in the other three concepts. In ’t Veld & Slatius (2010) note that it is important to determine if the current processes are effective. First, one has to do the right tasks (core business), then the tasks in a right way (delivering quality and being effective), and finally the tasks could be organized faster or cheaper (being efficient).

2.2.2 Unit, chain and network logistics

To improve performance, processes need to be reorganized, which might give an increase in P_{real}. Processes in a hospital can be viewed from two perspectives. A process can be managed from the view of a department, for example to utilize the beds as much as possible. It can also be viewed from the patient, which could have an objective of for example to minimize the waiting time. This is called respectively the unit perspective and chain perspective. The unit perspective discusses issues surrounding the allocation and control of resources within units. High occupancy level or use is seen as an important indicator of the ‘efficiency’ of the unit while balanced use is important not only for efficiency but also for the working climate of the personnel in the unit. Additional aims from the perspective of the unit are to produce the amount of output required with as few resources as possible or to produce as much output as possible with the amount of resources available. Chain logistics is comparable with the patient flow view and focuses on key uses surrounding the description and analysis of care chains. This implies the definition of the product to be delivered by the chain; the description of the operations in the chain and the duration of these operations and the coordination and planning of the different operations. Including both views is desirable. This is called network logistics. It combines the unit and the chain perspective and makes trade-offs between the service level provided in the chains and the utilisation of resources in the units. Integrated decision making can help to manage network logistics. Hulshof (2013) also argues that integrated decision making on all involved resources, taking into account a care chain perspective, is necessary.

2.2.3 Resource interactions

To manage processes, the type and number of resources in a hospital need to be clear. A hospital is a complex system consisting of many different patient flows and many types of resources. Furthermore, every patient is different: the care path is not only dependent on the diagnosis of the patient but many human-related factors are also substantial. Therefore, it is interesting to clarify the decisions related to resource allocation. These can be found in Figure 2.1. The figure shows the separation between inpatient and outpatient departments. Only the master surgery schedule connects them, because specialists are needed at both departments. Moreover, Figure 2.1 show how allocated resources are used for inpatient and outpatient production. It reflects the many interactions in the hospital system, requiring a concept of efficiency that focuses on the combined use of resources. At inpatient production, note that the Operations Theatres time-table determines when elective patients are admitted via admissions planning. This determines when the admitted patients will need a bed and nursing care. For the outpatient production, the outpatient department time-table is the driving force behind the outpatient production. This determines how scheduled patients get an appointment. This also determines when scheduled patients will require clinic resources and diagnostic department resources. Note that the OT time-table and the outpatient department time-table are linked via the specialty time-table. This time-table includes the availability of the specialists (Vissers, 1994).

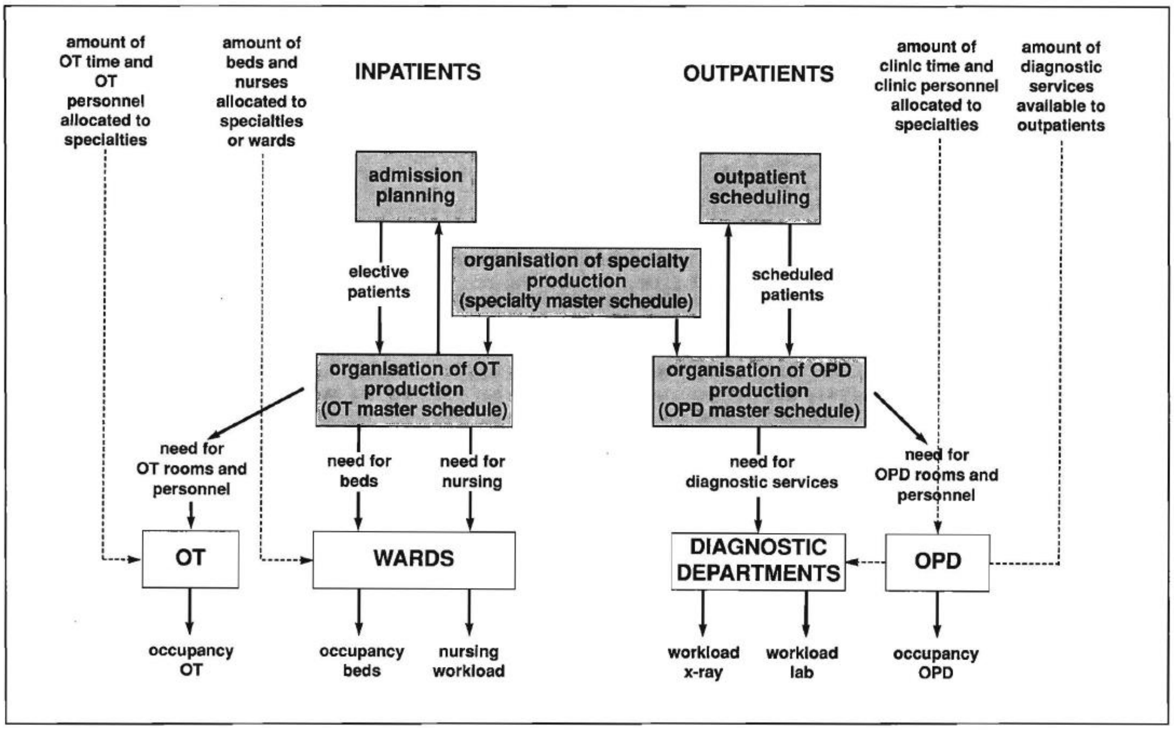

Figure 2.1: Representation of the hospital production system at resource allocation level (Vissers, 1994)

2.2.4 Models encompassing multiple departments

Figure 2.1 emphasizes the interrelatedness of different departments in a hospital. Therefore it is important to integrate capacity planning over the departments. An increasing number of authors address resource allocation across more than one department. Vissers and Beech (2005) approach the problem of patient flow planning for the OT (Operating Theatres) department, the IC and the ward. They developed an integer linear programming model to balance the workload of admission by taking into account the resource requirements of different patient categories within a specialty. Adan, Bekkers & Dellaert (2009) added stochastic length of stay to this model and successfully found that the stochastic duration turned out to decrease the deviations by more than 40%. Adan et al. (2011) also include arrival rates of emergency patients, to determine the needed reserved capacity. They also realise that if the average number of patient is equal to the maximum number that can be treated, the system will become instable in the end. Therefore they examine two strategies to obtain a feasible operational plan: slack planning and flexibility in patient groups. They conclude that their results are helpful in strategic decision making where hospitals determine their own focus in for example the degree of hospital efficiency and patient satisfaction. Hulshof et al. (2013) included the whole hospital in a Mixed Integer Linear Programming model, with the objective to minimize the waiting time. Helm & Van Oyen (2014) have developed a model to manage the hospital admission scheduling and control problem, and stabilizing processes in predicting patient volumes for elective patients by formulating a Poisson-arrival-location model. Ma & Demeulemeester also proposed a multilevel integrative approach to the planning problem (2013). Kortbeek et al. (2015) developed a generic analytical method that can support logistical decision making for inpatient care services by minimizing waiting time over all resources.

2.2.5 Gaps in the literature

To conclude, integrated decision making in hospital is an increasingly important topic. Recent papers focus on more than one department, but still not much research is available. Especially, research about optimizing hospital-wide, is mostly theoretical. Therefore, this study focuses on optimizing hospital-wide in redesigning and optimizing processes. Furthermore, few studies develop a decision support tool that can be used by hospitals to manage processes from the network logistics point of view. Moreover, most research focuses on improving efficiency, utilization or waiting time without including more than one performance measure. Also, other performance measures such as costs and quality are disregarded.

2.3 Objectives of the research

The aim of this research is to develop a solution to the problem of MZH, but also contribute to literature. Section 2.3.1 discusses how the research question is set. Section 2.3.2 gives an overview of the research assignment and the sub assignments.

2.3.1 Research question

After formulating the problem statement, we found that MZH was dealing with improving hospital-wide performance. Managers are interested in how patients are currently planned, how much capacity is needed, and how they should optimize this. Therefore, the purpose of this study is to optimize patient planning and capacity. Furthermore, in literature is not much research available about optimizing hospitals hospital-wide. Therefore, the main goal for this

study is to optimize patient planning and capacity for multiple departments. To be able to control processes a decision support tool covering this goal is developed.
So, the research question of this project is:

How can a decision support tool be developed to optimize patient planning and capacity for multiple departments in a hospital?

2.3.2 Research assignment

The research question is translated into a research assignment, and the research assignment is divided into three sub assignments.

Develop a decision support tool to optimize patient planning and capacity for multiple departments in a hospital.

The sub assignments are steps to answer the research question:

1. *Model the interactions between departments*
2. *Identify decoupling points in the patient flows between departments if existing*
3. *Determine what be changed to improve efficiency of capacity usage*

2.4 Methodology

To answer the research question, the model of Sagasti & Mitroff (1973) for methodology in Operations Management was used. In this model, the operational research approach consists of a number of phases. These phases were addressed in this master thesis. This section discusses the content of the phases as used in this study and links the phases to the sub research assignments.

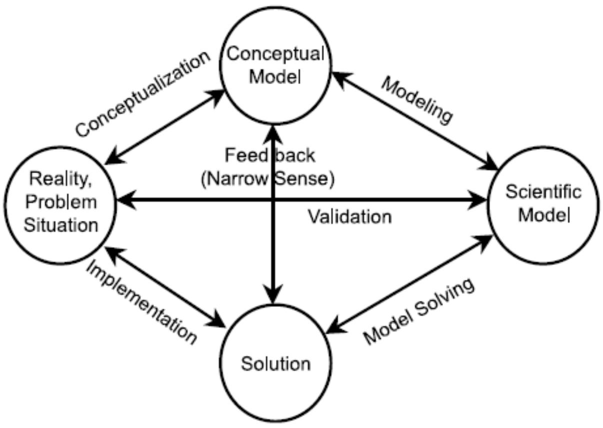

Figure 2.2: Research model by Sagasti & Mitroff (1973)

1. Conceptualization

To identify the problem in Maasziekenhuis Pantein further, first a detailed analysis was performed. This included an analysis of the current situation and a baseline measurement. Then, the interdependencies within a hospital were modelled to have an overview about how processes are linked. Then, a conceptual model was formulated. Concerning the research methods, the following methods were used:

Desk research: Literature in different domains of operations management was consulted, but also specifically for healthcare since there is also many research in the field of healthcare operations. Secondly, sources from the hospital are used, such as spreadsheets with information about the number of beds, but also recently obtained information by the hospital such as descriptions of care paths.

Interviews: People in different functions were interviewed, for example team managers, financial experts, and supporting staff.

Modelling: After information about the connection between units, demand and resources was acquired, the system was modelled in MS Visio to give a schematic overview of the relations between departments. The model also provided an overview of decoupling points within a hospital.

By completing conceptualization, sub assignment one and two were completed, because the interactions between departments were modelled and decoupling points were identified.

2. **Building the scientific model**

In this step, a scientific model was built which models the problem. In this study it was decided to use Linear Programming techniques as explained in 3.3.

3. **Solving the scientific model**

For the next step the model was solved by performing a case study. In this phase a decision support tool including the model was developed in MS Excel. The case study was performed at Maasziekenhuis Pantein in Beugen to verify and validate the model.

4. **Implementing the results of the model**

In the last step it was determined how the model can be implemented in a hospital. This means firstly how the results of the model can be interpreted and what impact they have. The impact on quality and costs were analysed in respectively Chapter 7 and 8. Secondly, in this study Chapter 9 discusses how to implement the results of the model on operational level.

By completing step two, three, and four the third sub assignment was fulfilled. A model was built to optimize patient planning and capacity for multiple departments, which makes capacity usage more efficient. Finally, by following the method, the research assignment was fulfilled.

2.5 Scope

This section gives an overview of the elements within and out of scope of this study. First, the level of detail is determined by using the framework developed by Vissers and Beech (2005) (Figure 2.4). This study focuses on the level ‘Resource planning and control’ which includes decisions concerned with the allocation of resources to specialties and patient groups, which is related to the objective of this study. Therefore, the schedules at operational level such as staff planning and individual patients assigned to time slot are excluded from scope. Furthermore, the arrival rates of emergency patients are out of scope. Since emergency patients cannot be planned, and most patient in MZH are elective, the major improvements can be achieved by improving the planning of elective patients. Furthermore, emergency patients are in principle operated in another OR than the electives. Figure 2.3 gives an overview of the scope.

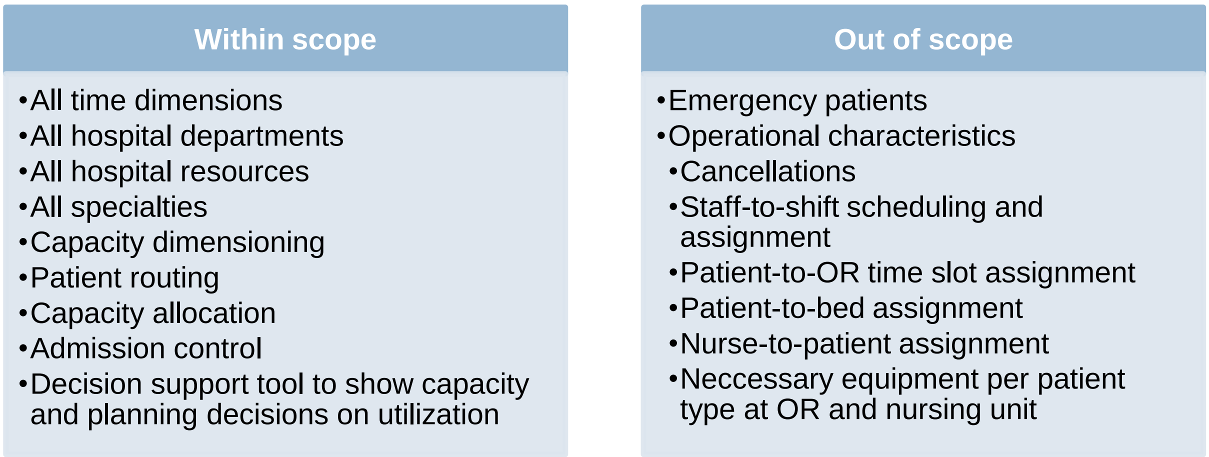

Figure 2.3: Scope

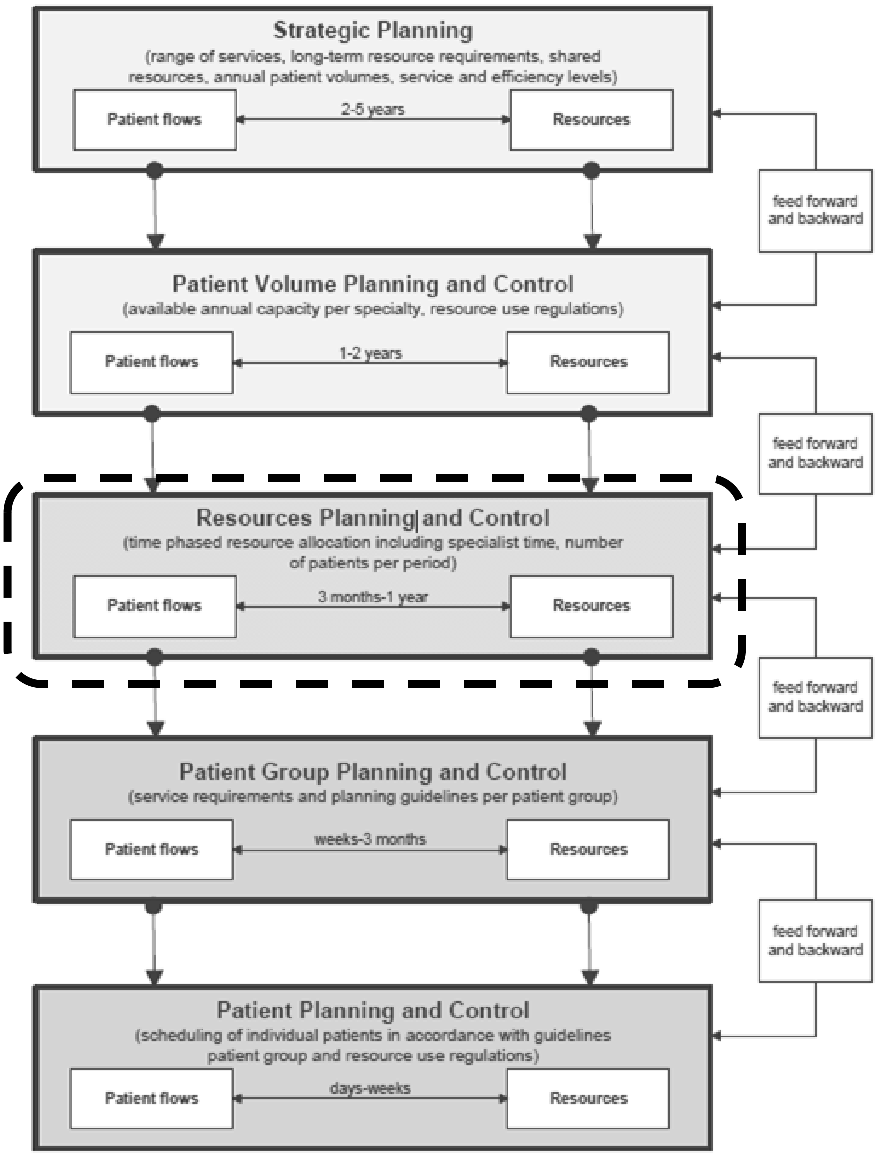

Figure 2.4: Framework for production control of hospitals (Vissers & Beech, 2005)

3. Detailed analysis

This chapter elaborates the problem as faced by MZH. In Section 3.1, the dataset is described and an analysis of the current situation with regard to patient planning and capacity usage in MZH is given. Section 3.2 provides general information about interdependencies within hospitals between departments and the resources available per department, to clarify which resources are related to the problem and where should be decided upon. Finally, in Section 3.3, a description of a conceptual model is given.

3.1 Analysis of current situation

This section first discusses the dataset provided by MZH (Section 3.1.1) The, the results from data analysis for all specialisms in the hospital (Section 3.1.2). It also discusses the current methods of planning in MZH. In Section 3.1.3, data analysis is focused on the specialty surgery, as this is the specialism performing most operations.

3.1.1 Dataset provided by MZH

MZH provided a dataset including the attributes as presented in Appendix 2. The provided data by MZH was based on operation number. Data started from January 2013 until August 2013 and contained 20,871 operations, with 3,466 for surgery.

Data verification: outliers and missing data

Patients with no registered diagnosis or no surgery registration (for example if their surgery is planned in the future), were filtered out of the data. Furthermore, cases with extremely long surgery duration were deleted from the data. Finally, few patients were registered at nursing unit '201'. Since this was very rarely, and this was not recognized by MZH, these cases were deleted from the data.

3.1.2 All specialisms

In this section, results from data analysis and interviews for all specialisms are discussed. First the arrival pattern of patients is analysed, followed by the current method of research allocation. Note that not every specialism performs surgery, as a distinction is made between non-surgical and surgical specialisms. This section is only about patients who had surgery.

3.1.2.1 Arrival pattern

First, the number of arrivals per day of the week and the number of surgeries per day of the week are evaluated. Figure 3.1 and Figure 3.2 show the total number of arrivals and surgeries per day of the week at MZH for all specialisms. 0 indicates an elective patient, 1 emergency. Data analysis revealed that for surgeries Monday and Friday are the least productive in terms of number of patient operated on that day. Wednesday has a little dip, which makes Tuesday and Thursday the most productive. Both arrivals and operations of elective patients happen mainly on weekdays. This is probably due to outpatient appointments planned on weekdays: if a patient needs surgery, he visits the department Admission straight after the appointment to get a surgery date. Therefore, date of registering is mostly a weekday.

The analyses further show that the number of emergency patients are approximately the same per weekday, with a slight decrease in the weekends. The number of emergency patients arriving per week is also about the same every week. For the elective patients, we see a slight decrease in the summer weeks and a large dip at the end of the year. During for example the summer, Carnival and Christmas vacations, specialists work less than during an average week, which can be the reason for the decrease in patients registering for a surgery date. We therefore can conclude that no obvious seasonal pattern of patient arrivals exist in the arrival pattern.

Figure 3.3 indicates the number of operations per specialty. Surgery performs the most operations per year of all specialisms. Finally, data analysis revealed a large difference the ratio between emergency and elective patients per speciality undergoing surgery. Pulmonology, Anaesthesiology, and Cardiology see the most emergency patients. Ophthalmology, E.N.T., Urology, and Plastic Surgery see mostly elective patients.

