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Optimizing the surgical patient flow in a German Hospital

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Management summary

Hospital personnel are working hard and long hours, and give their utmost trying to provide the best care for their patients. But why do German hospitals still struggle to run their processes in a profitable way?

For the surgical specialties, the biggest revenue is earned in the operating room (OR). Managers are therefore under the assumption that more surgeries will result in a higher profit. But in order to generate this revenue, one has to consider all the capacities a patient needs before he is cured, such as a bed or nursing.

The Marienhospital Kevelaer (MHK) applies an interdisciplinary bed division, meaning that patients of every specialty are divided over all wards. When a new patient arrives, it can occur that no bed is available, but it is not clear where the problem is. In 2017 a new specialty opened and the number of patients that did not have a bed on arrival increased even further, increasing the length of their stay (LOS). This is a costly aspect since the German health insurance agencies are only required to reimburse a predetermined number of days, based on a so-called diagnosis-related group (DRG). This led to the question if the hospital needed more capacity. The goal of this thesis is to determine:

"How should MHK assign its beds to generate an optimal patient flow in the hospital and to the OR in particular, such that the average length of stay is reduced in the current environment?"

During a period of four months, all processes that contribute to the cure of the patient were analyzed. To measure the performance, key performance indicators were established. The model of Vanberkel et al. [1] was used to explore the effects of a different surgery schedule, but only a small reduction from 85 to 82 beds was realizable. This can be achieved even if only three of the four ORs are used.

This thesis concludes that developing a new planning method will only have an effect if the following three conditions are met:

1. The schedule should start on time
2. The planned durations need closely resemble the actual time spend
3. The schedule must be able to anticipate for changes due to emergency patients

Since these conditions are not met at the MHK, a roadmap is set out on things that have to change before adapting a new way of planning will bring the desired improvements.

To start the schedule on time, capacity utilization above 85% should be avoided. This includes the capacity needed for emergency patients. The morning is the busiest moment in the hospital, requiring different tasks to be performed all at the same time, causing delays at the start of the OR day. The main reason for this is that there are too many patients in the hospital waiting to be treated by the personnel capacity. This waiting time is not reimbursed by the health insurance agencies. Personnel has to do too much at the same time.

To get a reliable planning, historical data should be used to estimate the length of the surgeries. The support software *iMedOne*, that is used in the MHK, has already the option *OP-Profilzeiten und aktuellen OP-Zeiten*, that can be used to compare planned and actual surgery times. The option also allows to use the historical durations as a default.

To anticipate for emergency surgeries, the schedule should reserve some time for surgeries that have to be performed within one day. For the General surgery (MCHA) and trauma surgery (MCHU), half an hour should be kept free. For the vascular surgery (MCHG), one hour of surgery time should be kept available to anticipate for changes. The operating room coordinator should be the only one who can assign these reserved capacities.

Further improvements are set out in a roadmap and cover the whole patient flow. The roadmap is further specified for short- and long-term improvements.

An optimal patient flow is generated if the number of patients in the hospital do not exceed the capacity needed to treat these patients. Patients can be cured faster and discharged sooner, by admitting less patients at the same time. A new patient can be admitted earlier while the LOS declines, which reduces the amount of unpaid days. The capacity needed to achieve this flow are shown in Table 1. Based on the current LOS, a capacity of 218 beds is needed, which is precisely the capacity of the current setup. If the LOS of the DRG is met, only 198 beds are needed.

Combining these numbers with the results of the model of Vanberkel, this thesis concludes that even with the current LOS, the MHK has no OR or bed capacity problem at this moment.

Specialty	MCHA	MCHG	MCHU	MIM	MKA	MNEU	MHK
Assigned beds for 2018	15	30	24	71	30	40	210
LOS MHK	15	28	23	86	21	45	218
LOS DRG	16	30	20	66	24	42	198

Table 1: Division of the capacities per specialty. The current division is given along with the required capacity based on the current LOS of the hospital and the capacity that is needed if the prescribed LOSs of the DRG are followed.

This was the first time that the processes in the MHK were analyzed from an industrial engineering point of view. The roadmap provides suggestions for further research and the hospital could try to collaborate with research institutes in the neighborhood, who also offer an industrial engineering program.

Preface

As a child I always said that I never wanted to become a teacher or would work in a hospital. Later I asked myself if this came due to the work itself, or because I knew what kind of problems there were in hospitals. It was in that period that I took the course *Optimization of Healthcare Processes* from Erwin. He showed that a different way of thinking with some small improvements could already make a big difference.