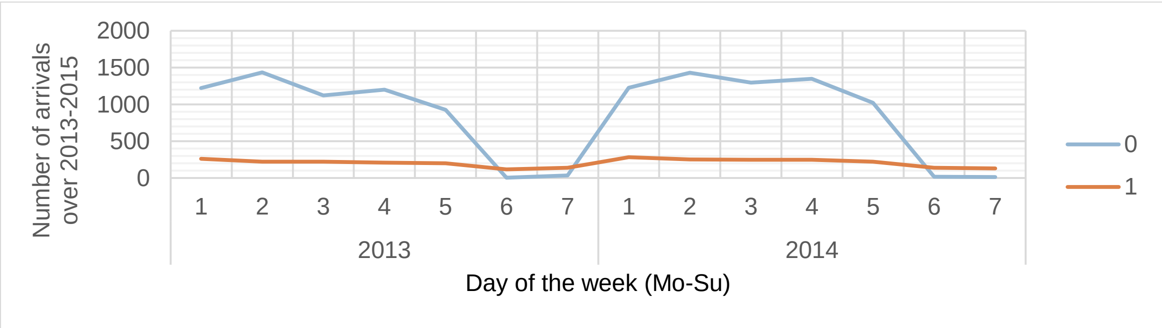

Figure 3.1: Arrivals per day of the week

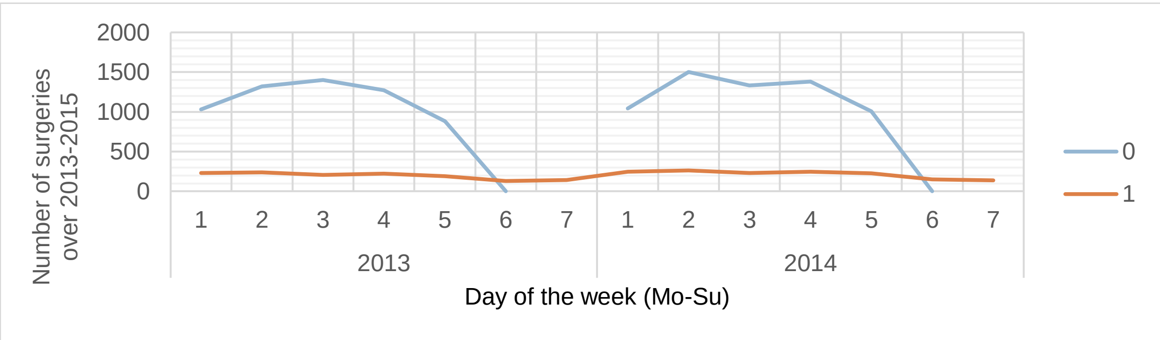

Figure 3.2: Surgeries per day of the week

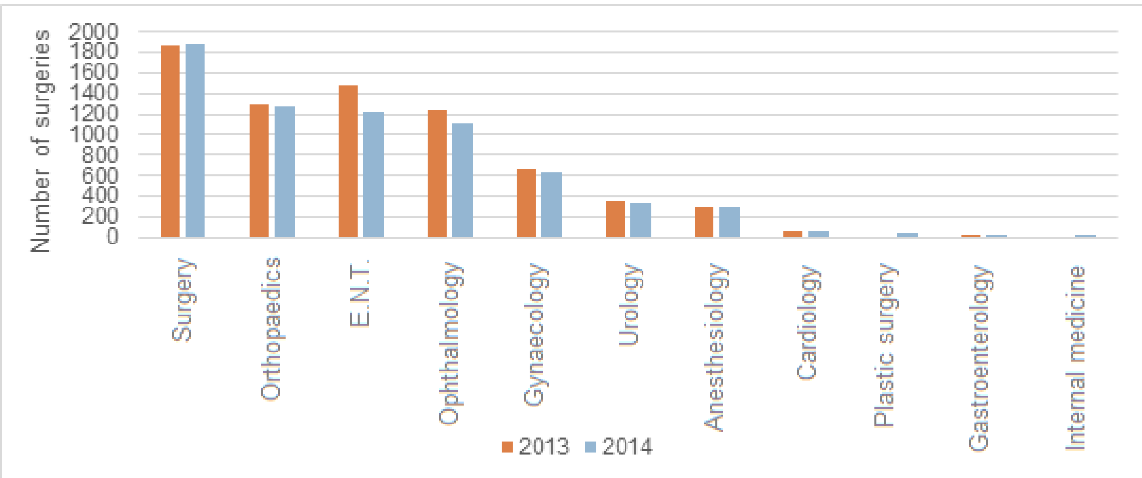

Figure 3.3: Number of surgeries per specialty

3.1.2.2 Current methods of resource allocation

OT department capacity: MSS (2014)

The OT department is responsible for the Master Surgery Schedule (MSS). Figure 3.4 shows the general MSS of MZH in 2014 for the 4 main ORs. It fluctuates per week, depending on circumstances. In the beginning of the year, a basis MSS is made for the whole year, but is adjusted per week at specialist level. 13 weeks per year MZH works with a reduction schedule, during for example the summer and Christmas holidays. In general, 'flex' blocks are reserved for emergency patients, the other blocks for elective patients. At the operational level, emergency patients are also operated in other blocks if necessary, as they can have priority.

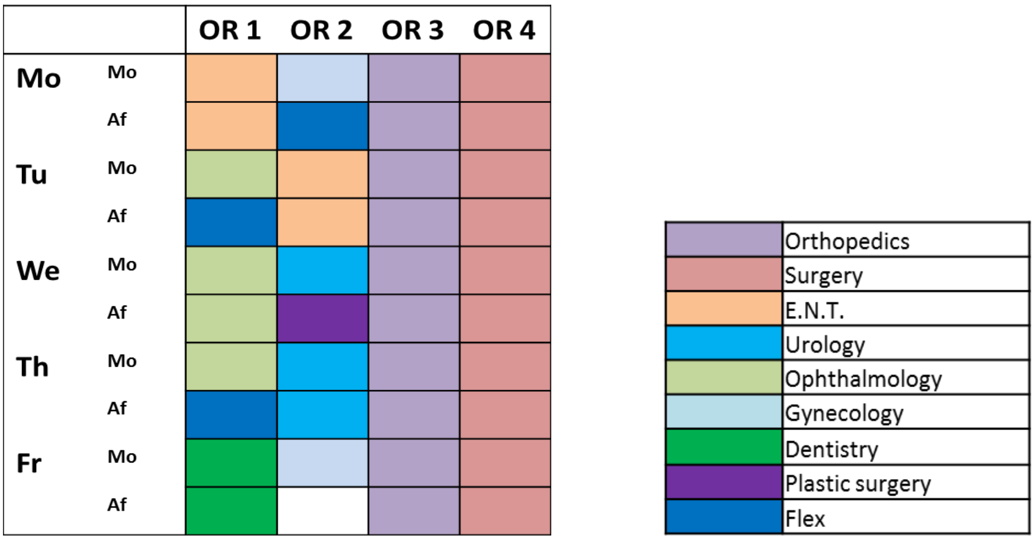

Figure 3.4: Basic MSS of MZH in 2014

Wards capacity

MZH has 167 beds, allocated over 10 units. The number of beds per unit varies from 4 to 30. Table 3.1 provides information about the wards. As explained in Figure 1.1, MZH has wings A-D. Therefore, for example B1 corresponds to floor 1, wing B.

Table 3.1: Overview characteristics wards

Ward	*Specialities*	*Number of beds*	*Bed hours per week*
B1	Day care RUCO[6]	10	40
B2	Short stay / Elective	30	108
B3	Intern	27	168
B4	Mother	12	168
C1	ED/Observatory	4	168
C2	Surgery/snijdend	27	168
C3	Cardio/Long	24	168
C3-S	Stroke	3	168
C4	Child	22	168
E2	IC/CCU	8	168
Total number of beds		167	

[6] RUCO = Radboud Universitair Centrum voor Oncologie

Planning

The primary goal for this study, is to develop a decision support tool to optimize patient planning and capacity for multiple departments. Therefore, it is interesting to know how decision are made concerning patient planning and capacity in the current situation. This is described for patient admission and staffing.

Patient admission

If a specialist takes the decision that a patient needs to have surgery, the patient reports himself after the appointment at the outpatient department, to the department Admission. In MZH admission planning is centrally coordinated for all specialties. They immediately give the patient a surgery date, by checking availability in the OR schedule. The availability at the wards is not checked at this stage, since it is known that only rarely no bed is available. At the wards, the secretaries are informed by department Committal when patients have surgery and therefore need a bed at the ward. The department Committal also provides a planned date of discharge. If a ward is full, patient are rescheduled to other, predetermined wards. If the whole hospital is full, a special protocol is launched. The specific time of surgery on the day of surgery is announced by call the day before the surgery.

Note that patients also get some pre-operative screening before surgery, but this is out of scope for this study. Pre-operative screening includes appointments before surgery to inform the patient and for example check the medical health of the patient.

Staffing

The current personnel planning practices are different per department. For example, at one ward, one of the nurses schedules the staff per time period, and the secretary fills the gaps. They say to have no idea about in demand patterns per patient group. Most wards work with people who have contracts with few hours. For the OT department the MSS is the basis for staff planning. Specialists in general have their own block of time, which also means that their outpatient department appointments are scheduled around these block(s). The supporting staff at the ORs is scheduled according to the planned patients.

3.1.3 Specialty surgery

Since most patients are from the specialty surgery, and specialisms operate independently of each other, this study focuses only on this specialty. This means a large number of patients in MZH is analysed. This section discusses the arrival pattern and the resource use of surgery patients

3.1.3.1 Arrival pattern

Patients register at the department Admission, when they need surgery. Figure 3.5 demonstrates the variation in number of arrivals over the weeks in 2014. The average number of patients per week is 24.2, with a standard deviation of 6.6 patients.

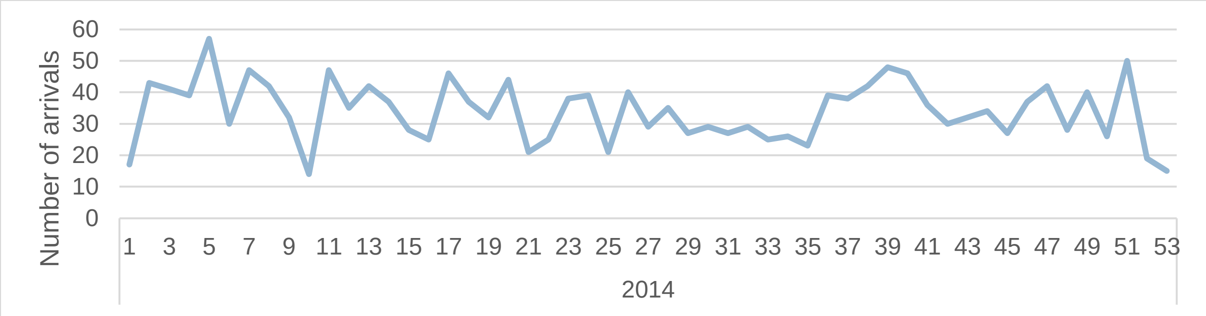

Figure 3.5: Number of patients registering for operation at the department Committal per week

To identify the current situation of the processes of surgery within MZH, the waiting time between registration for surgery and the actual surgery is analysed. In its annual report MZH indicated a waiting time for surgery patients of two weeks in 2013, and three weeks in 2014 (Pantein, 2015). Figure 3.6 demonstrates the amount of waiting time in weeks for surgery patients in 2014 and 2015. The mean of the number of waiting weeks is 2.2 weeks, with a standard deviation of 0.64 in 2014. The standard deviation within weeks is 1.3 weeks. From the information of both sources, we can conclude the average waiting time varies mostly between two and three weeks.

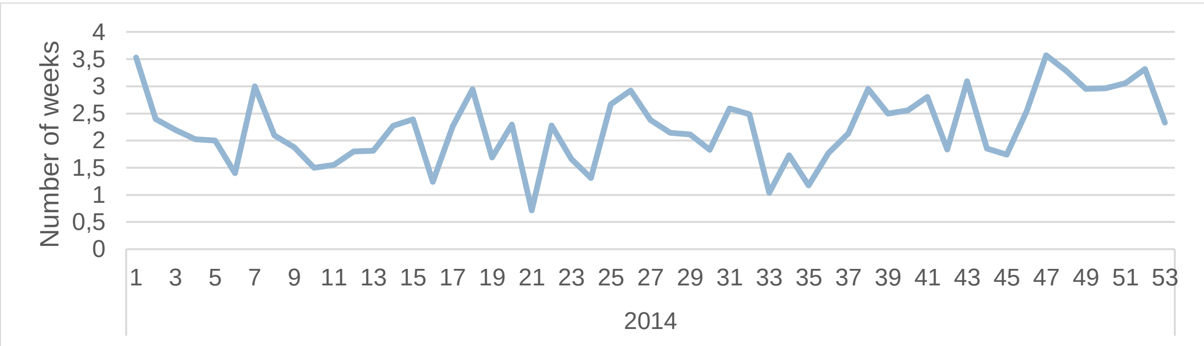

Figure 3.6: Average number of waiting time in weeks for surgery patients in 2014

3.1.3.2 Resource use

In this section, the use of resource by surgery patients is analysed. Surgery patients stay normally at wards B2 and C2. If intensive care is needed, they stay at the IC (Intensive Care).

Surgery duration

Appendix 6 gives an overview of the subspecialties within surgery, their average surgery duration and standard deviation, and their average length of stay and standard deviation. Oncology has the longest average surgery duration (106 minutes), while general surgery has the shortest average surgery duration (58 minutes).

Nursing units

Surgery patients are assigned to nursing unit B2 if they are in the hospital for MZH and to C2 if they will stay longer than one day. Data of MZH indicates C2 has an average occupancy rate of 73,6% in 2014; B2 is not available with the right performance measure. Exceptions are children, who go to a special ward for children and patients who stay at the Intensive Care. Figure 3.8 shows the distribution of nursing days over the units for surgery patients. It indicates that most clinical patients stay the longest at C2, and most day care patients at B2.

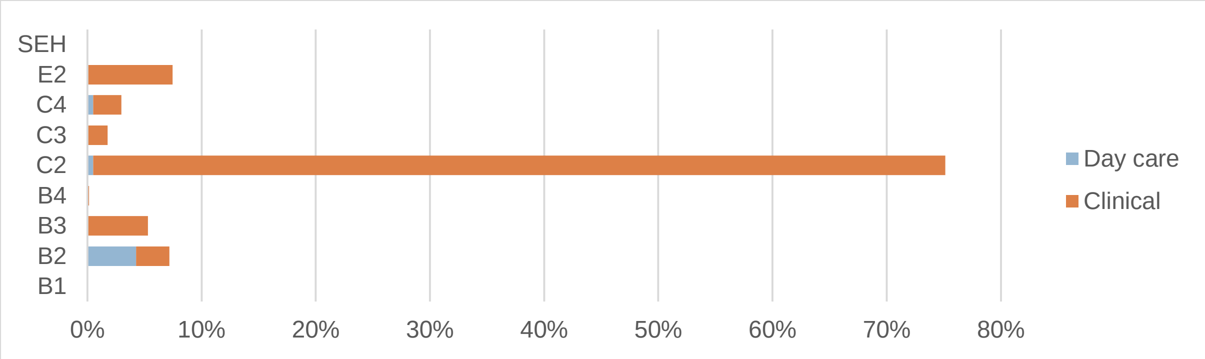

Figure 3.7: Distribution of nursing days over the units for surgery patients

Length of Stay (LOS)

The Length of Stay varies per surgery patient. Data analysis showed that most patients stay only one day. The number of patients who stay two days is only half of this amount. The number of patients staying three days is again about half the amount. A part of the patients receives day care, others stay for a minimum of two days. Figure 3.8 gives an overview of the LOS for patients at C2, which is a unit intended for patients staying longer than one day. For this unit, most patients stay at least two days.

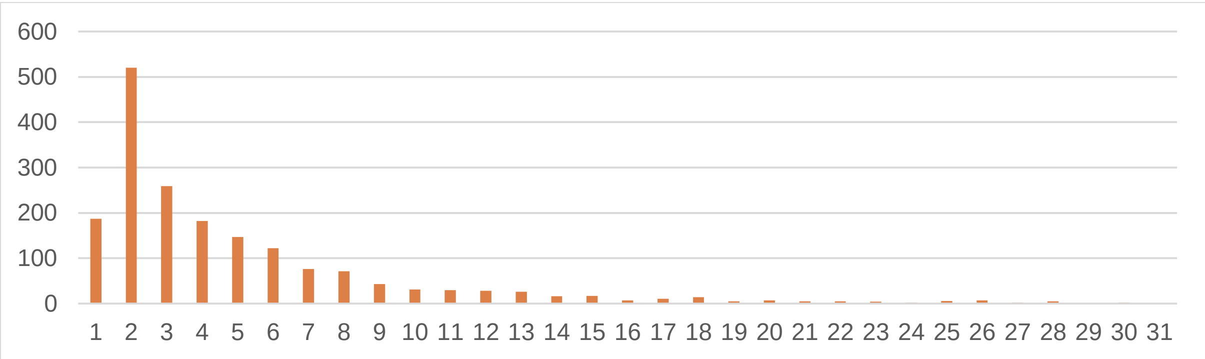

Figure 3.8: Length of stay of surgery patients at C2

3.1.3.3 Emergency patients and elective patients for surgery

Surgery had one OR every day of the work week in 2014 (OR 4). The acute patients are spread over other ORs in flex blocks. These blocks are also used by other specialties. When time is left in the 'elective' OR, specialist also treat acute patients there, but the goal is to fill the 'elective OR' with only elective patients.

3.1.4 Baseline measurement for surgery

In this section, the results of a baseline measurement of MZH is given, to have an indication about the current performance of the specialty surgery in terms of resource utilization. From the data analysis in this chapter, the use of capacity and the corresponding standard deviation per day of the week was derived for the OR 4, B2 and C2, and the IC since these are the resources surgery patients use (Figure 3.9, Figure 3.10, Figure 3.11, and Figure 3.12). B2 is a day care unit, which implies the unit is only open from Monday till Friday. The results indicate a relatively large standard deviation for all resources. The use of the operating room varies hours per day, which indicates an unbalanced process. For the wards B2 and C2, as the standard deviation is more than five at most days, the workload for nurses is very much fluctuating. Moreover, because the nurse patient ratio is normally during day time 1-5, it means it is hard to plan the appropriate number of nurses per day. As the hospital wants to ensure that enough staff is available at the wards, a high likelihood exist that too much staff is planned for few patients. For the IC, the value standard deviation is almost equal to the value of the mean, which indicates a high spread of the number of surgery patients at the IC. But, as the IC is only used for severely ill patients, it is likely that the number of patients at this unit is hard to predict. Overall, from these figures it can be concluded that processes could be organized more balanced.

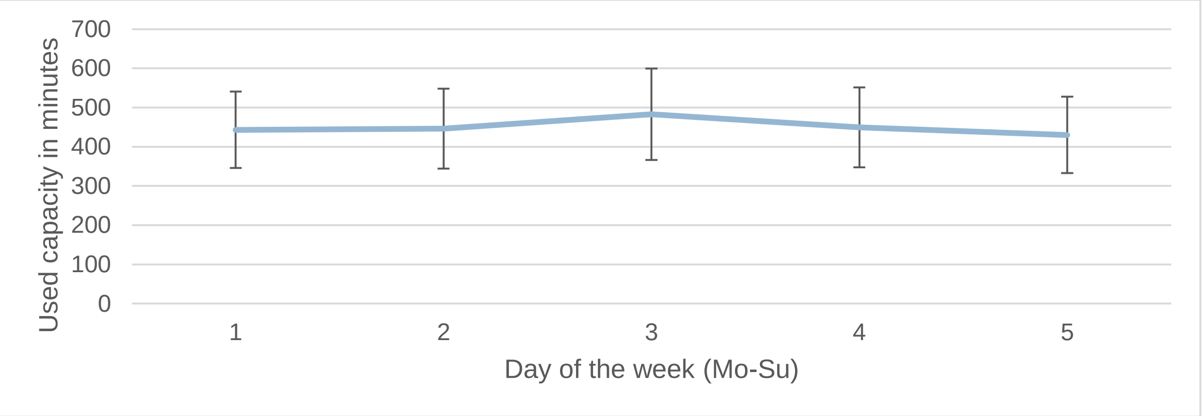

Figure 3.9: Current performance OT department

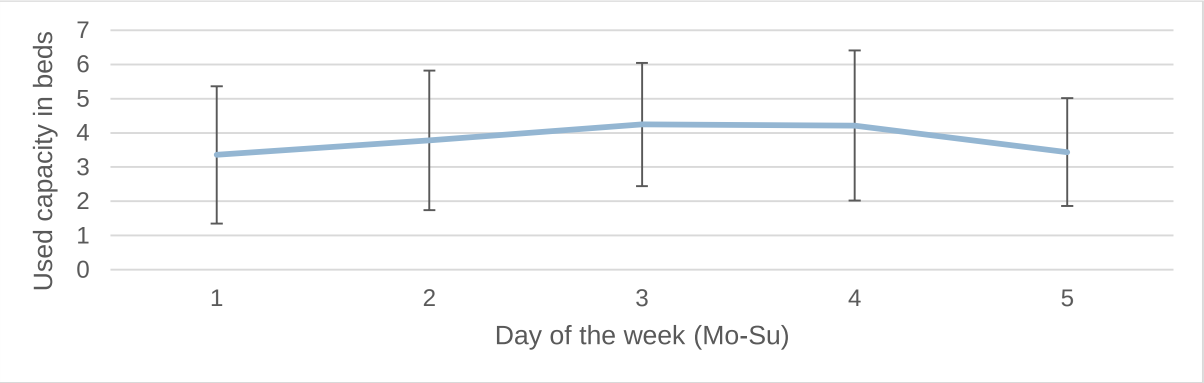

Figure 3.10: Current performance B2

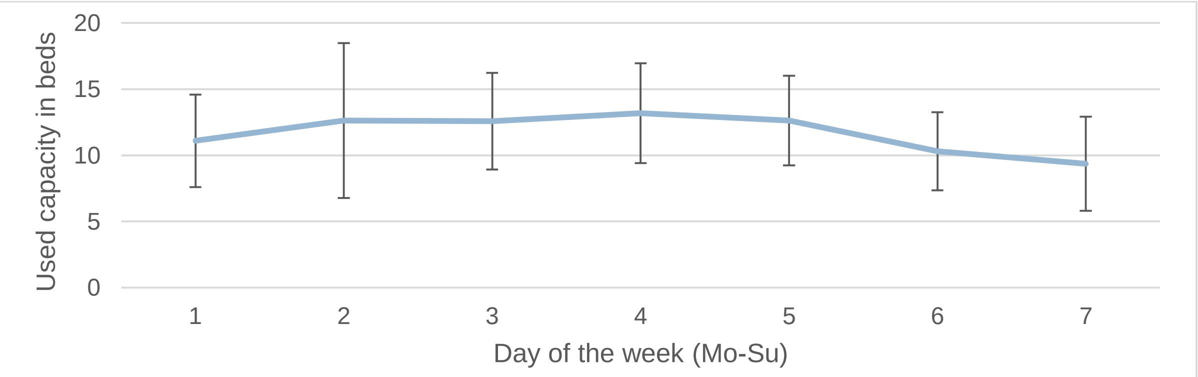

Figure 3.11: Current performance C2

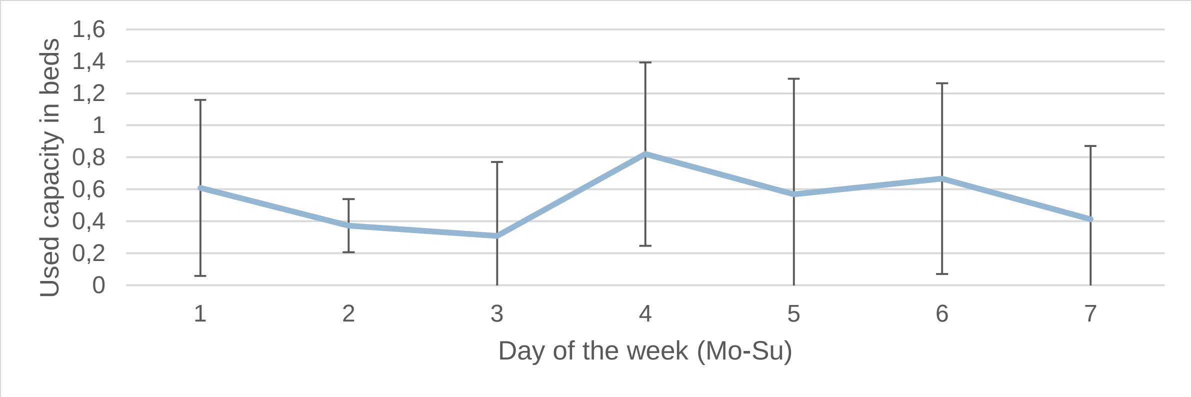

Figure 3.12: Current performance IC

3.2 Interdependencies within a hospital

To create a model to make decisions concerning patient planning and capacity for multiple departments, identifying all resources in a hospital is necessary. In this chapter an overview of interdependencies within a hospital is given.