I wanted to use my Master thesis as an opportunity to experience something new. Which had the benefit that if I didn't like it, would be over in half a year. So I waited until Erwin came back from his sabbatical and arranged all the paperwork with the hospital. I want to thank Erwin because he enabled me to gain this experience, not only before my thesis but also during the process. It was always my own project. I was the one who made the calls and decided what way it was going and Erwin helped me shape this project by guiding me with useful questions and tips on how I could pursue my journey.

I also want to thank Derya for being my second supervisor and for her time and questions.

Ganz besonders möchte ich Thomas bedanken, für das Vertrauen und die Freiheit die ich während meiner Arbeit von dir bekommen habe. Jede Woche hatten wir lange Diskussionen und ich denke das wir beide viel davon gelernt haben. Auch möchte ich mich beim Herrn Westerhoff und seinem Team bedanken für alle Daten und Informationen die ich immer wieder bekommen konnte und für den Kaffee (noch immer Schwarz).

Auch möchte ich mich herzlich bei den Kardiologen, mit den scönen Brillen, bedanken da sie immer gut für mich gesorgt haben, als Praktikant und als Patient. Ins Besondere möchte ich mich noch bei der Frau Ortman bedanken für unsere Gespäche und Einblicke aus einer anderen Perspektive während meiner Morgenrunde.

Natürlich auch einen Dank an alle Ärtzte, Dirk und sein OP Team, Herrn Meyer für seine Erklärungen der DRG, Hernn Thyssen und die Damen des Empfangs, die Sekretärinen, das Medizinische Controlling, alle Krankenschwestern und Krankenpfleger, die Damen der Ambulanz, die Kräfte des 4K service, die Küche und natülich die Schwestern des MHK und alle andere dich ich während meines Aufenthalts gesprochen habe. Ich habe mich immer Willkommen gefült und habe eine schöne Zeit gehabt.

Ik wil graag Davey bedanken voor het gebruik mogen maken van zijn model en voor zijn hulp bij het verder ontwikkelen ervan. Hierdoor kon ik snel met resultaten komen en me verder richten op de andere aspecten in het ziekenhuis.

Natuurlijk wil ik ook graag alle mensen bedanken voor de feedback en de spelling check, jullie hebben het mogelijk gemaakt dat mijn verhalen ook daadwerkelijk door mensen begrepen kunnen worden.

Daarnaast wil ik graag mijn ouders bedanken voor alle hulp bij het ontrafelen van de mysteries van een ziekenhuis en dat ik het afgelopen half jaar weer op mijn oude kamer kon slapen (al was het opstaan altijd wel een beetje vroeg).

Lieve Sanne, bedankt voor alle steun die je me tijdens mijn afstuderen, maar ook tijdens mijn hele studie hebt gegeven. Ik hou van je

Benno
Enschede - 20 Juli 2018

Contents

List of acronyms

CBS central bed station, in German: Bettenzentrale

CM case mix

CMI case mix index

DRG diagnosis-related group

e-bed electronic bed

ICU intensive care unit

KPI Key performance indicator

KHZV Krankenhauszweckverband Rheinland e. V.

LOS length of stay

ALOS average length of stay, in German: Mittlere oder durchschnittliche Verweildauer

MSS master surgical schedule

OR operating room

ORC operating room coordinator

PHI private health insurance

MSS master surgery scheduling

NHI national health insurance

KKLK Katholische Karl-Leisner-Klinikum

MHK Marienhospital Kevelaer

MCHA General surgery, in German: Allgemeinchirurgie

MCHG Vascular surgery, in German: Gefäßchirurgie

MCHU Trauma surgery, in German: Unfallchirurgie

MIM Internal medicine, in German: Innere Medizin

MINT Intensive care unit, in German: Intensivstation

MKA Cardiology, in German: Kardiologie

MNEU Neurology, in German: Neurologie

Augen Ophthalmology, in German: Augenheilkunde

MHH Otorhinolaryngology, in German: Hals-Nasen-Ohren-Heilkunde

Chapter 1

Research plan

This thesis makes a first attempt to look at the processes of a German hospital from an industrial engineering point of view. Dedicated personnel works hard, but specialties underperform on financial criteria while they cope with a high workload. Analyses of the various processes and data, reveals a huge potential for the hospital to improve its current way of working. The goal of this thesis is to let the people within the organization also sees this potential and understand why this is so important.