A hospital consists of several units. A unit is a department in a health system that performs operations of the same operation type. A unit also has access to the key resources (staff, capital equipment, and materials) required to undertake operations of the same type (Vissers & Beech, 2005). The following units can be considered in a hospital as described by Vissers & Beech (2005):

- Emergency Department
- Outpatient Department
- Diagnostic and Therapy Departments (e.g. Radiology, Pathology, Physiotherapy)
- Operating Theatres Department
- Intensive Care
- Wards

The connections between the departments are visualized in Figure 3.13, specifically created for this project. Since many patients visit more than one unit in a hospital, the units are highly interconnected. However, most processes include decoupling points. This is a point in the process where operations before and after are decoupled by a waiting list, as showed by the triangles in Figure 3.13. Only the units ED-Ward and Ward-OT department are directly connected. Furthermore, the OT department is normally working with a Master Surgery Schedule (MSS). This means that blocks within one specialty are scheduled separately, which implies that the different specialties can also be seen and optimized separately. However, if a ward is fully occupied, patients are moved to another ward where a bed is still available, which means indeed an interaction between specialties. Interaction between specialties is also the case when more than one specialty uses a ward. Note that the independency also holds for the outpatient units, since these are also separated.
Design choices are:

- The Intensive Care is not separately modelled, since it is one of the wards
- The dotted line is used to denote that the bed remains assigned to the patients

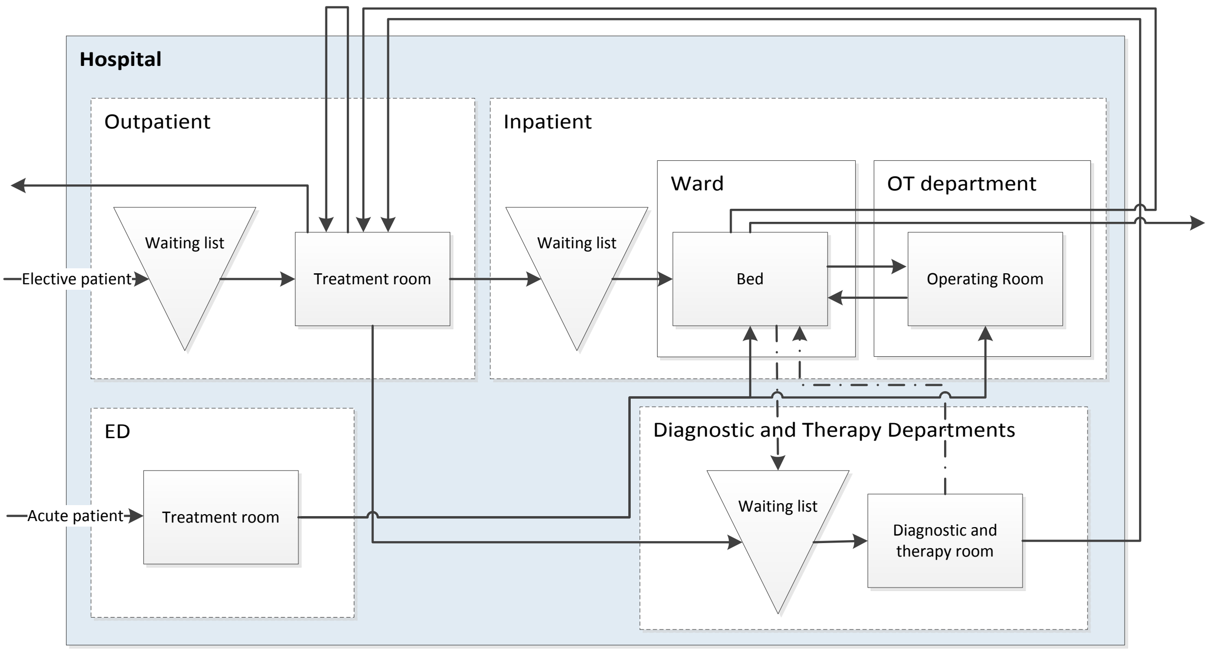

Figure 3.13: A schematic overview of the interactions between units a hospital

3.2.1 Incoming patients

Patients can be considered as elective, urgent or emergency patients. An emergency condition endangers a patient's life or permanently impairs it. An urgent condition means that a patient needs care within 24 hours. Elective patients do not have such an urgency, and can be planned arbitrarily. In a hospital, it is important to know (Vissers & Beech, 2005):

- The main patient groups served by general surgery
- The trajectories (or process chains) of patients within patient groups
- The number of patients served within patient groups, and the distribution over trajectories
- The workload placed on outpatient and diagnostic facilities
- The completion time for the trajectories

Elective patients are selected from a waiting list. Admission planning gives each patient a surgery data. Admission planning can be centrally coordinated for all specialities, or it can be decentralised. Admission planning decides on the number of patients admitted for a specialty, but also the mix of patients admitted. The type and use of resources required by a patient are different within a specialty. Differences exist in length of stay (ward), length of surgery (OR), nursing capacity (ward), and intensive care beds (IC). Therefore, determining the mix of patients is an important decision variable for the hospital to manage the workload of the inflow of inpatients (Vissers & Beech, 2005).

3.2.2 Resources

At every department multiple types of care are provided and different resources are used. In this section the departments are described concerning their activities and resources important. The resources per department considered are mostly derived from Hulshof, Kortbeek, Boucherie, Hans, & Bakker (2012).

3.2.2.1 Outpatient department

The outpatient department consists of different clinics where specialists can be consulted by ambulant patients referred by GPs (General Practitioners). The outpatient department is the 'leading' resource, since it causes demand at diagnostic departments (Vissers & Beech, 2005).

Patients who visit the Outpatient department flow through the hospital as visualized in Figure 3.13. An elective patient arrives at the outpatient department, if he has a referral from the GP. The patient calls with the outpatient department to make an appointment. From the moment of calling until the appointment, normally the patient has to wait some time. At the appointment, the specialist provides care to the patient and determines what the diagnoses and further treatment will be. Some patients need another appointment, some diagnostic or therapy treatments, and/or surgery, other will leave the hospital after this one appointment (outflow).

Resources

- Consultations rooms
- Staff
- Consultation time capacity
- Equipment
- Waiting room

3.2.2.2 ED (Emergency Department)

Patients who visit the ED flow through the hospital as visualized in Figure 3.13. At the ED, acute patients flow into the hospital. Patient can leave the hospital after treatment at the ED, but can also be immediately transferred to the OT department. Resources are the same as at the outpatient department.

3.2.2.3 Diagnostic and Therapy departments

Diagnostic departments are for example X-ray departments, laboratories and organ examination departments (electrocardiograms, lung functions, endoscopies, etc.). In the X-ray department most rooms are only suitable for specific categories of examinations linked to the equipment that is located in the room. Treatment departments are for example departments providing physiotherapy, radiotherapy and occupational therapy. Therapy departments do normally not have to treat emergency patients (Vissers & Beech, 2005).

Patients who visit the Diagnostic and Therapy departments flow through the hospital as visualized in Figure 3.13. The patient is referred to one or more of these departments by the specialist or GP. The results are evaluated with the patient at the ward or the outpatient department. Consequently, the Diagnostic and Therapy departments are considered to be departments used by both inpatients and outpatients.
Resources are the same as for the outpatient department.

3.2.2.4 Inpatient: OT (Operating Theatres) department

The operating theatres department (OT) is an important resource in a hospital. The work performed in the OT is very labour-intensive and involves expensive equipment and materials. Besides this, it is a shared resource and a 'leading' resource for the inpatient production of surgical specialties. We call a resource 'leading' if it is the trigger for generating production on other resource that 'follow' (Vissers & Beech, 2005). An average of 85-90 per cent is often used as the target level for the capacity utilisation of regular sessions in the operating theatre department (Vissers & Beech, 2005).

Patients who visit the OT department flow through the hospital as visualized in Figure 3.13. If a patient needs surgery, the patient visits the committal department to receive dates for appointments for preoperative assessment and surgery. When the patient arrives at the OT department, the patient first receives (local) anaesthesia. If this succeeds, the patient is transferred the OR (Operating Room). Then, the surgery is provided. After surgery, the patient goes to the recovery room. If the patient awakes, the patient is transferred to the ward.

Resources

- Operating rooms
- Operating time capacity
- Pre-surgical rooms
- Recovery wards
- Ambulatory surgical ward
- Equipment
- Staff
    - Specialist
    - (Trainee supporting specialist)
    - Anaesthetist
    - Nursing staff

3.2.2.5 Inpatient: Ward

The ward can act as 'leading capacity' or as 'following' capacity. It depends on the type of specialty: surgical versus medical (NL snijdend or beschouwend) and on the identification of the bottleneck resource. Mostly a bed-allocation scheme is used to allocate beds to specialties. Besides this, many hospitals have a centralised ward for day cases (one day admissions) or for short-stay patients (with a length of stay up to five days), but these beds are usually used by any specialty. Mostly, wards accommodate more than one specialty. Nursing staff is normally allocated to a ward. An average of 85-90 is often used as a target level for the occupation rate of beds during the week. For nursing staff the target level for patient-related workload is set at 100 per cent since this resource is flexible to adapt to circumstances (Vissers & Beech, 2005).

Patients who visit the ward flow through the hospital as visualized in Figure 3.13. At the ward the nurses monitor the patient and provide care. The specialist checks the patients every day, when he/she is at the ward. If the patient recovered sufficiently, he will be discharged.

Resources

- Beds
- Equipment
- Staff

3.2.2.6 Inpatient: IC (Intensive Care)

The IC is a special kind of ward as it is far more expensive due to extra equipment and a high intensity of workload for the nurses. Besides this, the resources are the same.

3.3 Conceptual model

In this chapter, a conceptual model for the problem is described which can be translated into a mathematical model. The model developed is general and therefore applicable to all hospitals. Figure 3.13 has shown an overview of the different departments. In this chapter a model is described which can optimize the patient planning and capacities of these different departments knowing the decoupling points. The chapter starts with the elements of the model (Section 3.3.1). Section 3.3.2 describes the model in words, and it is decided which method to optimize is most appropriate.

3.3.1 Elements of the model

We aim to optimize patient planning and capacity for multiple departments. To reach this goal different optimization goals are possible, which are described in Section 3.3.1.1. Section 3.3.1.2 describes the output to be provided by the model. Then, Section 3.3.1.3 gives an overview of the input variables for the model.

3.3.1.1 Optimization goal

The optimization goal of this study is to optimize patient planning and capacity for multiple departments, but different aspects can be optimized related to capacity. This could be for example:

- Minimizing total costs
- Maximizing number of patients
- Maximizing utilization
- Minimizing deviation from target utilization

Costs of healthcare consist of many elements and are therefore difficult to optimize. But, a part of the total cost are fixed costs and are divided over the number of patients. This means more patients result in a decrease in the fixed costs per patient. On the other side, we have the variable costs, which decrease when for example less nursing days are needed or less expensive days (weekends are expensive in terms of labour costs). Since costs are so difficultly structured, we can also look at the number of patients and utilization. Maximizing the number of patients misses the degree of illness of the patients. Therefore, this research is focused on utilization. For utilization, maximizing utilization and minimizing the deviation from the target utilization is possible. Since maximizing utilization is achieved by either increasing patients or decreasing capacity, we focus on meeting the targets for patient throughput and utilisation. This means in this study, the deviation form target utilization is minimized. This optimizes the patient planning and capacity, and balances the workload, and gives a predictable use of resources.

3.3.1.2 Output variables

This section discusses the output variables for the model. The model should give some output variables to evaluate the performance of the model.

Value objective function

The model should give the value of the objective function.

Decision variables patient admission

The output of the model should be an admission profile per planning cycle for the number and mix of patients.

Other performance measures

The model should give an indication of expected occupancy rates per resource, and the expected productivity of capacity.

3.3.1.3 Input parameters

This section discuss the input parameters for the model.

Planning period

An input parameter for the model should be the time period over which the admittance of patients has to be planned.

Patient groups

We can vary the variable 'admission of patients'. To take justified conclusions about the number of patients to be admitted, we need to divide them in categories, based on using the same constellation of resources. Usually, a hospital has an inflow of a wide variety of patients, therefore we categorise them to make the planning problem more manageable. In the Netherlands, care products are registered as combinations of diagnosis and treatment (DBC). However, these products are mainly intended for medical and financial purposes, instead of logistic. Moreover, there are more than 4,000 different DBCs. Since the DBCs are mostly medically oriented, another classification of patient is needed. Since in this research, a process-oriented view is used: patients need to be classified by the same constellation of resources. Many patients follow approximately the same care path. Therefore, the patients are grouped concerning homogeneity of resource consumption. The characteristics in Table 3.2 are considered in hospitals, which are the load on the resource and the probability of coming back/staying. Then, when patients are grouped according to these characteristics, the volumes per patient group need to be determined.

Table 3.2: Patient characteristics in a hospital

Patient category	Number of patients per time unit	Characteristics per resource	
		Load on resource (for example service time)	Probabilities of coming back/staying (dependent on kind of resource)
1			
2			
…			

Resources

Each resource in a hospital can be used as an input for this model.

Available capacity of the resources

We need to know the available capacity of the resource, this can be expressed in every unit. Typically, the availability of the resources varies over the planning period. The capacities are allocated in a cyclic pattern.

Target utilization of the resources

The target utilization of the resources can be set by the model. This is the desired utilisation (or occupancy rate) of the resources on each day of the planning cycle.

Service times
An overview of service times per resource is necessary as input for the model. Therefore, capacity requirements per patient group need to be determined.

Probability of stay
In order to determine the utilisation levels of the resources, the probability that a patient group stays at a certain resource (for example the ward), or returns (at for example the outpatient department) needs to be included in the model.

Preferred resource
Since for example some patient groups need to stay at a specific ward, because at that ward is the right expertise of care, patients should be assigned to a preferred resource.

Weight
To indicate the importance per resource, the parameter 'weight' is introduced.

Patient group restrictions
To include the availability of specialists, restrictions per patient groups can be set. This means that certain patient groups cannot be treated on a certain day of the planning cycle due to the unavailability of the specialist that day.

3.3.2 Model in words
The model optimizes patient planning and capacity for multiple departments. Regarding the optimization goal, this means we aim to find the mix of patient that ideally need to be admitted at each day within a cyclical planning period to optimize the use of resources, given an objective function and taking into account some restrictions (Adan, Bekkers, Dellaert, Vissers, & Yu, 2009). The optimization goal is to minimize the expected weighted sum of under-and overutilization. The main restriction of the model is the requirement that the number of patients planned per time unit in the model should meet the pre-set throughput of patients per time unit. Another constraint is to meet restrictions due to the MSS, i.e. including the availability of specialists. Furthermore, the total planned time shall not exceed the available capacity, only if necessary. A penalizing constant should prevent exceeding capacity. Finally, the admission scheme should provide the numbers as integers for the admission scheme. Over-, and underutilization, and (potentially) exceeded capacity should be above zero. Because all relations in the objective function and the constraints are linear, we can classify the problem as linear.

To find the optimal solution, several solution approaches are possible. From system dynamics, analytic stochastic models, discrete event simulation, deterministic models, and linear programming, linear programming is best appropriate for the problem in this study. Linear Programming is a method to achieve the best outcome in a mathematical model, where the requirements contain linear relationships. Therefore, linear programming can find an optimal solution, given some restrictions, and can be solved fast. Because the conceptual model only contains linear relationships, linear programming is possible. As the decision variables are required to be integers, but some other variables are not, the mathematical formulation can be classified as a Mixed Integer Linear Programming (MILP) problem. The model has similarities with the model developed by Adan et al. (2009), but is extended to achieve a hospital-wide approach.

4. Mathematical Model

In this chapter the mathematical formulation of the Mixed Integer Linear Programming model is given. Section 4.1 discusses the assumptions used to develop the model. Section 4.2 gives an overview of the sets as used in the model. Section 4.3 lists the parameters of the model. Then, in Section 4.4 the decision variables are presented, followed by the objective function in Section 4.5. Section 4.6 show the constraints of the model. In Section 4.7, the formulas of other performance measures than the objective function are presented. Finally, in Section 4.8 the solution approach is discussed.

For the model, let C denote the number of patient categories and T the length of the cyclic admission schedule. The most important decision variable is $X_{c,t}$ denoting the number of patients from category c admitted on day t of the admission schedule, where $c \in C$ and $t = 1,2, \dots, T$. The objective is to determine the variables $X_{c,t}$ satisfying certain constraints and for which the expected utilization of all resources matches the target as close as possible.

4.1 Assumptions

Several assumptions are included in the model. As in this study, the focus is on the tactical level, we limit ourselves to expected performance on utilization of resources (Adan, Bekkers, Dellaert, Vissers, & Yu, 2009). Therefore, the service times, patient arrivals, and capacities are assumed to be deterministic: we aim to optimize patient planning and capacity on the average.

The assumptions are:

1. Patient arrivals are considered to be deterministic and known.
2. Service times are considered to be deterministic and known.
3. Resource capacities are considered to be deterministic and known.

4.2 Sets

The model contains a set of resource types such as the OR or a bed, and a set of categories of patients.

R	$Set\ of resource\ types$
C	$Set\ of\ categories\ of\ patients$

4.3 Parameters

We introduce the parameter T to determine the cycle length. The target patient throughput per should be determined and is denoted as TPT_c. $C_{r,t}$ and $U_{r,t}$ denote respectively the available capacity and the target utilization, of resource r on day t. $s_{r,c}$ is the service time per resource for a patient category c. For OR this is the surgery duration, and for wards this is specified as 1, since a patient needs the bed a whole day in this tactical model. To formulate the constraints for the expected utilization $p_{r,c,t}$, giving the probability that a patient from category c, is at resource r, t days after admission, with $t = 0,1,2, \dots$.To weight the sum of the objective function, w_r is introduced, where a_r represents the importance of the resource in terms of costs and all weight together sum up to 1. $B_{r,t}$ the maximum number of patients of category c admitted per day due to patients who only can be treated by certain specialists, and should be working on the day patients are admitted. $OU_{r,t}$ and $UU_{r,t}$ are introduced as auxiliary variables to note the under-and overutilization.

T	Cycle length (days) $t = 1, \dots, T$
TPT_c	Target patient throughput of category $c \in C$ patients
$C_{r,t}$	Available capacity of resource $r \in R$ on day t
$U_{r,t}$	Target utilization of resource $r \in R$ on day t
$s_{r,c}$	Service time/load of category $c \in C$ patients at resource $r \in R$
$p_{r,c,t}$	Probability that t days after admission a category $c \in C$ patient is at resource r
w_r	Relative weight = $\frac{\frac{a_r}{\sum_{t=1}^{T} U_{r,t}}}{\sum_{r \in R} \frac{a_r}{\sum_{t=1}^{T} U_{r,t}}}$
$B_{r,t}$	Maximum number of patient of a certain category/categories at day t
$OU_{r,t}$	Overutilization of resources relative to the target utilization of resource r on day t
$UU_{r,t}$	Underutilization of resource relative to the target utilization of resource r on day t
$E_{r,t}$	Overuse of resource r on day t compared to the maximum capacity
$a_{r,t}$	Costs per resource at day t for resource $r \in R$
v	Constant for penalizing capacity excess

4.4 Decision variables

The objective is to determine the decision variables $X_{c,t}$ indicating the number of patients from category c operated on day t of the tactical plan.

$X_{c,t}$	Number of category $c \in C$ patients admitted on day t

4.5 Objective function

The objective (1) is to minimize the expected weighted sum of under-and overutilization per cycle. To avoid and penalizing any capacity excess, $E_{r,t}$ is multiplied by v.

$$\min \sum_{r \in R} w_r \sum_{t=1}^{T} \left(UU_{r,t} + OU_{r,t} + v * E_{r,t}\right) \quad (1)$$

4.6 Constraints

The total number of patients from group c to be operated on within the T-day horizon should be equal to the target patient throughput TPT_c and is formulated in (2). The over- and underutilization should be minimized to stabilize processes, which is denoted in constraint (3) and (4). These constraints should be treated *modulo T*: day 0 is the same as day T, day -1 is the same as day T-1 and so on. This way, patients admitted the weeks before are included in the model. The summation over i starts at -1 to include also pre-operative days at the wards. Then, for each of the resources, the available capacity should not be exceeded, but can be by $E_{r,t}$, which is reflected in constraint (5). Constraint (6) includes the restriction that patient group treated are dependent on the needed specialist is available that day. Constraint (7) is an integrality constraint and (8) ensures that over-, underutilization and exceeded capacity are above zero.

$$\sum_{t=1}^{T} X_{c,t} = TPT_c \qquad c = 1, \dots, C \tag{2}$$

$$U_{r,t} - UU_{r,t} \leq \sum_{c=1}^{C} \sum_{i=-1}^{\infty} p_{r,c,i} s_{r,c} X_{c,t-i} \leq U_{r,t} + OU_{r,t} \qquad t = 1, \dots, T \tag{3}$$

$$U_{r,t} - UU_{r,t} \leq \sum_{c=1}^{C} \sum_{i=-1}^{\infty} p_{r,c,i} s_{r,c} X_{c,t-i} \leq U_{r,t} + OU_{r,t} \qquad t = 1, \dots, T \tag{4}$$

$$U_{r,t} + OU_{r,t} \leq C_{r,t} + E_{r,t} \quad r \in R \quad t = 1, \dots, T \tag{5}$$

$$X_{c,t} \leq B_{c,t} \quad c = 1, \dots, C \quad t = 1, \dots, T \tag{6}$$

$$X_{c,t} = \{0,1,2, \dots\} \quad c = 1, \dots, C \qquad t = 1, \dots, T \tag{7}$$

$$UU_{r,t} \geq 0,\ OU_{r,t} \geq 0, E_{r,t} \ \geq 0 \quad r \in R\ t = 1, \dots, T \tag{8}$$

4.7 Other performance measures

To monitor the other performance measures of the system when searching for optimality, the performance measures 'average utilization resources' and 'productivity of capacity' are introduced.

- Average utilization resources

Gives the average utilization per resource per week.

$$\rho_r = \frac{1}{T} \sum_{i=1}^{T} \rho_{r,t}$$

- Productivity of capacity

Gives the productivity of capacity, i.e. the number of patients admitted to a resource divided by the available capacity. This formula is based on the formula in Table 2.1 (In 't Veld & Slatius, 2010). The result are the number of patients treated per period, the offer is the needed capacity per period.

$$P_r = \frac{\sum_{i=1}^{C} TPT_c}{\sum_{i=1}^{T} C_{r,t}}$$

4.8 Solution approach

The MILP developed is programmed in AIMMS (Advanced Integrated Multidimensional Modeling Software), and added as an add-in to MS Excel. A decision support tool is then created to make the model usable. The model is verified and validated by conducting a case study at MZH.

5. Case study

This chapter validates and verifies the developed model by conducting a case study at MZH. The model has been applied to the specialty of surgery, as this specialty performs most surgeries in MZH. A decision support tool which includes the MILP was developed. A screenshot of the decision support tool can be found in Appendix 3. This chapter discusses the results obtained from the use of the decision support tool for the specialty surgery. In Section 5.1, an overview of the specified scope for the case study is given. In Section 5.2 the input parameters for the model are defined. In Section 5.3 the output as provided by the model is verified. To indicate the impact of the input parameter 'weight', in Section 5.4 a sensitivity analysis is performed. Section 5.5 discusses the results of the output gathered by the application of the model to the specialism surgery. Finally, Section 5.6 discusses the conclusions that can be derived from the validation of the model.

5.1 Specified scope

The model developed in this study can be used hospital-wide, but to optimize several departments can be decoupled, as discussed in Section 3.2. The OT department and the wards are expensive for a hospital and therefore a main interest of the management of MZH. Furthermore, they can be decoupled, as concluded with Figure 3.13. Therefore, in this study is focused on the OT department and the wards. Besides this, because in MZH surgery performs the highest number of surgeries, the case study is conducted for the specialty surgery. Furthermore, only patients who visit both the operating room and the ward are included. Therefore, in this section a specified scope is given. Table 5.1 gives an overview of the specified scope for the case study. For this case study, we consider three main resources: Operating Theatre minutes, and beds at the IC and wards B2 and C2. These are the resources surgery patient use in MZH.

Table 5.1: Specified scope for case study

Within scope	Specified in case study
All time dimensions	Data from 2013, 2014, 2015
All hospital departments	OT department and wards
All hospital resources	For OT department: minutes For wards: number of beds
All specialties	Surgery
Capacity dimensioning	-
Patient routing	From OT department to wards
Capacity allocation	Capacity allocated to surgery
Admission control	-
Decision support tool to show capacity and planning decisions on utilization	-

5.2 Input parameters

In this section the input parameters for the model are determined. Therefore in Section 5.2.1, the values for the weights are determined. In Section 5.2.2, the patient groups for MZH are established. Finally, the input parameters for the target levels for the resources are set in Section 5.2.5.

5.2.1 Weight determination

The importance per resource of optimizing is determined by the costs. By using the costs we want to know the relative importance of the resources. As we can influence the patient flow with the model, we want to know which resource is most expensive for the hospital per patient. For the hospital it is important to organize the most expensive resources most efficiently. The cost price application of MZH has given the rounded costs in MZH per patient in 2014 and is demonstrated in Table 5.2. a_r can be calculated by taking the percentage.

Table 5.2: Determining a_r

Resource	**Cost price per patient on average**	$\boldsymbol{a_r}$
OT department	€856	25%
Intensive Care	€1984	57%
Nursing day at C2	€356	10%
Nursing day at B2 (day care)	€270	8%
Total	**€3466**	**100%**

5.2.2 Penalizing constant

We set the value for the penalizing constant to avoid excess capacity at 100. 100 is much larger than the over- and underutilization will be. Therefore, this number is large enough to penalize the excess capacity.

5.2.3 Patient groups determination

Patients can be classified using groups distinguished by similarities in their care path. For the OT department and the ward, surgery duration and length of stay are the indicators for the need for resources of the patient. A hospital is organized based on diagnoses of patients. Patients are grouped per specialism, and also planned according to their specialism: specialisms have their own block in the master surgery schedule of the OT department. Since we can therefore separate on specialism for the OT department, patients are already clustered on specialty. At the wards, it differs if one or more specialties are using these. In 2013 and 2014, respectively 1,684 and 1,784 were registered for surgery. From 2013-2015 MZH treated 128 different diagnoses for the specialty surgery. Within the specialty surgery, are sub specialties: 'general surgery and surgery for children', 'traumatology and emergency', oncology, 'lungs, and gastrointestinal surgery', and 'vascular surgery'. Appendix 5 gives a comprehensive overview of the diagnosis code within the sub specialties and Appendix 6 gives an overview about the averages per sub specialty.

To divide patients into patient groups, patients are first divided into the sub specialties, since these patient groups might also need different specialists. To indicate the load on resources, a distinction for the length of stay is made as well. Data analysis revealed that the length of stay increases when the surgery duration is longer. Moreover, because most patients stay only one day a separate category for these patients is created, because patients only staying one day also go in principal to another ward than patients staying longer. Patients staying 2-5 is quite normal after more difficult surgery, therefore also a separate category for these patients is created. Patients staying longer than 5 days are relatively unpredictable, because often these patient have complications. Therefore a category with patient staying longer than five days is created. This distribution of length of stay resulted in adequate distribution of number of patients within the categories. Most patient are staying one day, less patients 2-5, and the least patients longer than five days. Thus, we obtain three categories for the length of stay: 0-1 days, 2-5 days, and longer than 5 days.

So, each patient group is characterized by sub specialty and LOS. Then, we determined the average number of patient per group per week, and the OK duration plus changing time at the OT department. More data about the number of patient per week and the surgery duration can be found in respectively Appendix 7 and Appendix 8. Furthermore, the standard deviation of the OK duration plus changing time is given. Table 5.3 shows the patient groups as used in this thesis. The last column shows the mean of surgery duration plus changing time with the standard deviation.

Obviously, only data for the specialty surgery is selected. To determine the input parameters for the patient groups, historical data is use, where it is assumed that LOS, surgery duration and changing time would not change over these years. This way, the sample size of patients is large enough to draw conclusions.

In the decision support tool, deterministic surgery durations are assigned to each patient category. For the LOS (Length of Stay), a probability is assigned that the patient will be at the ward each day after admission. In this context, the day of admission means the first day in the hospital, so if a patient needs preoperative day(s), the first preoperative day is the day of admission. Also, the stay at the IC is included, as a probability of staying at the IC is assigned too.

Table 5.3: Patient groups

Patient group	**Subspecialty surgery**	**LOS**	**Average number per week in 2014**	**Percentage total (%)**	**Surgery duration + changing time**	
					Mean	**Standard deviation**
1	General surgery and surgery for children	0-1	10	33	61	21
2		2-5	3	10	75	33
3		>5	1	3	115	42
4	Traumatology and emergency	0-1	3	10	64	31
5		2-5	2	7	96	47
6		>5	1	3	123	55
7	Oncology, lungs, gastrointestinal surgery	0-1	2	7	75	26
8		2-5	5	17	97	30
9		>5	2	7	161	67
10	Vascular surgery	>0	1	3	84	46

5.2.3.1 Determination of the length of stay

The system of MZH automatically provides the length of stay of patients. This measure represents the actual stay of the patient: when a patient is admitted to a bed at noon and discharged the next day at noon, the length of stay is one. Because in this study we look at the tactical level, every day a patient is registered at a bed is counted as a nursing day. This means when a patient is admitted to a bed at noon and discharged the next day at noon, in this study the length of stay of the patient is two.

Pre-operative stays are established by calculating the probability the patient is at the ward the day before surgery. The rest of the calculations of the length of stay are done by firstly determining the total number of patients at all wards. Then, the number of patients still at the wards at each day at the wards, and divided by the total number of patients. A distinction is made for the IC: it is calculated how many patients are at the IC after surgery.

Finally, the probability of staying after the day of surgery, is based on empirical distributions, derived from historical data.

5.2.3.2 Determination of surgery duration plus changing time

To determine the use of the resource of the OR per patient, the gross surgery duration is added to the registered changing time per patient.

5.2.3.3 Clinical and day care patients

Patients in the hospital are classified as clinical or day care patients. In the registration, patient are seen as day care patients if patients stay minimal 2 hours at a nursing unit and do not stay overnight. In the data some of these patients are registered on a clinical bed instead on a day care bed. But, since we prefer patients with a length of stay shorter than 24 hours on a day care bed, all patients with a length of stay shorter than 24 hours are assigned to the patient group with a length of stay of 1 day. In the model, these patients are always assigned to day care beds.

5.2.3.4 Pre-operative stay

Some patients are admitted to the hospital one day of more before surgery. The probability a patient stays one day before surgery is calculated and added to the parameter determining the probability of staying after surgery, with day -1.

5.2.3.5 Validation of the patient groups

The patient groups were validated by a specialist of surgery, and different managers in the hospital. They checked of there are certain patient groups that can only be operated by a certain specialist. Despite selecting on subspecialty and length of stay, some variability remains within the patient groups concerning surgery duration plus changing time. This is due to the variability related to human characteristics: each patient is different. The patient groups are approved by MZH to be useful and detailed enough for categorizing and to be manageable at the operational level.

5.2.3.6 Current distribution of the patient groups per day of the week

Figure 5.1 gives an indication of the distribution of the patient groups currently spread over the days of the week. It reveals that patient groups are quite equally spread of the days of the week in the current situation. Every patient group occurs at every day of the week. On Mondays, less patient are admitted, but is probably caused by surgeries planned on Mondays with long surgery durations as indicated by specialists of MZH.

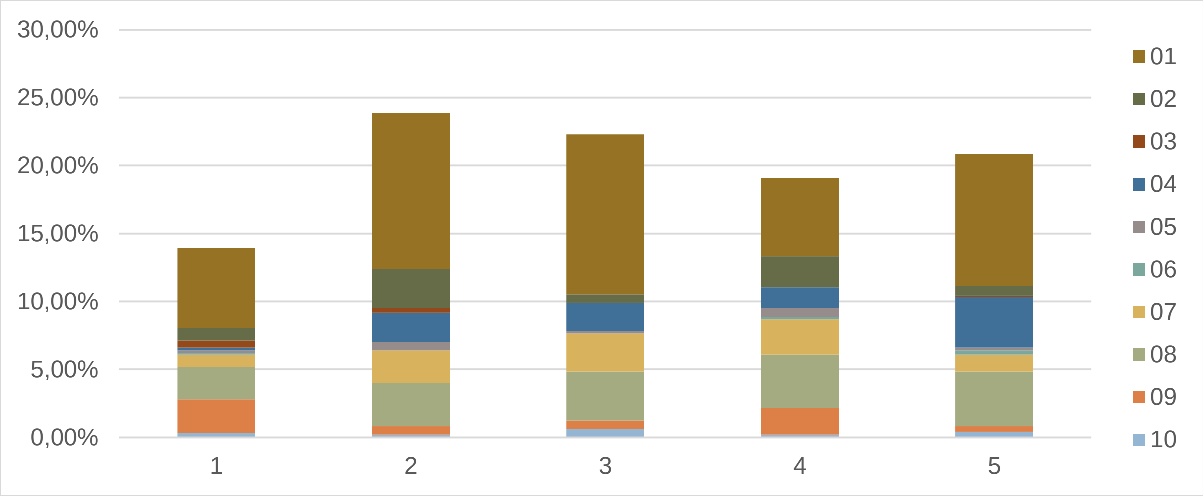

Figure 5.1: Current percentage patients per patient group per day of the week

5.2.4 Patient group restrictions

Due to the MSS some patient categories cannot be operated on every day of the week. In this case study, the subspecialty 'Oncology, lungs, gastrointestinal surgery' can only perform surgery on Mondays and Tuesdays.

5.2.5 Determination of target levels

In this section, the target levels per resource are determined.

5.2.5.1 OT department

In general a target level of 85-90 per cent is often used as the target level for the capacity utilisation of regular sessions in the operating theatre departments. Above this level it becomes difficult to handle semi-urgent and urgent operations that are added to the session (Vissers & Beech, 2005). Since this OR 4 is intended for elective patients in MZH, we set all available capacity for elective patients. Therefore, despite some variability in surgery duration within the patient groups, the target level is set at 100%, to plan the OR fully.

5.2.5.2 Wards

As a target level for the utilisation of beds during the week, in hospital practice one often uses an average 85-90 per cent. Above this level it becomes difficult on busy days to find an empty bed in case of an urgent admission (Vissers & Beech, 2005). Since at MZH wards are used by more than one specialty, only a part of the beds is allocated to surgery. Because in the database of MZH about 50% of the beds of C2 is normally used by the speciality surgery and the total number of beds is 27, we set the available beds for surgery at C2 on 56%, which is 15. In the weekends, we set the number at 10 to reduce the number of stays in the weekends. For B2 this is about 20%. The total number of beds of B2 is 30, which makes the available capacity 6 beds. For the IC, surgery uses less 1% of the beds, but if a certain patient group is admitted we know that there is a chance the patient will need a bed. Therefore we set the available beds at 1. For each ward we set the target utilisation percentage at 90%, so that beds for urgent patients are available.

5.3 Model verification

The model is verified to ensure that the model is computationally correct, i.e. that it calculates what it is supposed to. A model containing errors (of both omission and commission) is useless. The programmed problem in AIMMS contains no errors.

Furthermore, the following is checked:

- Model output results were checked for reasonableness
- The objective function should be above zero
- The number of patients admitted per week should be equal to the target set
- The number of patients admitted per category per day of the week should be a collection of natural numbers ($\in \mathbb{N}$)

All of these requirements are satisfied by the model.

5.4 Sensitivity analysis

This section discusses the relative importance of the input parameter 'weight' (w_r) by performing a sensitivity analysis. In Section 5.2.1, weights are determined based on costs per patient per resource. It is also possible to determine the weight based on importance according to the stakeholders. Therefore, sensitivity analysis is performance to determine the effect of a change in this parameter. Table 5.4 gives an overview of two weight scenarios (A and B), which are applied to the model. For situation A, the predefined parameters (Section 5.2.1) for the weights are used. For situation B, 100 points are divided over the resources, where OR is highly ranked, since the hospital might for example prefer to manage the OR most efficiently.

Varying the weight did not change much in resource utilization, as can be found in Table 5.5. The utilization at the IC stays exactly the same, the rest of the resources differs little. As it does not influence much we conclude the weight has a minimal influence on the optimal solution. This means the weight is not an influential factor in determining the optimal patient planning and capacity.

Table 5.4: Varying weight parameters

Resource	*A (Based on costs)*	*B (OR most important)*
OR	25	70
IC	57	10
B2	10	10
C2	8	10

Table 5.5: Resource use per weight parameter

Resource	*Weight scenario*	*Used capacity per day of the week (Mo-Su)*						
		1	*2*	*3*	*4*	*5*	*6*	*7*
OR (minutes)	A	505	513	469	506	505	-	-
	B	513	505	469	507	504		
IC (beds)	A	0.77	0.725	0.175	0.15	0.07	0.237	0.15
	B	0.77	0.725	0.175	0.15	0.07	0.237	0.15
B2 (beds)	A	2	1	4	5	3	-	-
	B	1	2	4	3	5	-	-
C2 (beds)	1	9.477	12.34	13.4	13.83	12.74	8.95	7.37
	2	10.29	12	13.35	13.68	12.56	8.78	7.46

5.5 Model results

This section presents the results gathered by entering the data from MZH into the model. The performance measure of interest is the difference between target utilization of the resources and the realised utilization as provided by the model. Furthermore, the model gives an output of number of patients per patient group to be admitted per day of the week. The data in the model are the data from 2014, for both the number of patients arriving each week and the MSS i.e. the available time for surgery. The outcomes of the model provide evidence that the model does what it should do. The objective function has a value of 5.42 This score is the outcome of objective function (1) as formulated in Chapter 4, and represents the weighted sum of the deviations between the realised and the target utilisation involved per day of the week. A lower score means a better fit between realisations and target. Therefore, the best possible solution would be solution of 0, indicating no differences between realised and target utilisation. However, this would mean patient demand would be equal to available capacity which is unrealistic.

Patient admission profile

Table 5.6 gives the patient admission profile for the OT department as calculated by the model. This profile gives an optimal balance between OT department and the wards used by the specialty surgery. Figure 5.2 visualizes the number of patients per patient group to be admitted per day of the week.

Table 5.6: Patient admission profile calculated by the model

Patient group	Day of the week							Total
	1	2	3	4	5	6	7	
1	0	1	4	2	3	0	0	**10**
2	0	0	3	0	0	0	0	**3**
3	0	0	0	0	1	0	0	**1**
4	0	0	0	3	0	0	0	**3**
5	0	0	0	2	0	0	0	**2**
6	0	0	0	0	1	0	0	**1**
7	2	0	0	0	0	0	0	**2**
8	2	3	0	0	0	0	0	**5**
9	1	1	0	0	0	0	0	**2**
10	0	0	0	0	1	0	0	**1**
Total	**5**	**5**	**7**	**7**	**6**	**0**	**0**	**30**

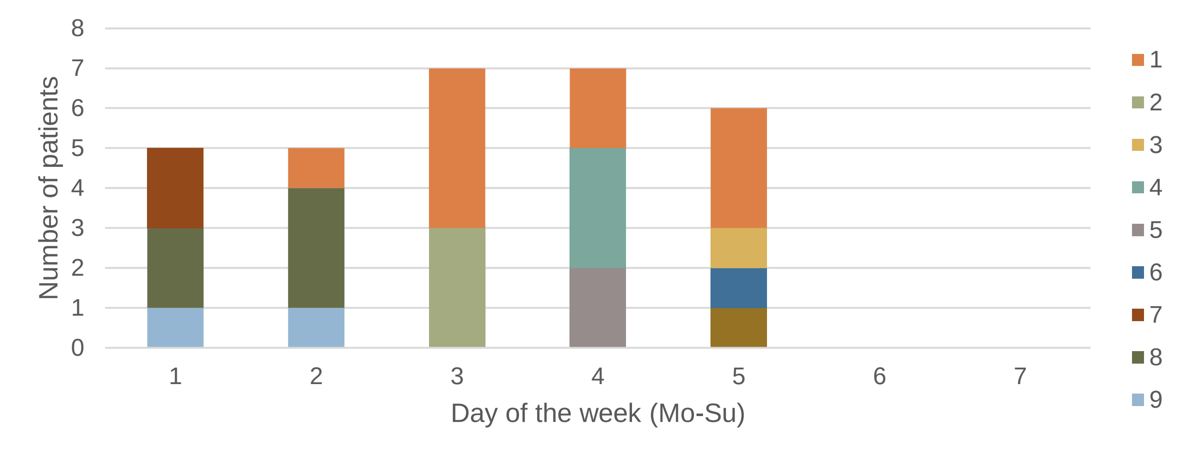

Figure 5.2: Number of patients to be admitted per day of the week

Resource utilization

Figure 5.3, Figure 5.4, Figure 5.5, and Figure 5.6 give an overview of the resource utilization per resource compared to the target resource utilization previously set, and the current situation as described in 3.1.4.