This chapter provides the first steps in order to do that. For the external readers, a small introduction to the research context will be given in Paragraph 1.1. Next in Paragraph 1.2, a research motivation is given and the problem will be described in Paragraph 1.3. This chapter will be concluded by the research objective (§1.4) and questions of this thesis in Paragraph 1.5.

1.1 Research context

To provide some perspective to the external readers, the context in which this thesis is conducted will be clarified. First, the question will be answered why this thesis was conducted in a hospital in the first place and why it is relevant to other hospitals as well. Next, the hospital where this thesis was performed will be introduced. Finally, the German health care system is summarized to give the required background to this research.

1.1.1 Operations Research and Health Care

The challenges in this case study are not restricted to only the research hospital, but are experienced by health care facilities in general. The demand for health care services is rising, along with the patients expectations of high service quality. Rapid increase in health care expenditures in conjunction with increasing numbers of elderly people and decreasing work forcemakes the need for improving the efficiency of the health care sector crucial, to keep health care available and affordable for everyone [2].

Doctors and nurses are not trained to cope with these problems. By reducing the need for scarce resources, such as employees and equipment, operation research helps guide

Figure 1.1: Map of the Netherlands and the German Bundesland North Rhine Westphalia. source: d-maps.com

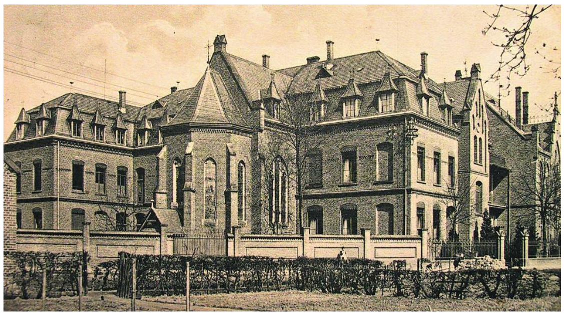

Figure 1.2: Picture of the MHK from around 1900. The room where this thesis was written is already on this picture in the bottom right. source: www.blattus.de/kaz/texte/k_kaz/krankenhaus-chronik.html

processes on a more efficient way. This will also result in higher quality of care which increases the satisfaction of patients, making the process more effective. Hospital optimization is achieved by reducing all types of waste, such as waiting times or unnecessary movements. In this way, staff does not have to do more with fewer personnel, but can do more with the available capacity.

Although hospital care can be very diverse, groups of patients show comparable characteristics. By considering them as a group, processes can be organized such that the quality of overall care can be increased and costs can be reduced. This may seem contradicting, but these aspects go often hand in hand when care is better managed.

1.1.2 Marienhospital Kevelaer

The Marienhospital Kevelaer (MHK) is located in the German pilgrimage town Kevelaer, close to the Dutch border (Figure 1.1). The hospital merged with three hospitals in the neighbourhood (Kleve, Goch and Kalkar) into the Katholische Karl-Leisner-Klinikum (KKLK) in 2013.

The hospital has a lot of missions[1], but the most relevant one for this report is: *"Wir sind kein Unternehmen der Wirtschaft, aber auch wir brauchen schwarze Zahlen."* So, they see themselves not as a financial organization, but like every organization they need to make a profit in order to exist.

Dating back to 1831, the hospital built in 1866 is still in use, although over the years the hospital has expanded in also newer parts. A picture from the archive (Figure 1.2) shows how the hospital looks liked around 1900 and shows the chapel of the hospital. Next to that, the old building includes two of the wards and mainly offices, in one of which substantial parts of this thesis were written.

[1] www.kkle.de/leitbild.html accessed on March 7th 2018

Bed capacity	218
In patient visits	9671
Operating Rooms	4
Number of specialties	6
Staff	310
Medical specialists	63

Table 1.1: Key figures of the MHK in 2017.
source: OP-Benchmarking_Datenerfassung and VK-Zahlen

The key figures of the MHK are shown in Table 1.1. For the abbreviations of the specialties in this report, the German names are used, because they correspond with the used data. The first three are so-called surgical specialties, which use the operating rooms (ORs). The remaining specialties do not require an OR, but do need bed capacity:

- General surgery, in German: Allgemeinchirurgie (MCHA)
- Vascular surgery, in German: Gefäßchirurgie (MCHG)
- Trauma surgery, in German: Unfallchirurgie (MCHU)
- Internal medicine, in German: Innere Medizin (MIM)
- Cardiology, in German: Kardiologie (MKA)
- Neurology, in German: Neurologie (MNEU)

Two external specialties, who used to be part of the hospital, rent OR capacity from the hospital (see Table 2.2 for the OR division). The specialties only require OR capacity and no beds:

- Ophthalmology, in German: Augenheilkunde (Augen)
- Otorhinolaryngology, in German: Hals-Nasen-Ohren-Heilkunde (MHH)

The KKLK is member of the Krankenhauszweckverband Rheinland e. V. (KHZV)[2], which represents the interest of more than 160 hospitals during budget negotiations and advices its members on hospital financing. One of their hospital analysis is a benchmarking report, which is used in this thesis.