Note that for the OR the capacity is equal to the target level, which means the blue line is not visible. The OR utilization is near target level, with a slight decrease at Wednesdays. Furthermore, we see that currently the resource utilization is lower than the utilization planned by the model.

For the IC, on Mondays and Tuesdays, the need for one bed is higher than on the other days for the capacity calculated by the model. It does, however, not reach the target level. This is due to the low probability that a surgery needs to go the IC. In the current situation, the need for a bed is higher at the end of the week, but we know from 3.1.4, the standard deviation is high.

For B2, Wednesday is the busiest day, since five beds are needed. On Mondays and Thursdays is respectively only two and one bed needed. In the current situation the number of beds needed seems smoother than the number of beds needed in the optimal situation, but this is due to the average: we know from 3.1.4 the number of beds needed in the current situation fluctuates a lot.

For C2, the number of beds during the working week is higher than in the weekends. On Thursdays the target number of 14 beds is practically reached. Especially on Mondays, less beds are needed according to the optimal schedule. Since in the weekends the OR is not used, at Mondays less patients are in the hospital, while at the Tuesdays, Wednesdays, Thursdays, and Fridays the number of patients accumulate. In the current situation on Mondays, more beds are needed than in the optimal situation. Also, in the weekends are more beds needed. It seems the model has shifted more patients to the work week at C2. The results of the model can influence the number of nurses needed, as further elaborated in 8.2.

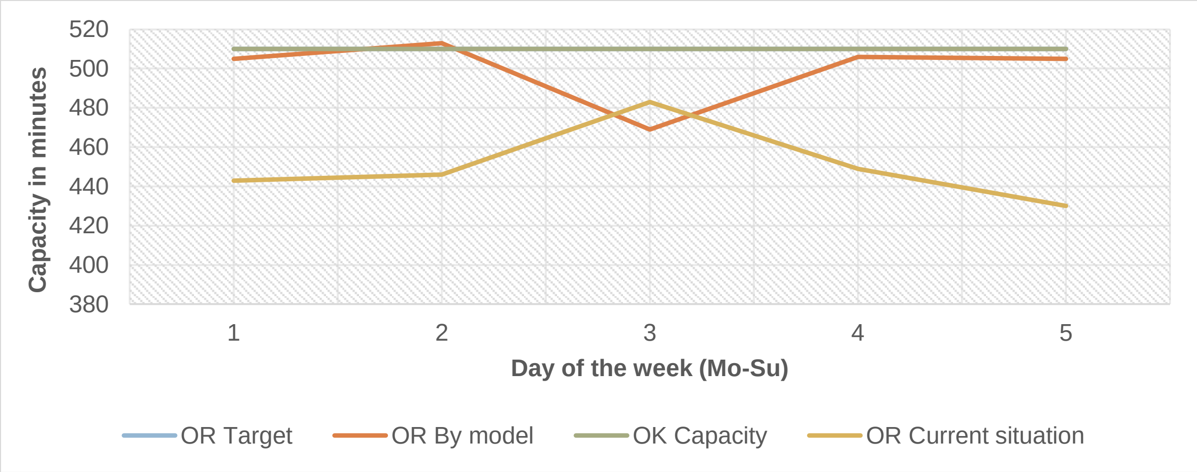

Figure 5.3: Target, realised and current use of capacity OR

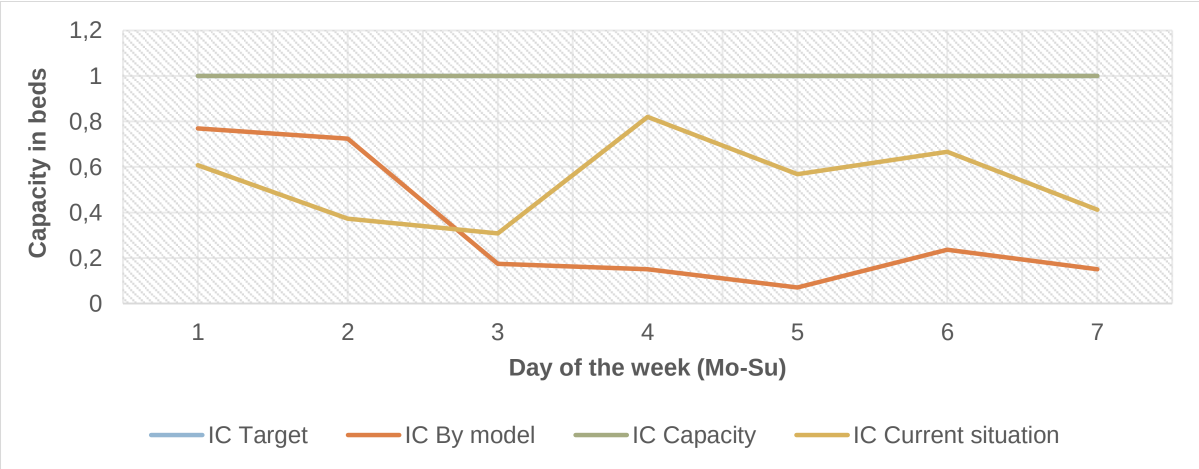

Figure 5.4: Target, realised and current use of capacity IC

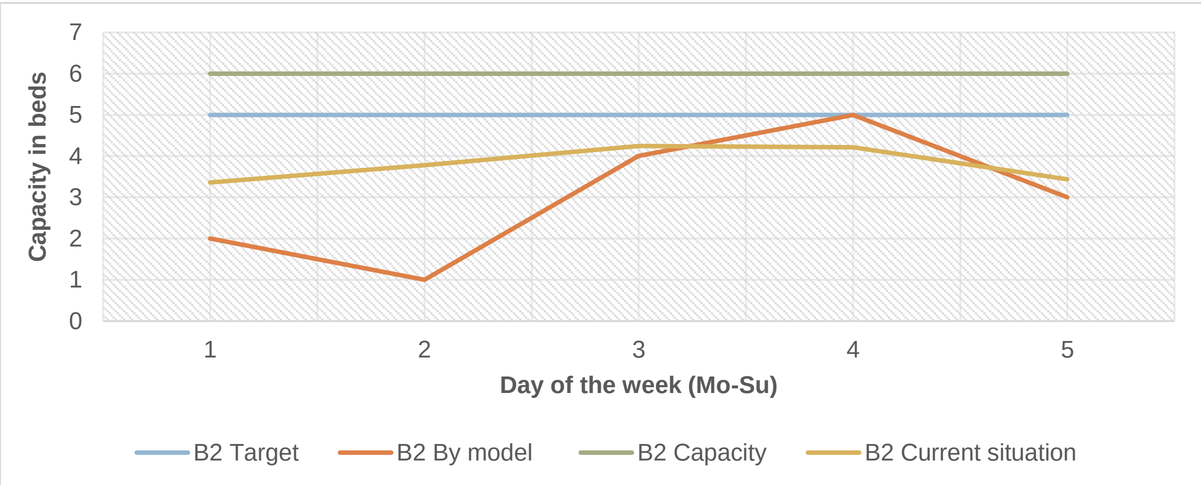

Figure 5.5: Target, realised and current use of capacity B2

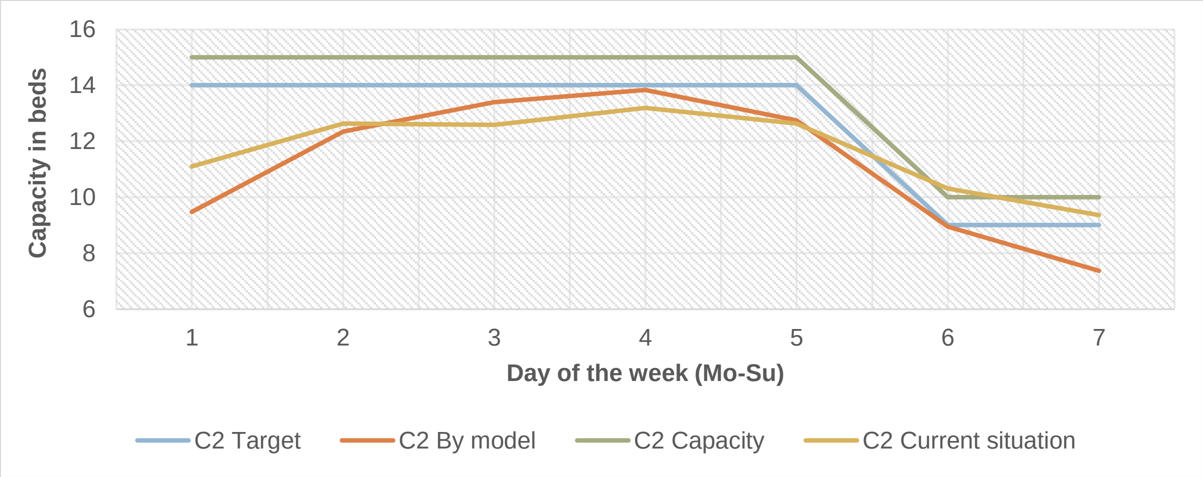

Figure 5.6: Target, realised and current use of capacity C2

5.6 Conclusions from the case study

The decision support tool correctly captures the objective to optimize patient planning and capacity over different departments. Furthermore, the decision support tool satisfies the requirement that the behaviour in the conceptual model should be identical to the behaviour of the executable model.

Therefore, the decision support tool is able to support the management of Maasziekenhuis Pantein in optimizing patient and capacity planning at the tactical level. Besides the optimal patient admission scheme, it provides an overview of the expected need for capacity for each day of the week. Furthermore, the tool gives an overview of the capacity used per patient group.

6. Scenarios

By testing the model in MZH in Chapter 5, the model is considered validated and verified. The model works appropriate, and has shown to be a good approach to optimize patient planning and capacity for multiple departments. In this chapter, three different scenarios are tested to review on three decisions that could be made at the strategic level, in comparison to the basic scenario presented in Chapter 5. The goal of this scenario analysis is to find a better balance in resource use, which means improving the objective function: the weighted sum of the deviations between the realised and the target utilisation involved per day of the week. Furthermore, data for 2015 is used as input to find an optimal solution for 2015. Therefore, in this chapter, other input parameters are used, and a new optimal solution is obtained per scenario. Finally, the results of the different scenarios are discussed, to conclude for MZH about the impact of possible changes at strategic level.

In collaboration with MZH, four scenarios are applied to the model. These are:

1. Expand operating room capacity to 7:00 PM
2. Lower capacity to avoid costs in the weekends
3. No restrictions on the patient groups per day
4. Apply 2015 to the data

The chapter describes per section the content of a scenario and discusses the results of applying the scenario to the model. Table 6.1 gives an overview of the occupancy per day of the week per scenario, Table 6.2 gives the values of the objective function per scenario.

6.1 Scenario 1: Expand operating room capacity to 7 PM

The MZH knows that some hospitals operate until 7 PM. Therefore they would like to know what results in efficiency this scenario would give. It might be possible that if the OR operates until 7:00 PM, the patient flow at the wards may be more stabilized.

This scenario has a value for the objective function of 5.72, which is lower than the basic scenario. Furthermore, this scenario results in a lower occupation rate at the OR, which of course due to the extra minutes and the same number of patients to be planned. The wards are not more balanced, as occupancy rates differ more than in the basic scenario. This means this scenario does not give a better situation than the basic situation.

6.2 Scenario 2: Lower capacity in the weekends to avoid costs

Since we know that beds are more expensive in the weekends than during work weeks due to more expensive staff, we can lower the capacity in the weekends. We lowered C2 from 10 to 5.

The value of the objective function for this scenario is 13.4, which is a large increase. This is due to the result of an average occupation of 1.04 at C2, since in the weekends five beds is not enough. The penalizing constant for excess capacity causes then a large increase in objective function. In this new scenario, on Saturdays now one patients less is expected (from about 9 to 8). But, this also results in a less stable utilization at C2, since on Fridays now less patients are expected (from 14 to 10), and the other days differ somewhat more from each other in utilization. As a less balanced resource utilization is obtained, this scenario is not better compared to the basic situation.

6.3 Scenario 3: No restrictions of patient groups per day

This scenario gives an indication of what the optimal situation would be if surgeons are available every day of the week to perform every operation. The hospital is interested in this scenario because it has the feeling this would be manageable, and also to know what the impact of such a decision is.

The output for this scenario gives a negligible gain in the objective function compared to the impact this decision has on the organization of the hospital. The value of the objective function for this scenario is 5.08. Regarding the occupancy rates, no (rounded) difference exist between the basic scenario and scenario 3, which means the gain in ignoring the patient groups is negligible.

6.4 Scenario 4: Apply 2015 to the data

For this scenario, the arrival rates in number of patients for 2015 are used as input for the mode. Furthermore, in 2015 surgery has an extra block in the MSS on Monday, which means on Monday the amount of OR time doubles to 1020 minutes.

The objective function is quite high for this scenario, this is due to exceeding capacity at the IC. Therefore, the capacity at the IC should be increased in 2015. This is due to the increase of OR utilization, and the different number of patients per patient group to be admitted in 2015 It seems like a large increase but it has only reached to an expected number of patients of 1.33 at the IC on Mondays. Figure 6.1 gives the model to implement in 2015.

Patient group	Day of the week 1	2	3	4	5	6	7	Total
1	0	2	2	5	4	0	0	**13**
2	1	0	2	0	0	0	0	**3**
3	0	0	1	0	0	0	0	**1**
4	2	1	0	0	1	0	0	**4**
5	0	0	0	2	0	0	0	**2**
6	0	0	1	0	0	0	0	**1**
7	0	2	0	0	0	0	0	**2**
8	5	0	0	0	0	0	0	**5**
9	2	1	0	0	0	0	0	**3**
10	0	0	0	0	2	0	0	**2**
Total	0	2	2	5	4	0	0	**36**

Figure 6.1: Patient admission profile calculated by the model for 2015

6.5 Conclusions from scenarios

This section discusses the conclusions that can be derived from the different scenarios. Table 6.1 and Table 6.2 present respectively the different results in average occupancy per resource and the result of the objective function. Scenario 3 (no restrictions of patient groups per day) gives the lowest number for the objective function. This indicates that for scenario 3 the realised level by the model differs least from the target level. This makes sense, since less restrictions are set on patient groups, but as mentioned before the gain is negligible. Furthermore, none of the factors applied to the scenarios is most influential, because for scenario 1, as expected, the OR decreases since more time is available, but does not cause a better occupation rate at the wards. Reducing capacity in the weekends (scenario 2) results in a less stable utilization at the wards, however if reducing capacity in the weekends is desirable this scenario can be an option to implement. Thus, we can conclude that applying the basic situation works best in terms of minimizing over- and underutilization. However, there are trade-offs regarding goals that are met, because also other goals than resource utilization are possible. In Chapter 7, the scenarios are also evaluated with respect to quality.

Finally, also the 2015 scenario is given, with the same characteristics as for 2014, this means as capacity for OR utilization stays the same, this scheme can be implemented for 2016.

Table 6.1: Occupancy per day of the week per scenario

		Day of the week (Mo-Su)						
		1	**2**	**3**	**4**	**5**	**6**	**7**
OR	**Basic**	0.99	1.01	0.92	0.99	0.99	0.00	0.00
	1	0.93	0.91	0.88	0.48	0.59	0.00	0.00
	2	1.01	0.99	0.94	0.99	0.97	0.00	0.00
	3	0.94	0.99	0,98	0.98	1.00	0.00	0.00
	4	0.99	0.97	1.00	0.97	0.93	0.00	0.00
IC	**Basic**	0.77	0.73	0.18	0.15	0.07	0.24	0.15
	1	0.67	0.73	0.18	0.32	0.17	0.17	0.05
	2	0.67	0.73	0.18	0.15	0.24	0.17	0.15
	3	0.08	0.21	0.80	0.18	0.77	0.11	0.14
	4	1.33	0.79	0.29	0.36	0.20	0.21	0.06
B2	**Basic**	0.33	0.17	0.67	0.83	0.50	0.00	0.00
	1	0.50	0.33	0.83	0.00	0.83	0.00	0.00
	2	0.17	0.33	0.17	0.83	1.00	0.00	0.00
	3	0.17	0.17	0.67	0.83	0.67	0.00	0.00
	4	0.33	0.83	0.33	0.83	0.83	0.00	0.00
C2	**Basic**	0.63	0.82	0.89	0.92	0.85	0.89	0.74
	1	0.69	0.86	0.92	0.88	0.80	0.86	0.72
	2	0.68	0.81	1.00	1.00	0.70	1.61	1.45
	3	0.69	0.92	0.93	0.81	0.74	0.89	0.78
	4	0.96	1.00	0.94	0.94	0.94	0.99	0.91

Table 6.2: Value objective function per scenario

	Objective function
Basic	5.42
1	5.72
2	13.4
3	5.08
4	35.6

7. Quality

This chapter discusses the influence of the model on quality. In Section 7.1 the effects of the model on quality regarding the basic scenario are analysed. Section 7.2 describes the trade-offs with respect to quality for each scenario as discussed in Chapter 6.

7.1 Effects on the basic scenario

Considering the results of this study, in this section it is specified how it contributes to a higher quality of care. Besides optimizing patient planning and capacity, a major concern is the effects of the model on quality as this is an important aspect for healthcare. A common used definition of quality is: “Quality is the extent to which health services for individuals and populations increase the likelihood of desired health outcomes and are consistent with current professional knowledge” (Institute of Medicine, 1990 as cited in Ozcan, 2009). Research revealed multiple models with elements of high quality of care. For this project the model of Institute of Medicine is used with the elements of high quality healthcare (Institute of Medicine, 2001). In order to clarify these outputs, different aspects of the model are linked to the elements of high-quality healthcare defined by the Institute of Medicine:

- ***Safety:*** minimizing medical errors and injuries
- ***Effectiveness:*** maximizing intended health outcomes
- ***Patient-centeredness:*** focusing on patient and family preferences, goals, and priorities in making treatment plans,
- ***Timeliness:*** minimizing delays and waits
- ***Efficiency:*** providing maximally cost-effective care
- ***Equity:*** providing care of equal quality regardless personal characteristics (gender, ethnicity, insurance coverage, etc.)

Each of these elements are of value in this project, since with these elements, we can determine the effect of the model on quality of care. The elements can be translated to factors actually influencing these aspects. In patient satisfaction these factors are all reflected. The main effect of the results of this study that processes are stabilized by minimizing over- and underutilization. Litvak et al. (2005) addressed the variability in patient demand and concluded that by reducing unnecessary variability, hospitals can reduce many stressors and thereby improve patient safety and quality of care. In the current situation in MZH, nursing units do not have an overview of averages about incoming patients per week. With the model, nursing units can respond to the prediction of needed beds in their nurse planning. The results is a less likely chance of stress for nursing staff.

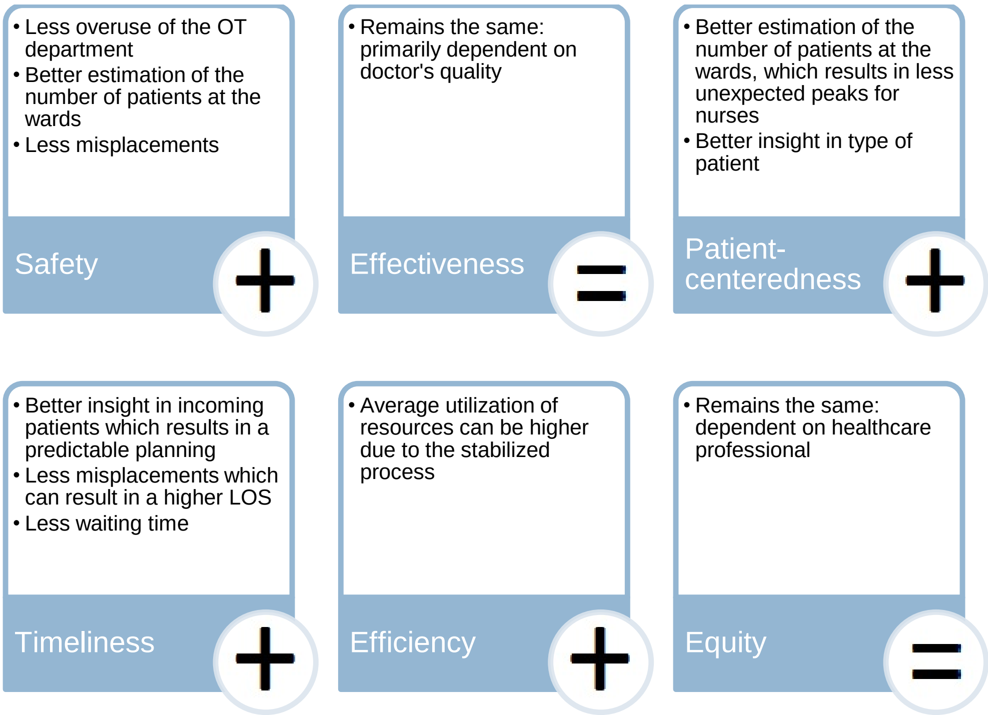

Figure 7.1: The effect of the model on the elements in determining quality of care

Firstly, safety is influenced by the overuse of the OT department. If the staff need to work longer than expected, there might be a risk on safety. People can be tired, but also demotivated since they did not expect to work. The staff need to be flexible, and this depend per person how much the person is influenced by sudden change in schedules. With the model, a lower risk exists on overuse, because overuse can also be better indicated since now information is available about surgery durations based on historical data. Secondly, a better estimation of the number of patients at the wards is given, which results in a lower likelihood that nurses have to care too much patients, and therefore do not have enough time for these patients. Finally, since the average number of patients is known, a lower likelihood exist that patients are misplaced at a ward which does not belong to their specialty. Since wards are specialized in type of patients, being at the wrong department has a negative impact at the safety.