1.1.3 The German Health care system

The German national social health insurance system was introduced by Otto von Bismarck in 1883 and is the oldest in the world [3]. The system started with one segment of workers and slowly expanded to mandate coverage for the entire population. Since the fundamentals of this legislation differ somewhat from other countries and have a huge impact on how hospitals in Germany operate today, a small introduction will be stated below.

The German hospital system is a state and federally guided system for the provision of in-patient health care services for the population. The states of Germany (Bundesländer) are obligated to plan all care within their jurisdiction to assure medical requirements of its

[2]www.khzv.de/ accessed on May 14th 2018

population are guaranteed. Hospitals are designated for a certain level of care according to these planning goals. Any changes in the department or spectrum of services must be approved, generally by both the corresponding state government oversight committee and the national medical insurance committee [4]. Hospitals receive funds for capital investments for new equipment from the Bundesländer, but the proportion of this source of hospital income has been declining sharply over time.

In 2016 the 1.951 German Hospitals (498.700 combined beds) treated 19.5 Million Patients [5]. 36.2% of the German Hospitals are in private, so called, *Trägerschaft* and this portion keeps growing each year. But since most private hospitals are small, only 18.7% of the total number of beds belong to private hospitals [5]. 2008 statistics show that privatized ORs productivity were not significantly higher than public OR's, although a shorter length of stay (LOS) was apparent for privatized hospital's.

Health insurance agencies only reimburse elective surgeries if they are performed on in-patients, which require an overnight stay either before or after the surgery. In the event of over-scheduling, less urgent cases are expected to move to the next day. Hospitals try to avoid multiple re-scheduling of less urgent treatments because this affects patient satisfaction negatively. Under the old (pre-2002) compensation system, the costs of an additional night in the ward were reimbursed. The in 2002 introduced diagnosis-related group (DRG) system, operating on a fixed payment schedule, assigns these extra costs to the hospital [4].

In contrast to other countries, Germany implements legal requirements which for example makes the presence of an anesthesiologist obligatory for the duration of an entire procedure, further impacting the hospital's scheduling capacity. Although there is no legal obligation, patients usually only share a room with the same gender, unless there is really no alternative space available. In Germany patients are free to choose any hospital. Therefore it is also important for the hospital to have a good name in order to attract new patients and generate revenue.

Insurance system

Most Germans are insured via the *Gesetzlichen Krankenversicherung*, the national health insurance (NHI) or sometimes called statutory health insurance. The premium is primarily based on 15.5% of the person's income, of which 7.2% is covered by the employer. Family members are often included free of charge and stay insured even if the employee looses his job. Retirees also remain covered by their health insurance, with a portion of health care expenses covered by retirement funds. Total out-of-pocket payments are not permitted to exceed 2% of an individuals annual income [6].

Since a fixed percentage of income can result in a high contribution for higher incomes, not justifying the expected entitled care, salaries above 59.400 euro (2018) are allowed to join a private health insurance (PHI). Since self-employed people do not have the benefit of having half of their insurance paid by an employer, they may also choose this option. This also applies for public officers. The contribution to the PHI is not based on income, but on age, health and the kind of treatment. Privately insured patients can choose a preferred treatment, desired (chief) doctor, shorter waiting times and other aspects during the stay in the hospital like a private room, electric bed and better food. Usually PHI patients have their own ward, separated from the NHI patients. In contrast to PHI patients, NHI patients sometimes share their room with five other patients. Furthermore, a PHI patient can specify more easily to what extent they want to be covered insurance wise. This level of insurance can go below the standard of the NHI since the person's has enough income to pay everything out of their own pocket.

Revenue generated by PHI patients used to belong to the chief doctor of the specialty, which resulted in PHI patients receiving the chief's full attention and faster treatment. The last decades have seen a change in this system. Younger chief's are less likely to be a part of such arrangements, even though the system is still adhered to in the older chief's contracts.

Diagnosis-Related Group

In Germany the DRG-system is the principal mechanism to allocate financial resources to hospitals. It allocates about 85% of financial resources (142.2 billion Euros in 2016, [5]) to hospitals, which is internationally one of the highest share of DRG-based hospital payment. The German DRG system was introduced in 2002 as a reimbursement system for the treatments of in-patient care. It applies to all hospitals, regardless of ownership status, and (almost) all patients, regardless of their insurance. But PHI patients can get additional treatments and have other costs regarding their stay in the hospital. After the introduction, the LOS declined by 20% and the number of surgeries grew by 12% [7]. DRG -systems have become the most common basis for hospital payment in European countries. The German DRG classification, based on the Australian system, groups together several parameters, such as diagnosis, procedures, patient's age, complications and so on into one code [8]. Such that in the end *the same price is reimbursed for the same service* [9]. From now on the term DRG will refer to the German system.

The base value of a DRG is based on the main diagnosis of the treatment. All possible principal diagnoses are divided into 25 mutually exclusive diagnosis areas representing the clinical complexity level of the treatment. Additional interventions, procedures, complications, intensive care, artificial respiration, age or pregnancy can influence this level.

The reimbursement is (primary) based upon the average length of stay, in German: Mittlere oder durchschnittliche Verweildauer (ALOS) over all patients. This average stay is adjusted every year to resemble the true average. If the LOS of the individual patient exceeds the average, the hospital will not receive extra money (to a certain degree). In addition, no other patient can be placed into this bed, resulting in loss of opportunity costs.

Figure 1.3 shows a schematic representation of how the eventual value of the DRG is determined. It is assumed that costs grow linear over the LOS of the patient. The DRG prescribes a certain ALOS in which the hospital should be able to cure the patient. The reimbursement is rated so that if the ALOS is achieved, a small profit can be made. Since the reimbursement is set to a fixed price, achieving a lower LOS will bring in the same

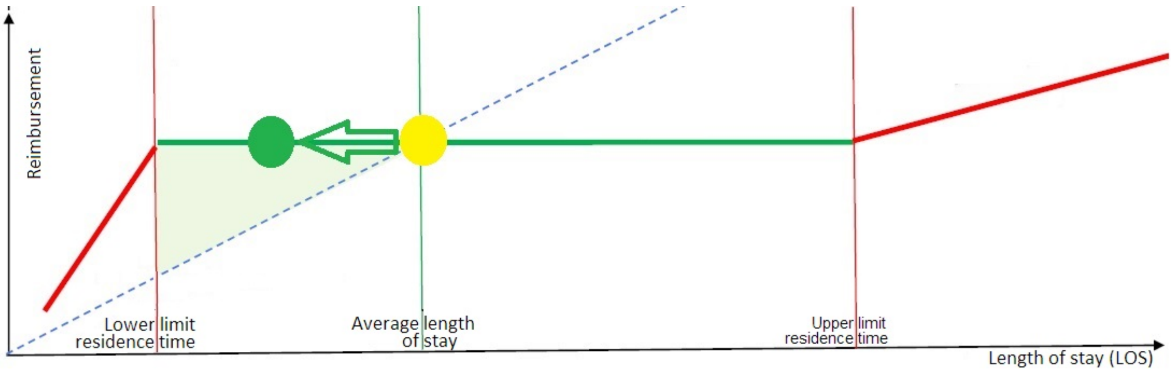

Figure 1.3: Revenue based on the DRG, if no other figure can be found, this will be translated. Source: http://www.sananet.com/medizintechnik-kostenerstattung-medizinprodukte-90.html

revenue, but with fewer presumed costs, resulting in a higher profit. In a financial optimal case, the LOS lies below the ALOS. However, every procedure has also a lower bound which required to cure the patient, this is called the lower limit residence time (German: Untere Grenzverweildauer). If a patient is cured (and discharged) before this time, the health insurance agencies will question if the presumed DRG was diagnosed correctly and if the performed treatment was indeed necessary. For every day below this limit a penalty will be enforced on the case mix (CM). The reimbursement for the DRG will stay the same also if the ALOS exceeds the prescribed LOS, since costs will keep increasing, the loss will be entirely for the hospital, as can be seen in Figure 1.3. Since not every patient and treatment are the same, it is possible that the LOS of the patient does not correspond to the prescribed number of days. If the patient requires a stay that exceeds the upper limit of the residence time (German: obere Grenzverweildauer), a small premium is added to the CM. But this additional revenue does not rectify the costs that were made. In order to generate a profit, the LOS of the patient should be equal or below the prescribed LOS by the DRG, but above the lower limit in order to get the full amount of revenue. It is however better to be below the limit instead of above, since an early discharge will stop the costs from growing and the bed will be available for a new patient who can generate new revenue. These values differ of course per DRG and are adjusted every year. In general, a financial optimal duration is one day below the prescribed LOS.