Effectiveness focuses on the intended output. This can be for example measured in number of intended consult versus realised consults or intended versus realised length of stay to measure the quality in recovery. The model in this master thesis does not has impact on these measures.

Patient-centeredness increases while applying the model. Applying the model results in a better estimation of the number of patients at the wards, and therefore less unexpected peaks for nurses. Peaks are in disadvantage of the patient, since the nurse should distribute attention. Furthermore, the model indicates types of patients, since data analysis with historical data has revealed what type of patients stay at MZH. Therefore, when nurses know that for example patients from patient group 1 and 3 differ in the need in care. Patients of group 3 normally have had a longer surgery time, which means they also need to recover more.

Timeliness increases due to awareness of numbers of incoming patients. This means a higher utilization of resources can be reached which means a higher throughput, which results in a shorter waiting time on average. Furthermore, by implementing the model the probability that a patient is placed at the wrong unit is decreased which means patient will stay on average shorter in MZH. This means the patient will be home sooner and gives therefore an increase in timeliness.

Efficiency means here providing maximally cost-effective care. Since utilization can be increased at the department, it means with the same amount of input, we can create more output. This is an increase in cost-effective care.

Equity is not changed by implementing the model, since we assume in the planning of patients no distinction is made regarding personal characteristics. Furthermore, the way of providing care to the patient is also assumed not to be changed.

7.2 Trade-offs per scenario

Chapter 6 has concluded that the basic scenario works best in terms of minimizing over-and underutilization. However, resource utilization is only one aspect of quality of care, because it is only directly related to the element Efficiency. Therefore, in this section the trade-offs in quality per scenario are analysed.

1. Expand operating room capacity to 7:00 PM

This scenario has a positive effect on the element Timeliness, because more capacity is available and therefore more operating time is available. Waiting lists will shorten. In contrast, Efficiency decreases as resource utilization is lower. Expanding the operating room capacity to 7:00 PM does not influence the other elements of capacity.

2. Lower capacity to avoid costs in the weekends

This scenario does not affect the elements of quality in general, because it is only about costs. Since capacity had been lowered in the weekends, a shift occurred in bed occupation from the weekends to week, but did not result in a large increase or decrease in efficiency. Therefore, also this element of quality is not affected.

3. No restrictions on the patient groups per day

This scenario only affects the element Efficiency, because the resource utilization increases little, but minimal. The other elements remain unaffected as the only difference in this scenario for the patients is the possibility to be operated on another day of the week.

4. Apply 2015 to the data

In this scenario, surgery has extra operating time available. This results in an increase of the element Timeliness as patient can be operated sooner. Although, resource utilization decreases which means Efficiency decreases.

8. Estimation of the impact on costs

To get an idea about the impact of implementation of the results of the model, in this section an estimation of the impact on costs is given. The main advantage of the use of the model, is stability in the use of resources which implies on average less variation in at the OR, and less variability in use of beds. In this chapter, the calculated optimal scenario is compared to the current situation in MZH.

MZH has a cost price application which calculates the cost price for all activities in the hospital. Using this, we can determine the cost price per resource per patient. Per resource the cost price is dependent on direct and indirect costs. Indirect costs are for example the cost of the building. Direct costs are for example food at the nursing unit for the patient. Table 8.1 gives in the first column an overview of the costs per resource per patient at MZH, and within brackets specifically the costs related to staff.

Table 8.1: Resource costs at MZH

Resource	*Costs per patient in 2014 (cost directly related to staff)*
OK	Price of a care activity at the OR €856 (€228)
IC	IC day €1984 (€895)
B2	Day care €270 (€97)
C2	Nursing day €356 (€138)

Then, we identified three factors related to this project which influence the costs per resource per patient. These are:

- The degree of overtime at the OR
- The number of misplacements
- Work-weekend ratio at the wards
- Nurse-patient (n-p) ratio

The degree of overtime at the OR leads to an increase in costs due to expensive irregular hours for the staff as can be found in Table 8.2. Furthermore, the number of misplacements is an important factor, since research showed that patient not on the most appropriate speciality ward for their condition can lead to length of stay increasing by an average of 2.6 days (Emergency Care Intensive Support Team, 2010; Royal College of Physicians, 2012a; Alameda and Suárez, 2009 as cited by Lewis & Edwards, 2015). An increased length of stay results in higher costs for the hospital because no other patients can use the bed at that moment. Work-weekend ratio of patients at the wards is important because the staff is more expensive in the weekends as can be found in Table 8.2 as well. The extra costs are compensation for irregular hours (NL: ORT = Onregelmatigheidstoeslag). The n-p ratio gives an indication of the number of patients per nurse, and is important because if the number of patients arriving at the wards is known, the number of nurses can be better determined. MZH has applied the following ratios per part of the day in its cost price application:

Normal bed and day care (day care only during daytime):

- Daytime 1-5
- Evening 1-10
- Night 1-15

IC:

- Daytime 1-2
- Evening 1-5
- Night 1-7.5

Table 8.2: Extra costs for the hospital at irregular hours (Nederlandse Vereniging van Ziekenhuizen, 2014-2016)

Day of the week	*Part of the day*	*Increase in salary in percentage*
Mo-Fr	8-10 PM	+22%
Mo-Fr	10 PM – 6 AM	+47%
Sa	6 AM – 8AM	+38%
	12 PM noon - 12 AM midnight	+52%
Sa	12 AM – 6 AM	+52%
	10 PM – 12 AM	+52%
Su	12 PM midnight – 12 PM midnight	+60%

The model provides information about the need of resources of patients treated in the hospital. With this information, utilization of ORs and beds is stabilized. The following sections discuss three reductions in costs for the specialty surgery by implementing the admission scheme to improve patients flow between OT department and wards, and gives a total saving potential in costs of over €100.000:

- Reduce in misplacements
- Reduce in number of nurses
- Reduce in overtime at the ORs

8.1 Reduce in misplacements

As the expected number of patients at the wards is known with implementing the model, the probability that a patient needs to stay at another department decreases. This results in a reduction of the total number of nursing days at the hospital, because patients are treated at the right unit. Currently, the most misplacements for elective surgery in MZH are patients who stay at the day care unit while being a clinical patient, since in 2014 13% of the nursing days for elective clinical patients were at B2. This also holds the other way around, because in 2014 9% of the nursing days for day care patients were registered at C2. With the output of the model, the focus is more on the type of patients entering the hospital. Knowing that many patients are day care patients, it is important to let them stay at the day care unit because 1) the cost price for a nursing day is lower, and 2) patients get the appropriate care, which result in a lower length of stay. The ideal scenario would be that the percentage misplacements as mentioned above would be reduced to zero. As mentioned in Chapter 7, the LOS can increase to 2.6 days extra. Since MZH is a small hospital, relatively more elementary operations are performed, which means on average patients stay shorter than in the large academic hospital. Therefore we set the extra days to 1.5. Table 8.3 demonstrates the number of misplacements in 2014. Since a day care nursing day at B2 has a cost price of €270, and at C2 €356, and multiplying this with the difference in number of misplacements in Table 8.3, the total difference in cost price for nursing days by preventing misplacements is more than €20.000.

Reducing the number of nursing days, thus saves a lot of money. But note that one patient less at a unit does not directly result in less costs. But, in the long term, other patients can use those beds, which gives an increase in revenue.

Table 8.3: Overview of number of misplacements in 2014

Unit	*Number of misplacements in 2014*	*Without misplacements*	*Difference*
Day care	21	14	7
Clinical	199	133	66

8.2 Reduction in number of nurses

As the bed utilization is now quite variable over the weeks, nursing staff is mostly planned at the level of the maximum number of patients at the unit. As nurses now have the feeling that patients are coming unexpectedly, applying these ratios to the output of the model, means possibly a lower number of nurses at the units. Number of nurses are based on graphs created by staff of MZH. In MZH general nurses costs €24,50 per hour for the hospital, as calculated by Finance & Control. With ORT this makes for +22%, +38%, +47%, +52% and +60%, respectively rounded €30, €34, €36, €37 and €39. Note that the minimum of nurses that should be available at a unit is two. The current number of nurses at the unit is derived from graphs created by MZH, which can be found in Appendix 9. Table 8.4 demonstrates the current number of nurses per unit and what the number in the future could be, based on the number of patient at the units calculated by the model (Figure 5.5 and Figure 5.6) and the n-p ratio. Note that at B2, no savings can be made despite the variation in number of patients varies per day from 1 to 5. This means at Thursdays the one nurse is fully dedicated to surgery patients, while at Tuesdays the nurse can also treat patients from other specialties. Taking the sum of patients from all specialties each day, this might also result in one nurse less at Tuesdays.

Table 8.4: Overview of number of nurses per unit in current and new situation

Unit	*Number of nurses per part of the week (n-p ratio)*	*Current situation # of nurses*	*# allocated to surgery (20% B2, 56% C2, see 5.2.5.2)*	*New situation*
B2	Week Daytime (1-5)	4	1	1
C2	Week Daytime (1-5)	7-8	4	**3**
	Week Evening (1-10)	4	2	2
	Week Night (1-15)	2	1	1
	Weekend Daytime (1-5)	6	3	**2**
	Weekend Evening (1-10)	3	1-2	**1**
	Weekend Night (1-15)	2	1	1

Unit C2 is open every day of the week, however, when the OR schedule is reduced, the number of needed beds is also reduced. This is for 13 weeks per year. Since at C2 fewer nurses can be scheduled, we calculate the cost savings possible at C2 with Equation (9).

$$(52 - 13) * \# \, days \, per \, week * number \, of \, hours \, per \, service * (€24{,}50 * 1 + \frac{ORT}{100}) \qquad (9)$$

This formula is used to calculate the savings concerning personnel. As mentioned, 13 weeks per year MZH works according to a reduction scheme for the OR. Therefore, 52 is distracted from the number of reduction weeks per year. This number is multiplied by the number of days a reduction in nurses can be applied. Then, the number of hours per service is (mostly 8 hours) is multiplied by the costs of one nurse for MZH. These calculations give a result of over €80.000 savings in cost for MZH. Note that in reduction weeks, also a lower number of nurses can scheduled since the expected length of stay of patients is known.

8.3 Reduce in overtime at OR

A reduction in overtime at the OR can be achieved, because in this study the average surgery durations per diagnosis are calculated based on historical data. This means a better estimation of surgery duration is available and can be used for planning.

With the optimal scenario, we can assume a normal distribution for OR duration per patient as also is done in Choi & Wilhelm (2014). Appendix 8 gives histograms with normality plot for each patient group's surgery duration. None of them fits perfectly the normal distribution but to calculate in this section normality is assumed. Calculating the probability of overuse, means all normal distributions per day are added. If X and Y are independent random variables that are normally distributed, then their sum is also normally distributed. Since patients are operated independently from each other, we can assume their OR durations are independently from each other.

$X \sim N(\mu_X, \sigma_X^2)$

$Y \sim N(\mu_Y, \sigma_Y^2)$

$Z = X + Y$

Then,

$Z = N(\mu_Y + \mu_Y, \sigma_Y^2 + \sigma_Y^2)$

Therefore, to calculate the probability to have overtime, Equation 10 is used.

$$1 - P(x \leq \mu) = 1 - P(x \leq \frac{X-\mu}{\sigma})) \qquad (10)$$

This gives Table 8.5 for the optimal scheme from the basis scenario (with 1-5 = Mo-Fr). It shows that probabilities in general around 0.5. This makes sense, since the utilization of the OR is near 100%. However, within the patient groups exist variation in surgery duration as demonstrated in Appendix 8. At the operational level, each patient has a given diagnosis from which a reliable OR duration can be derived. Patients can then be divided over the days while keeping in mind the expected surgery duration, which leads to a decrease of probability of overuse.

Table 8.5: Probabilities of overuse

	1	*2*	*3*	*4*	*5*
Expected total OR duration	505	513	469	506	505
Standard deviation total OR duartion	179	178	183	229	206
Maximum OR duration	510	510	510	510	510
$P(x > k)$	0,49	0,51	0,41	0,49	0,49

For this factor, no cost savings are calculated, since it is not yet known to which degree the above method can be applied at the operational level. At the implementation level it is known, how much planners can shift patients over the days to create a schedule with a less likely chance of overuse.

9. Operationalization of the model

The model optimized patient planning and capacity for multiple departments at the tactical level, which provided information about the type of patients in the hospital and their need of capacity. The optimal solution of the model has been an output which provides a weekly planning about the number of patients per patient group to be admitted at each day of the week. This planning can be implemented in the hospital, but is calculated at the tactical level which means it is based on averages. Therefore, in this section, a method is described how to implement the optimal planning at the operational level.

At the operational level, the optimal planning is influence by several factors. Joustra, de Wit, Van Dijk, & Bakker (2011) identified five factors that might influence an operating room's utilization rate:

1. Management decisions
2. Patient-mix characteristics
3. Organizational factors
4. Personnel-related factors
5. Cancellations due to other reasons

An example of a management decision is the maximum allowed percentage of cancellations due to overrun of previous surgeries. An example of patient-mix characteristics is economy of scale: a large department may be able to use the available operating time more efficiently than a small one. An organizational factor is for example the division of operating time among various specialties. In general, a more flexible use of capacity among various specialties results in a higher operating room utilization rate. A personnel-related factor is for example the punctuality of surgeons and anaesthesiologists. And finally, cancellations due to other reasons such as a patient that did not show up influence the operating room's utilization rate at operational level (Joustra, de Wit, Van Dijk, & Bakker, 2011).

Research concerning implementing the model at operational level has been done by Adan, Bekkers, Dellaert, Jeunet, & Vissers (2011), who have evaluated a tactical model at the operational level by using an algorithm to modify the schedule on a daily basis to account for emergency patients' arrivals. At the operational level, planners experience fluctuations in number of patients per patient group arriving per week. Adan, Bekkers, Dellaert, Jeunet & Vissers (2011) describe slack planning and patient group flexibility as the two factors to decide about at the operational level. They define slack planning as increasing the target throughput of patients and vary this from no slack planning to large slack planning. Patient group flexibility is defined as the degree of flexibility in allowing patient from other categories in a pre-determined time slot to avoid unused capacity. Their research discusses cancelled elective patients, and emergency patients sent to other hospitals. This means this research evaluated the degree of the impact of emergency patients disrupting the scheduled patients. In MZH, emergency patients are treated in another OR. However, specialists can be called to perform surgery on emergency patients if it concerns a type of patient that can only be operated by the specialist already scheduled for another elective operation. Research indicated that in Dutch hospitals 2.10% of the elective operations is cancelled (either by patients or hospital) (Inspectie voor de Gezondheidszorg, 2006). Since in MZH on average 30 elective patients are admitted to the hospital (5.5), this indicates that per week the expected number of cancellations is less than one.

Figure 9.1 shows the steps from tactical to executed plan, in terms of the framework as presented in Figure 2.4. The tactical plan (i.e. resources planning and control) as formulated in this thesis needs to be translated to the operational plan to use it, which includes for example the decisions concerning how to deal with the variability of number of arriving patients per week, and days off of specialists per week. The executed plan also includes for example arriving emergency patients or cancelled patients on the day of surgery. From data analysis some information about emergency patients is already known, was found in Figure 3.1 and Figure 3.2, which shows a quite stable number of emergency patients per day for all specialisms. Furthermore, data analysis revealed that the average numbers of acute patients per week is 12 with standard deviation 4, and can be found in Appendix 7. Figure 9.1 gives an indication of the differences in characteristics between the levels.

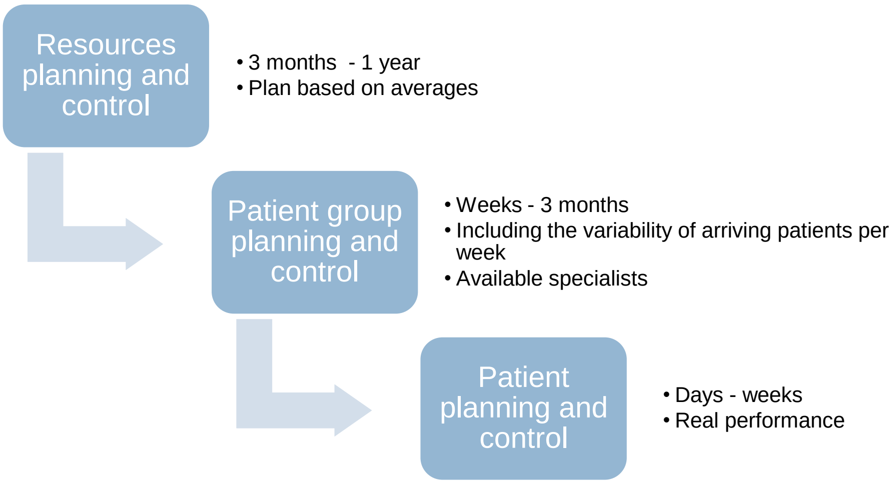

Figure 9.1: From tactical to executed plan

9.1 Use of the decision support tool

This section describes how planners and managers should use the decision support. This is twofold: how managers should use decision support tool to make tactical decisions and how planners should use the results of decision support tool.

9.1.1 Use of the decision support tool by managers

Managers should use the decision support tool if capacity changes (such as changes in the MSS or number of beds) or differences in patient demand are noticed. The second can be revealed by analysing historical data on regular basis. Therefore, if nothing changes during the year, managers should normally use the tool once a year to set the appropriate capacity and find an optimal admission scheme.

9.1.2 Use the results of the decision support tool by planners

To flow from the level ‘resources planning and control’ to ‘patient planning and control’, the main issue for translating the tactical plan into the operational plan is how to manage the variability in patient demand. In this section discusses how planners should use the results of the decision support tool

.

The number of patients to be admitted is based on an average throughput of patients arriving per week. Currently, the waiting time of patients is between two and three weeks (as discussed in 3.1.3), which means that in making an OR planning per week, it can be chosen which patients will be operated at which day. Furthermore, MZH works 13 weeks per year according to a reduction schema for the MSS. In reductions weeks less ORs are in use. When a particular patient group has at certain point in time an increased waiting time, in the reduction scheme relatively many patients from that patient group should be treated to compensate. Figure 9.2 gives the method for planners to plan patients according to the optimal patient admission scheme. The best method is to plan the whole week at a certain week. This means a shift in the hospital from providing patients a surgery date at the day of registration, to providing the date later. At step one, a list of patients waiting for an operation is generated. Secondly, for each patient the patient group is determined. At step three, the places in the scheme were the patient fits in is determined. Due to the waiting list, in most weeks, patient(s) from each patient group will be available. In weeks where this is not the case, a patient from another patient group can fill the gap. This results in another resource utilization than expected, but can be predicted, because the expected surgery duration and length of stay are known.

Action plan for planners

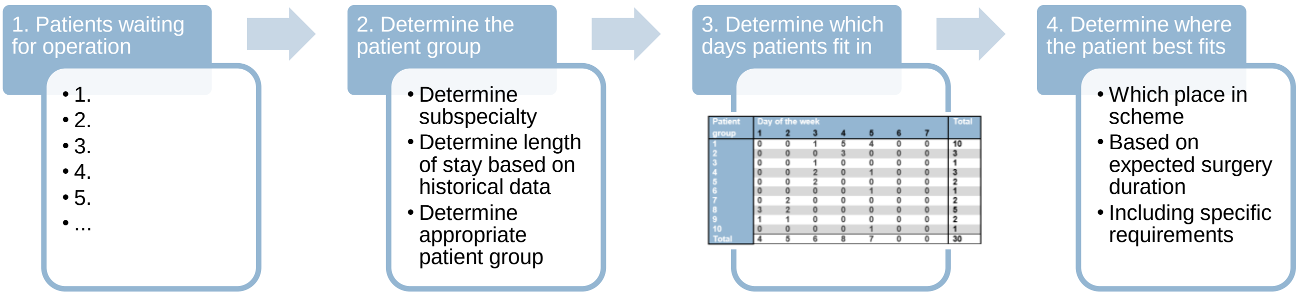

Figure 9.2: Action plan for planners

As analysed before, the elective inpatient service has a substantial waiting list and, thus it is reasonable to assume that these planned slots could be filled every week. In this project we set an optimal mix and volume of patient admissions allocated to slots, which the planning personnel should fill with any patient that matches the criteria for the slot. A management challenge lies in changing the culture to work according these scheme every week.

To conclude, obviously, the developed model simplifies the dynamic property of the healthcare system. Patients are assigned to a patient group, while within the patient group some variety exist. The surgery duration of a patient group is set, which causes a variability in realised surgery duration each day. At the implementation stage, the tactical model should be applied, and evaluated at the operational level and possible changes and scheduling rules can be set.

10. Conclusions and recommendations

The aim of this research has been to develop a decision support tool to optimize patient planning and capacity for multiple departments. The decision support tool helps the hospital in grounded decision making about the case mix and use of capacity of patients. This section formulates the answers to the research question (Section 10.1), the theoretical (Section 10.2) and practical contributions (Section 10.3), and the limitations and further research directions of this study (Section 10.4).

10.1 Conclusions

This section answers the research question as formulated in Section 2.3.1.

Research question: *How can a decision support tool be developed to optimize patient planning and capacity for multiple departments?*

This study has developed a valid decision support tool which optimizes patient planning and capacity over different departments. The decision support tool is developed in MS Excel with an add-in of AIMMS and is validated and verified by conducting a case study. The decision support tool is general and therefore applicable to all hospitals.

Analysis revealed that every department is connected to other departments. Patients flow from one department to the others, and many have a different path. From this analysis has been concluded that the outpatient department, the inpatient department, the diagnostic and therapy departments can be viewed separately from each other. To optimize patient planning and capacity, these departments can be optimized separately.

To optimize the departments a Mixed Integer Linear Programming model is developed, which minimizes over- and underutilization. The model therefore ensures processes can be organized more stabilized to avoid unexpectedly arriving patients at the department and a lack of information about in incoming patient at the departments. To achieve that, the type of patients and the available capacity have been identified. The model has generated an optimal admission profile is for patients per patient group to be admitted at each day of the week. This means a profile that results in the smallest possible deviation between the realised and the target resource utilisation, while the total available capacity of the different resource is exceeded as little as possible, the target patient throughput is met and the given restrictions are not violated. For both the OR and the wards, it has given an expected use of resources per day of the week. A sensitivity analysis has revealed that varying the parameter ‘weight per resource’ in the objective function resulted in a negligible difference in the optimal solution, which implies the weight is not an influential factor in determining the optimal patient planning and capacity.

As it was found that the model works correctly, a scenario analysis have been conducted to conclude for MZH about the impact of possible changes at strategic level. Optimizing the situation with current capacity settings seems to be best in terms of over- and underutilization.

Moreover, the model seems to have a positive effect on quality and saving costs. More specifically, from the elements of quality: safety, patient-centeredness, timeliness, and efficiency increase, effectiveness and equity are indifferent. In terms of costs, more than €100.000 can be saved in MZH by implementing the model.

Finally, with the decision support tool, it is possible to make grounded decisions on the number of patients to be admitted, to determine available capacity, and the number of nurses needed at the nursing units. It also has benefits for other departments as organizing one department smoothly results in a smooth outflow, and thus a smooth inflow at the next department. This makes planning at other departments easier.

10.2 Theoretical contributions

This project contains several contributions to theory. At first, the mathematical model that minimizes over- and underutilization is applicable to each department of the hospital, which is not available in the literature yet. Secondly, a case study is performed to test this Mixed Integer Linear Programming model, which has shown the effects on the associated aspects of the model meaning costs, quality, and operational implementation. Currently, managing an entire hospital is poorly described, and this study also gives an overview of the different departments, how they interact, and how you can optimize the entire hospital. Therefore, this study is a good addition to the field of optimizing resources in hospitals.

10.3 Practical contributions and recommendations

This research is practically relevant to organizations in several ways. First, this research gives a method to optimize patient planning and capacity over different departments. As an organization, it is important to know which departments interacts with each other. This research revealed, that several departments can be decoupled, and sub optimized. Furthermore, the model developed can minimize over- and underutilization over as many resources as required. Finally, this study gives an overview of the effects on costs and quality if the model is implemented, and how the model should be used at the operational level.

Besides the general contributions, this study has provided MZH information about how many patients are arriving at the hospital for surgery and what resources they need. For each resource the expected use per day of the week has been calculated when implementing the model. Therefore, the results of the model has given the hospital an instrument to control use of their resources and setting appropriate capacity in terms of rooms but also for example staff. Since more is known about the resource utilization of patients, staff planners can immediately react to changes in patients admission. Moreover, the hospital can make reasoned decisions in how respond to changes if needed. Furthermore, in this study performance measures are developed such as utilization. For the hospital, it supports grounded decision making and MZH is urged to constantly monitor the associated performance measures, resulting in a timely control over the processes in the hospital.

It is recommended that MZH first implements the optimal planning for admission of patients, as it has many benefits. The new planning should be tested and evaluated. If parameters change, they can be used in the decision support tool and a new optimal planning can be calculated. Furthermore, changes in patient demand should be noticed by analysing historical data. A half-yearly evaluation should be satisfactory, to determine about changes in demand. Information can also be obtained from constantly monitoring utilization and other performance measures such as number of overtime hours per year or week, misplacements and occupations of blocks of the MSS. After testing and evaluating the performance of the new planning, further implementation should be about the calculations of other specialisms. Extra groups can be created, and used as input for the model. A decision should be made regarding optimizing all specialisms together in one schedule (as the linear programming model might become large), or sub optimizing them independent of each other. Moreover, some special time is reserved for emergency patients in MZH. To calculate the needed reserved capacity for these patients the calculations from the model Adan, Bekkers, Dellaert, Jeunet, & Vissers (2011) could be used. When the OT department and wards are optimized, the patient planning and capacity in other departments can be optimized, using the model.

Moreover, in the future probably more integrative practices can be implemented such as sharing waiting list information, sharing planning information, cross-departmental planning, and creating combined appointments found to help in reducing either non-value added activities or variability in patient flow (Drupsteen, van der Vaart, & van Donk, 2013).

However, changing such a large (mostly bureaucratic) organization as a hospital, remains very difficult. Nowadays, the government tries to change the triggers of hospital production by reinventing financial instruments and stimulating market forces by for example changes in reimbursement. However, because of the organizational structure of hospitals (for example specialists working in partnerships, managers being responsible for units), and a value of providing good care as first priority independent of everything else, makes it difficult to changes processes in a hospital. Different actors (patients, managers, clinical staff, board of directors) have different interests. For example, the manager responsible for a unit may not be not very interested in patient waiting time, or the impact of decision he/she makes on other units. To address this problem adequately, unit managers should be held responsible for their contribution to chain service as well as their resource performance (Vissers & Beech, 2005).

10.4 Limitations and further research directions

In this section limitations of the project are discussed and some recommendations are given for further research.

- The results of this study are limited to the specialty surgery at the Maasziekenhuis Pantein. The conclusions are based on a MILP problem which includes some assumptions and therefore is a simplification of the real situation.
- In this research the speciality surgery is considered independently from the other specialisms, while at the ward they come together. Solving the specialisms independently results in a smooth inflow of the process at the ward, but this is suboptimal. Combining all specialisms in the model overcomes sub optimality, and is possible by using the developed model, but might lead to a model with a huge number of restrictions and decision variables. Therefore, it might be unsolvable. In the future, research can focus how to solve such a large problem.
- Another limitation is the exclusion of the arrival pattern of emergency patients in the model. In the literature also emergency patients are included (Adan, Bekkers, Dellaert, Jeunet, & Vissers, 2011). In this study the focus was only on elective patients but in the future, also emergency patients can be included in the general model, presumably based on the model of Adan et al. (2011).
- Due to time limits, the optimal planning is not tested in a real situation. In the future, the planning should be tested an evaluated to determine the performance.
- Furthermore, waiting time is not included in the model, since it is not the objective of the model. In the future, a performance measure for waiting time can also be included

to monitor it. Or waiting time can be included in the model as an objective, to evaluate the effects on the results of the model by including waiting time.

- The model does not have a direct link with costs except for the weights. In the future, cost parameters can be included in the sense of cost of capacity to make a distinction between for example work week and weekend.
- The case study is performed at a rural hospital which means surgery has relatively few patients compared to the large hospitals. The model is not tested at a larger hospital, which might have different characteristics in the nature of patients and the amount of resources. Future research could test the model at a larger hospital with a higher number of patients and more patients.
- In this study, the optimal admission schedule is generated for one week. It is not tested if for example a two-week schedule might give a smoother utilization of resources. In further research, the optimal planning period could be determined.
- The model is only tested at the OT department and the wards, in the future it should be investigated how it behaves at other departments such as the outpatient department.

11. References

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Appendices

Appendix 1 Organization structures

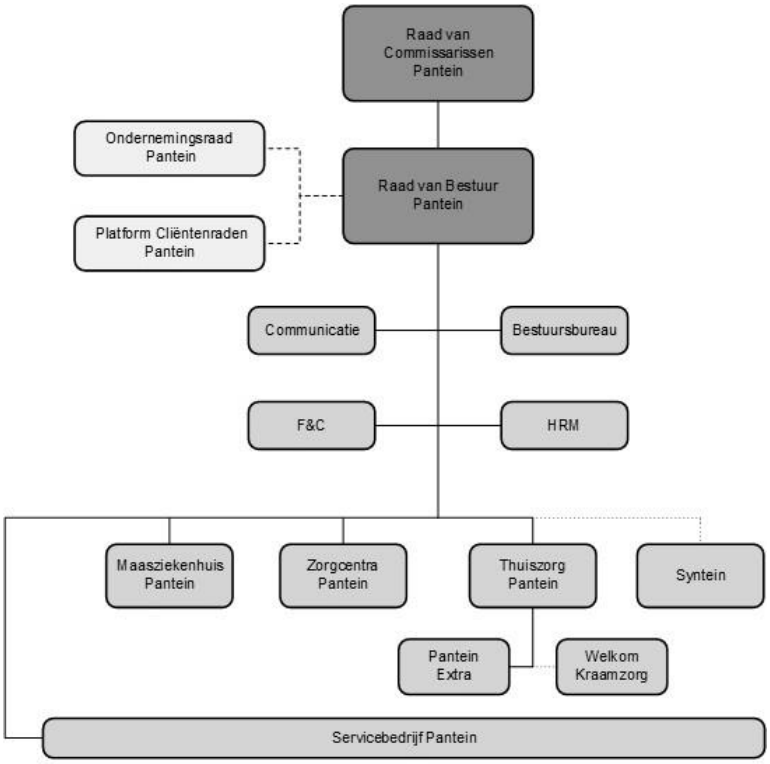


Figure A1. 1: Organizational structure Stichting Pantein

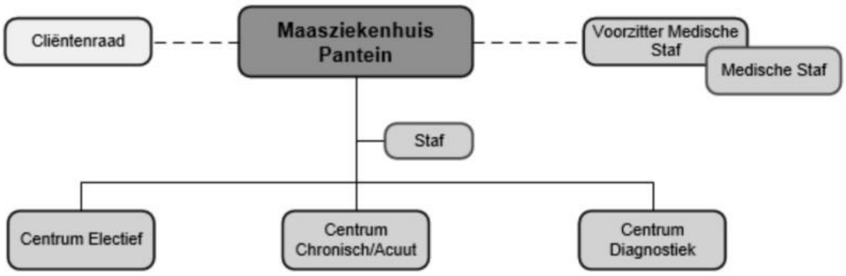


Figure A1. 2: Organizational structure of MZH

Appendix 2 Available data

The patient data is split up in three tabs: TabelOperaties, TabelOpname, and TabelDBC. The tabs are connected by operation number and includes all patients that had an operations from all specialisms. The time period varies for the operation date from January 2013 to August 2015. The patient data includes the attributes demonstrated by the tables.

Table A2. 1: Available data

TabelOperaties

Operatienr	Number
Patientnr	Number
DBCNumber	Number
Specialismecode	Text
BeginOK	Date
EindOK	Date
BrutoOKtijd	Number
NettoOKTijd	Number
Wisseltijd	Number
Aanvraagdatum	Date
IsSpoed	Binary
Okkamer	Number
WachttijdWeken	Number
BrutoOKtijd + wisseltijd	Number
Patientgroep	Number/Text

TabelOpname

Operatienr	Number
Opnamenr	Number
Patientnr	Number
OKkamer	Number
IsSpoed	Binary
OpnameType	Text
Begindatum	Date
Begintijd	Time
Einddatum	Date
Eindtijd	Time
Afdelingcode	Text
Kostenplaatscode	Number
Specialisme	Text
Verpleegdagen	Number

TabelDBC

Operatienr	Number
DBCNummer	Number
Patientnr	Number
Geslacht	Text
Geboortedatum	Date
Begindatum	Date
Einddatum	Date
Specialismecode	Text
Zorgtypecode	Number
Diagnosecode	Number
Zorgproductcode	Number
Zorgproductomschrijving	Text

TabelVerrichtingen

Patientnr	Number
DBCNummer	Number
Verrichtingdatum	Date
Verrichtingcode	String
VerrichtingOmschrijving	Text
VerrichtingSpec	Text
WerkelijkAantal	Number
KostenplaatscodeVER	Number
OmschrijvingVER	Text
Kostprijs	Number
Opnamenr	Number
Operatienr	Number

Appendix 3 Screenshot Decision Support Tool

Below, some screenshots from the decision support tool are presented.

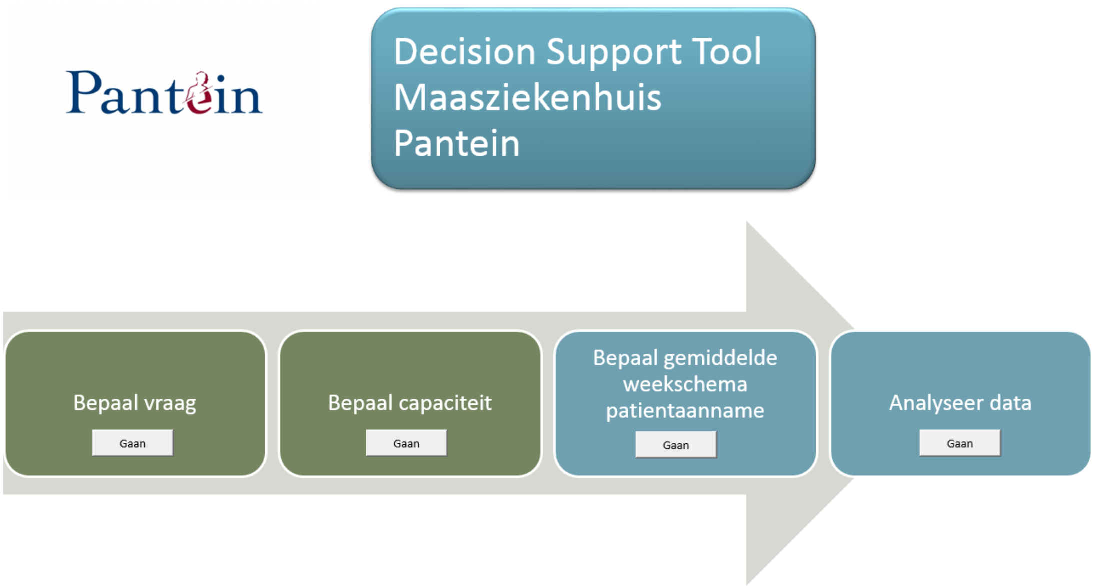
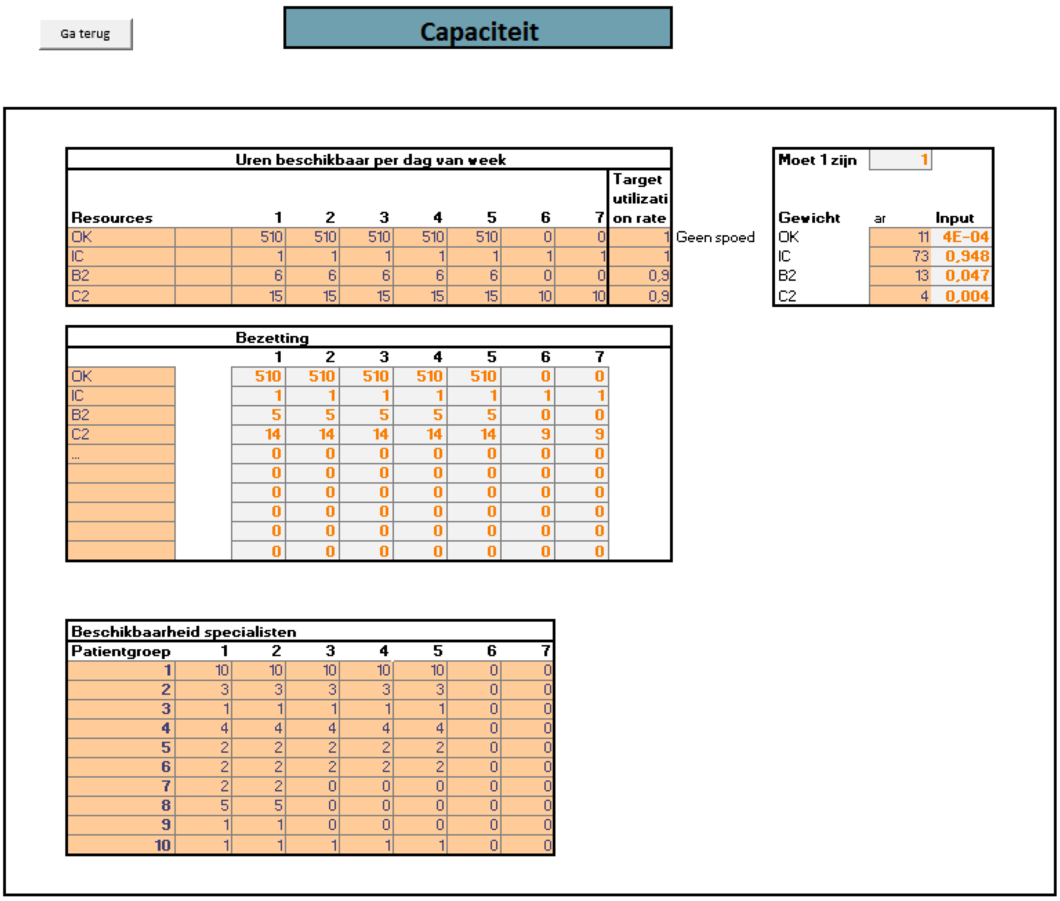


Figure A3. 1: Main menu decision support tool



Ga terug

Capaciteit

Uren beschikbaar per dag van week

Resources		1	2	3	4	5	6	7	Target utilization rate	
OK		510	510	510	510	510	0	0	1	Geen spoed
IC		1	1	1	1	1	1	1	1	
B2		6	6	6	6	6	0	0	0,9	
C2		15	15	15	15	15	10	10	0,9	

Moet 1 zijn	1	
Gewicht	ar	Input
OK	11	4E-04
IC	73	0,948
B2	13	0,047
C2	4	0,004

Bezetting

		1	2	3	4	5	6	7
OK		510	510	510	510	510	0	0
IC		1	1	1	1	1	1	1
B2		5	5	5	5	5	0	0
C2		14	14	14	14	14	9	9
...		0	0	0	0	0	0	0
		0	0	0	0	0	0	0
		0	0	0	0	0	0	0
		0	0	0	0	0	0	0
		0	0	0	0	0	0	0
		0	0	0	0	0	0	0

Beschikbaarheid specialisten

Patientgroep	1	2	3	4	5	6	7
1	10	10	10	10	10	0	0
2	3	3	3	3	3	0	0
3	1	1	1	1	1	0	0
4	4	4	4	4	4	0	0
5	2	2	2	2	2	0	0
6	2	2	2	2	2	0	0
7	2	2	0	0	0	0	0
8	5	5	0	0	0	0	0
9	1	1	0	0	0	0	0
10	1	1	1	1	1	0	0

Figure A3. 2: Input parameters capacity

Appendix 4 Code AIMMS

In this appendix the code as programmed in AIMMS is given.

```
Set Resources {
        Index: r;
    }
    Set CategoriesPatients {
        Index: c;
    }
    Set Time {
        SubsetOf: Integers;
        Index: t;
    }
    Set IndexProb {
        SubsetOf: Integers;
        Index: i;
        InitialData: data { -
1,0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25};
    }
    Parameter TPT {
        IndexDomain: (c);
        Range: integer;
    }
    Parameter Capacity {
        IndexDomain: (r,t);
    }
    Parameter ServiceTime {
        IndexDomain: (r,c);
    }
    Parameter Prob {
        IndexDomain: (r,c,i);
    }
    Parameter WeightR {
        IndexDomain: r;
    }
    Parameter TargetUti {
        IndexDomain: (r,t);
        Range: integer;
    }
    Parameter ProdCapacity {
        IndexDomain: r;
        Definition: SUM[c,TPT(c)]/SUM[t,Capacity(r,t)];
    }
    Parameter AvUtilization {
        IndexDomain: r;
        Definition: 1/7*SUM[t,UtilizationPerc(r,t)];
    }
    Parameter UtilizationPerc {
        IndexDomain: (r,t);
        Definition: CalculatedTime(r,t)/Capacity(r,t);
    }
    Parameter Specialist {
        IndexDomain: (c,t);
    }
    Variable UnderUti {
        IndexDomain: (r,t);
        Range: nonnegative;
    }
    Variable ExceededCap {
        IndexDomain: (r,t);
        Range: nonnegative;
    }
    Variable CalculatedTime {
        IndexDomain: (r,t);
        Range: free;
```

```
        Definition:
SUM[(c),SUM[i,Prob(r,c,i)*ServiceTime(r,c)*DecisionVar(c,mod((t-i),7))]];
    }
    Variable OverUti {
        IndexDomain: (r,t);
        Range: nonnegative;
    }
    Variable DecisionVar {
        IndexDomain: (c,t);
        Range: integer;
    }
    Variable ObjectiveFunction {
        Range: free;
        Definition: (SUM[(r), WeightR(r)*SUM[(t),
UnderUti(r,t)+OverUti(r,t)+100*ExceededCap(r,t)]]);
    }
    Constraint TargetPatients {
        IndexDomain: (c);
        Definition: SUM(t,DecisionVar(c,t))=TPT(c);
    }
    Constraint ConSpecialists {
        IndexDomain: (c,t);
        Definition: DecisionVar(c,t)<=Specialist(c,t);
    }
    Constraint MaxCapacity {
        IndexDomain: (r,t);
        Definition: TargetUti(r,t)<=CalculatedTime(r,t)+ UnderUti(r,t);
    }
    Constraint MaxCapacity3 {
        IndexDomain: (r,t);
        Definition: CalculatedTime(r,t)- OverUti(r,t)<=TargetUti(r,t);
    }
    Constraint MaxCapacity2 {
        IndexDomain: (r,t);
        Definition: TargetUti(r,t)+OverUti(r,t)-ExceededCap(r,t) <=Capacity(r,t);
    }
    MathematicalProgram MinDifference {
        Objective: ObjectiveFunction;
        Direction: minimize;
        Constraints: AllConstraints;
        Variables: AllVariables;
        Type: Automatic;
    }
    Procedure MainInitialization;
    Procedure MainExecution {
        Body: {
            solve MinDifference;
            if ( MinDifference.ProgramStatus <> 'Optimal' ) then
                    empty DecisionVar, ObjectiveFunction;
            endif;
        }
    }
    Procedure MainTermination {
        Body: {
            return DataManagementExit();
        }
    }
}
```

Appendix 5 Diagnosis codes

Below, the content of the diagnosis codes is explained.

Table A5. 1: Diagnosis codes

Algemene chirurgie en chirurgie bij kinderen	**Hoofd en hals**	**101**
	Buik en bekken	111-129
	Bovenste extremiteiten	131-135
	Onderste extremiteiten	140-141
	Diversen	150-159
	Infecties	160-163
	Algemeen	170-179
Traumatologie	Fracturen	201-249
	Distorsies	250-254
	Luxaties	255-258
	Kapsel-band / pees- / spier-ruptuur	261-269
	Contusies	270-271
	Intracranieel letsel / zonder schedelfracturen	272-273
	Inwendig letsel borst, buik en bekken	274-279
	Wonden	280-282
	Thermisch letsel	283-285
	Brandwonden in gespecialiseerde centra	701-710
	Oppervlakkig letsel	286
	Stand- en lengte-afwijking	287-288
	Corpus alienum	290-291
	Overige diagnoses	292-299, 602
Oncologie, long en gastrointestinale chirurgie	Hoofd en hals	301-306
	Thorax	310-318
	Buik en bekken	320-349
	Diversen	350-359
Vaatchirurgie	Hoofd en hals	401-402
	Thorax	403-404
	Buik en bekken	405-409
	Bovenste extremiteiten	410-413
	Onderste extremiteiten	416-427
	Diversen	431-449

Appendix 6 Patient group determination

The table in this appendix gives an overview about the patient group.

Table A6. 1: Patient group determination

Diagnosis Group	Diagnosis code occurred in MZH	Number in 2013-2014 (%)	Average surgery duration (standard deviation)	Average LOS (standard deviation)
General surgery and surgery for children	111, 113, 115, 116, 117, 121, 123, 124, 127,129, 131, 132, 133, 134, 135, 141, 150, 151, 159, 160, 161, 163, 170, 171, 172, 174, 179	1524 (43,97%)	58 (30)	2 (4)
Traumatology and emergency	205, 207, 208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 224, 236, 237, 238, 239, 241, 251, 252, 253, 254, 255, 256, 257, 258, 261, 262, 263, 269, 270, 271, 274, 275, 279, 280, 281, 282, 283, 286, 287, 291, 292, 293, 297, 298, 299	1057 (30,50%)	77 (41)	5 (10)
Oncology, lungs, gastrointestinal surgery	302, 303, 306, 313, 317, 318, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 332, 333, 334, 335, 336, 338, 339, 340, 343, 344, 346, 349, 350, 351, 352, 353, 354, 359, 360, 361, 362	832 (24,00%)	106 (58)	5 (6)
Vascular surgery	401, 405, 418, 420, 423, 426, 427, 432, 435, 442, 449	53 (1,53%)	74 (41)	6 (9)

Appendix 7 Arrival rates per patient group

This appendix gives an overview of the number of patients per patient group that arrive on average per week in 2013, 2014, and 2015. Reduction weeks are excluded from calculating the average. Since carnival is every year at another moment, for 2013 week 7 is excluded, for 2014 week 10 is excluded, and for 2015 week 8 is excluded. For 2015, data was available until week 28.

Table A7. 1: Surgeries per patient group per week over the years

		1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***Acute***
Gem	**2013**	9,23	2,64	1,43	3,94	1,87	1,17	1,48	4,18	1,87	1,27	9,90
Gem	**2014**	9,92	2,60	1,00	2,94	1,72	1,25	2,06	4,72	2,06	1,13	11,77
Gem	**2015**	12,04	2,32	1,00	3,24	1,20	1,00	1,57	4,48	2,40	1,33	13,00
St dev	**2013**	3,71	1,87	0,73	1,66	0,85	0,37	0,63	1,72	0,76	0,44	3,38
St dev	**2014**	2,32	1,94	0,00	1,63	0,96	0,43	0,95	3,00	1,35	0,34	3,85
St dev	**2015**	3,74	1,14	0,00	1,69	0,40	0,00	0,90	1,31	1,59	0,47	3,83

Table A7. 2: Arrivals per patient group per week over the years

		1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***Acute***
Gem	**2013**	9,49	2,88	1,13	3,65	1,73	1,00	1,86	4,13	1,96	1,29	9,92
Gem	**2014**	9,51	2,36	1,20	2,81	1,59	1,27	2,27	5,27	2,03	1,14	11,90
Gem	**2015**	10,57	2,62	1,00	3,10	1,27	1,00	1,78	4,00	2,14	1,00	12,88
St dev	**2013**	4,57	1,74	0,33	2,55	0,81	0,00	1,39	2,33	0,68	0,57	3,35
St dev	**2014**	3,76	1,34	0,40	1,77	0,68	0,62	1,08	2,67	0,89	0,35	3,64
St dev	**2015**	3,90	1,65	0,00	1,63	0,45	0,00	0,85	1,98	1,32	0,00	3,63

Appendix 8 Expected duration

The tables in this section provide information about the determination of the input parameters for the patient groups. The surgery duration is analysed with SPSS, while the data about the LOS is analysed by MS Excel. For the surgery duration, a histogram with normality plot is provided.

Table A8. 1: Statistics about the OR duration per patient group

Statistics

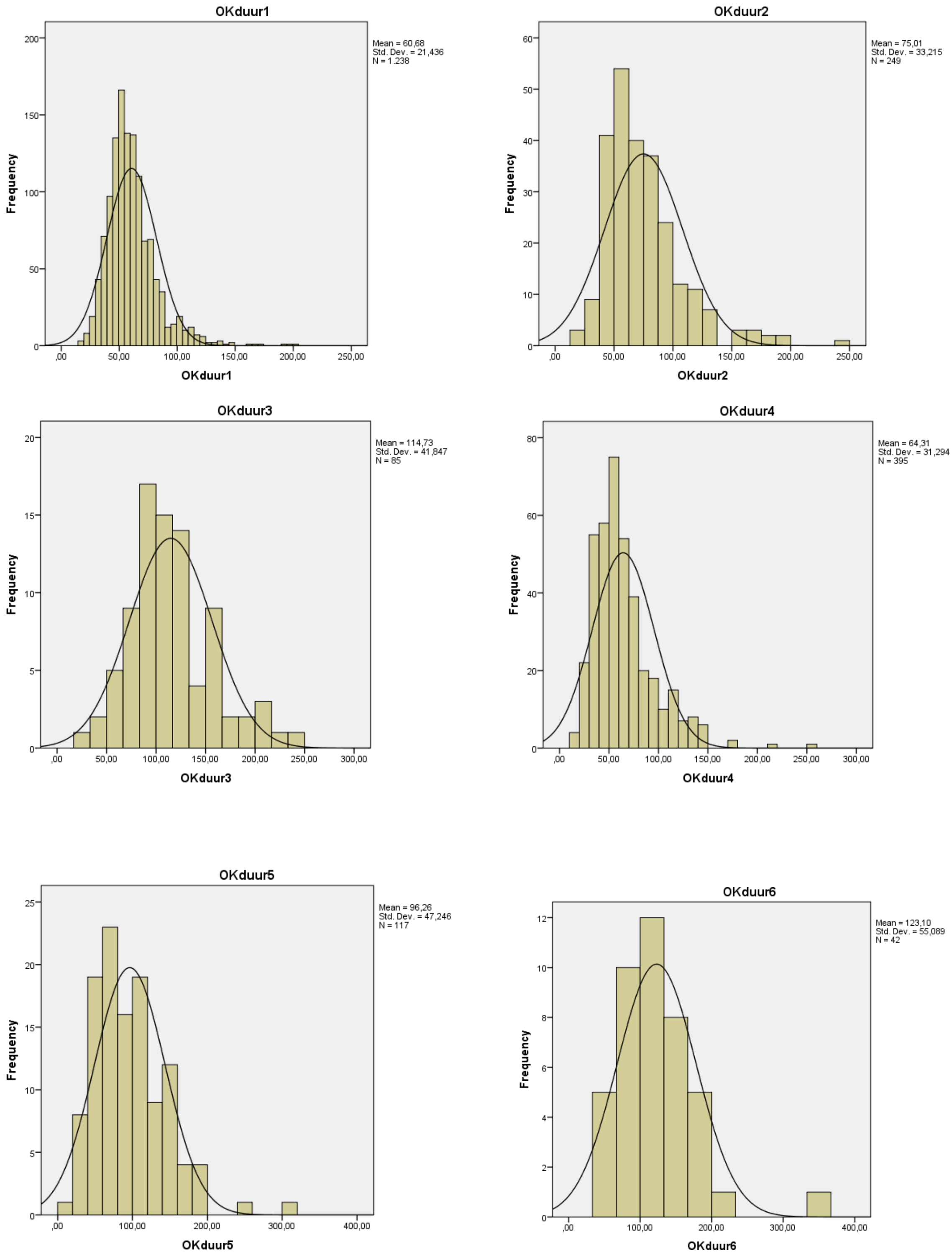
		OKduur1	OKduur2	OKduur3	OKduur4	OKduur5	OKduur6	OKduur7	OKduur8	OKduur9	OKduur10
N	Valid	1238	249	85	395	117	42	180	410	377	52
	Missing	0	989	1153	843	1121	1196	1058	828	861	1186
Mean		60,6817	75,0120	114,7294	64,3063	96,2564	123,0952	75,3333	96,9415	161,0027	83,5769
Median		57,0000	68,0000	106,0000	58,0000	88,0000	118,5000	74,5000	92,0000	148,0000	68,5000
Mode		50,00	49,00[a]	106,00[a]	59,00	59,00	157,00	75,00[a]	85,00	91,00	53,00[a]
Std. Deviation		21,43612	33,21478	41,84705	31,29416	47,24626	55,08920	26,22656	30,41540	66,78381	46,45738
Skewness		1,674	1,650	,660	1,659	1,276	1,759	1,071	1,683	,707	2,023
Std. Error of Skewness		,070	,154	,261	,123	,224	,365	,181	,121	,126	,330
Kurtosis		5,869	3,981	,475	4,897	3,191	6,417	2,656	5,160	,005	4,075
Std. Error of Kurtosis		,139	,307	,517	,245	,444	,717	,360	,240	,251	,650
Minimum		17,00	13,00	26,00	13,00	15,00	41,00	21,00	43,00	25,00	32,00
Maximum		202,00	240,00	237,00	256,00	312,00	355,00	188,00	270,00	377,00	243,00

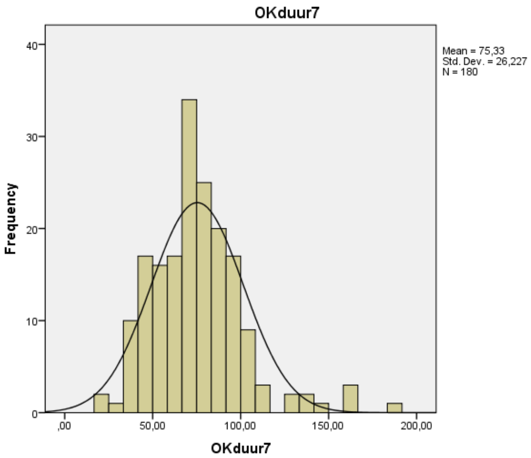
a. Multiple modes exist. The smallest value is shown

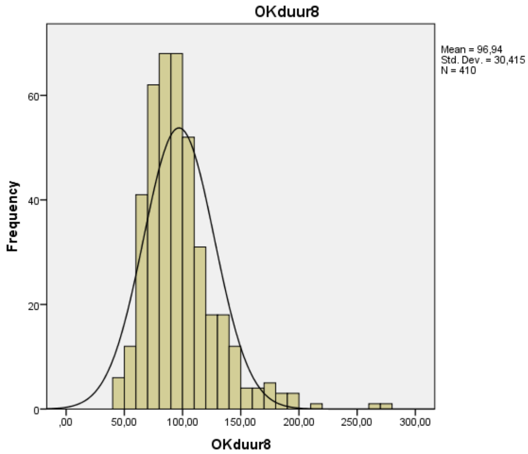
Table A8. 2: Statistics about the LOS per patient group

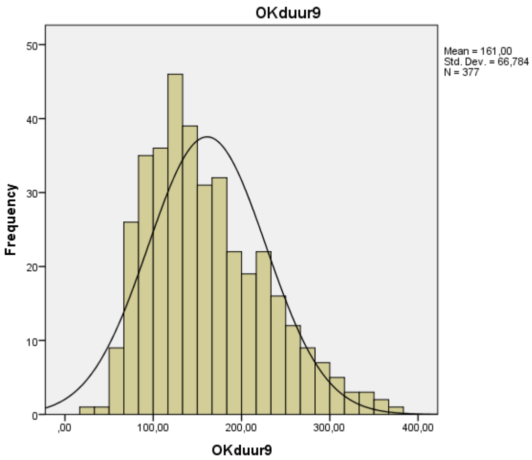
Patient group	*Average LOS*	*Standard deviation LOS*
1	1	0
2	2,703947368	0,907168487
3	14,8	16,43881026
4	1	0
5	2,558139535	0,789649613
6	25,26666667	20,67137507
7	1	0
8	2,933682373	1,078622479
9	11,04672897	7,275120866
10	3,307692308	6,279560561
Emergency	7,075324675	10,46486936

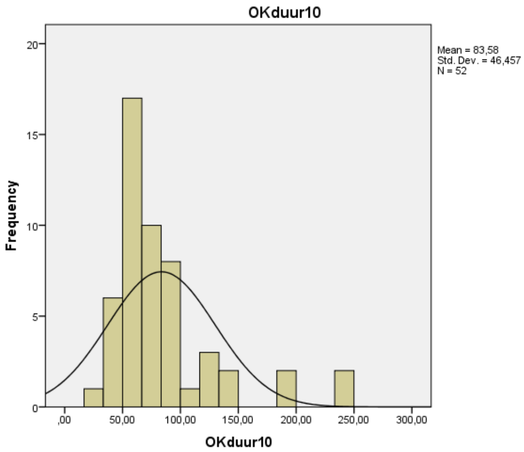
Figure A8. 1: Histograms with normality plot for the surgery durations per patient group




OKduur7
Mean = 75,33
Std. Dev. = 26,227
N = 180
Frequency
0
10
20
30
40
,00
50,00
100,00
150,00
200,00
OKduur7


OKduur8
Mean = 96,94
Std. Dev. = 30,415
N = 410
Frequency
0
20
40
60
,00
50,00
100,00
150,00
200,00
250,00
300,00
OKduur8


OKduur9
Mean = 161,00
Std. Dev. = 66,784
N = 377
Frequency
0
10
20
30
40
50
,00
100,00
200,00
300,00
400,00
OKduur9


OKduur10
Mean = 83,58
Std. Dev. = 46,457
N = 52
Frequency
0
5
10
15
20
,00
50,00
100,00
150,00
200,00
250,00
300,00
OKduur10

Appendix 9 Productivity graphs of MZH

Figures about productivity provided by MZH.

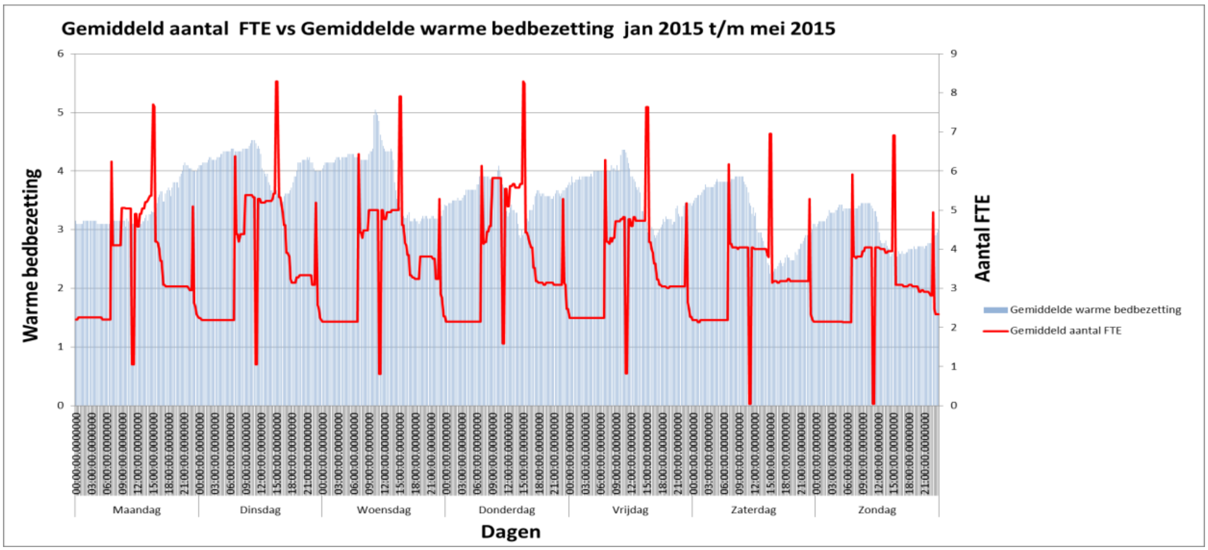


Figure A9. 1: Productivity graph IC

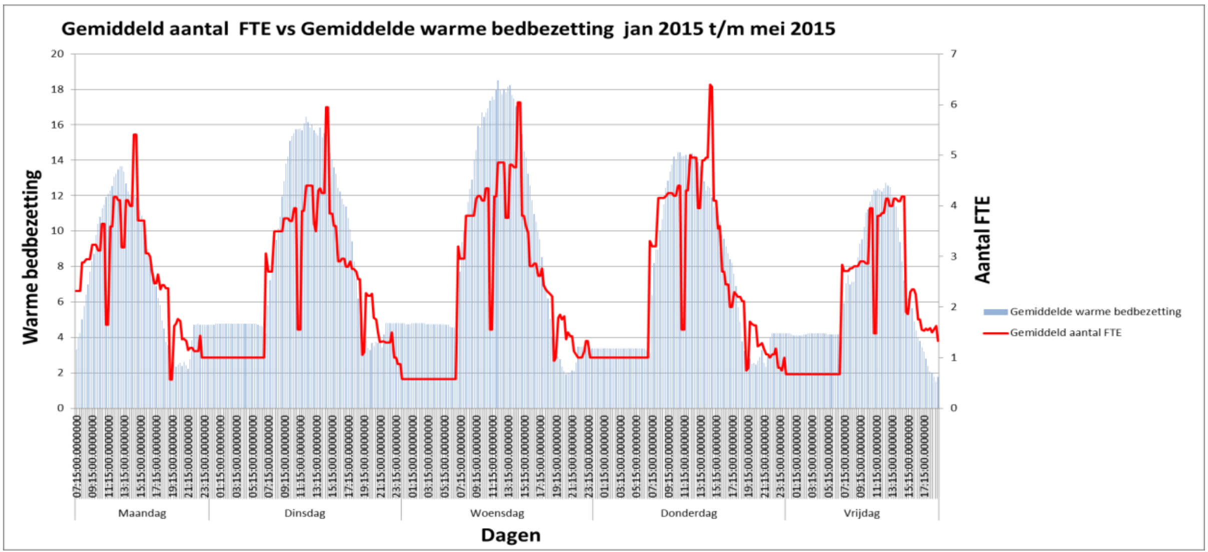


Figure A9. 2: Productivity graph B2

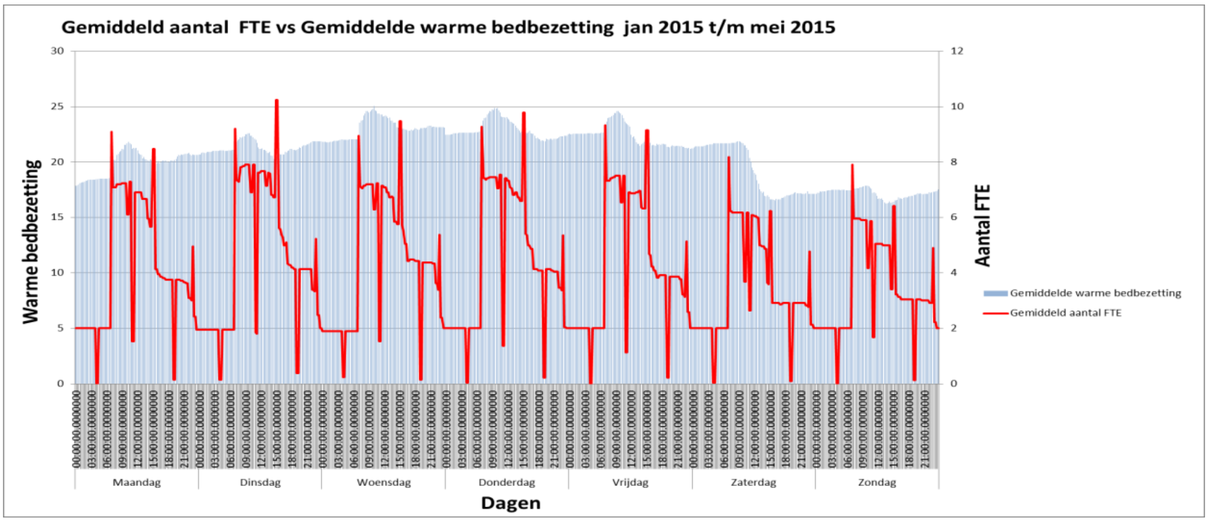


Figure A9. 3: Productivity graph C2