For a more detailed analysis of the developments and calculation of the DRG payments, see Tuschen and Ulrich, (2009) [7].

1.2 Research motivation

Generally, a company performs profitable if it works efficiently. However, the German legislation compels this efficiency by directly linking the remuneration of a procedure to a benchmarked efficiency (DRG), forcing the hospitals to perform on this frontier in order to be financial stable and survive. The OR is often described as the engine that drives the hospital [10],

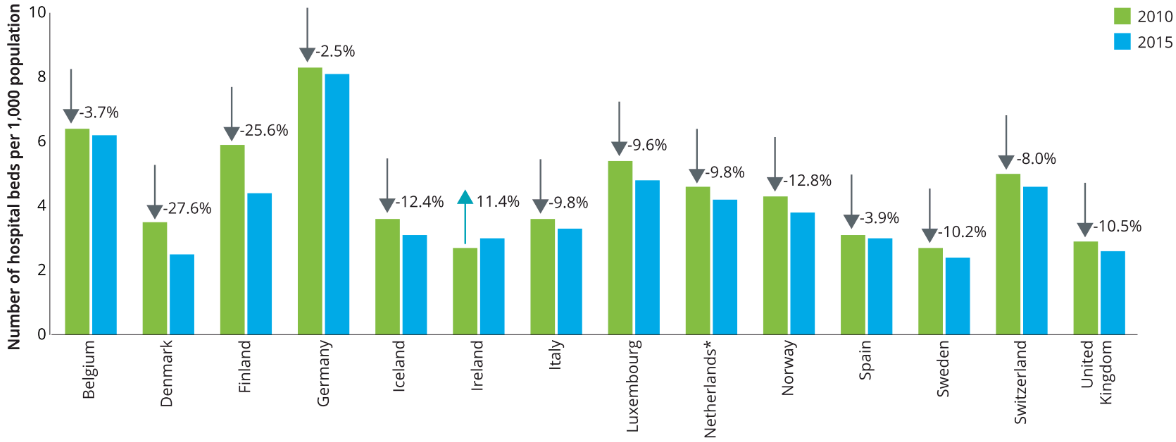

Figure 1.4: Changes in numbers of hospital beds, per 1.000 population, from 2010 to 2015 (or nearest year).*Hospital beds data for the Netherlands 2009 and 2013, *Source: OECD, 2017*

implying many other departments are impacted by the master surgery scheduling (MSS) [1]. And also at the MHK, the OR planning has a huge influence on the other processes in the hospital. Small changes in the schedule can cause big disruptions in other departments. But, since the OR is the hospital's most expensive resources, costing 30 euro per minute at MHK, hospitals wish to maximize its performance through high resource utilization, minimal overtime and minimal cancellations [1]. The whole process in the hospital is driven by an OR schedule planned to maximum capacity.

This would be a logical approach if the OR would be the bottleneck of the hospital. But this approach causes big problems along the pathway, creating other bottlenecks which disrupt the primary process that is to help as many patients as possible. Therefore this research focuses not primary on the planning of the OR, but on the patient flow through the hospital. It targets the capacity of the wards and tries to provide insights in the OR schedule using this new division and focus on the LOS of patients.

Reducing the LOS is especially important for the German health care system since they have the highest number of hospital beds per population of Europe (OECD 2017), as Figure 1.4 clearly shows. Looking at the surrounding countries, who have manage to reduce the total number of beds even further over the years, it should be possible for Germany to reduce their number of beds. To achieve this, fewer people need to simultaneously require a bed. This will be the case if the number of patients that require care stays the same and their LOS declines. But when looking at the LOS of Germany compared to the other European countries (Figure 1.5), the same pattern is shown. If a county has a high amount of beds available per population, the LOS in these countries is also high. Looking at the other European countries, shows that it should be possible to improve the German health care system with regard to these aspects. This research will focus on the German system and aims to provide a solution for the German system.

The high number of beds and LOS result in a high workload. This translates to the highest perception of workload in Europe, where German doctors and nurses describe their

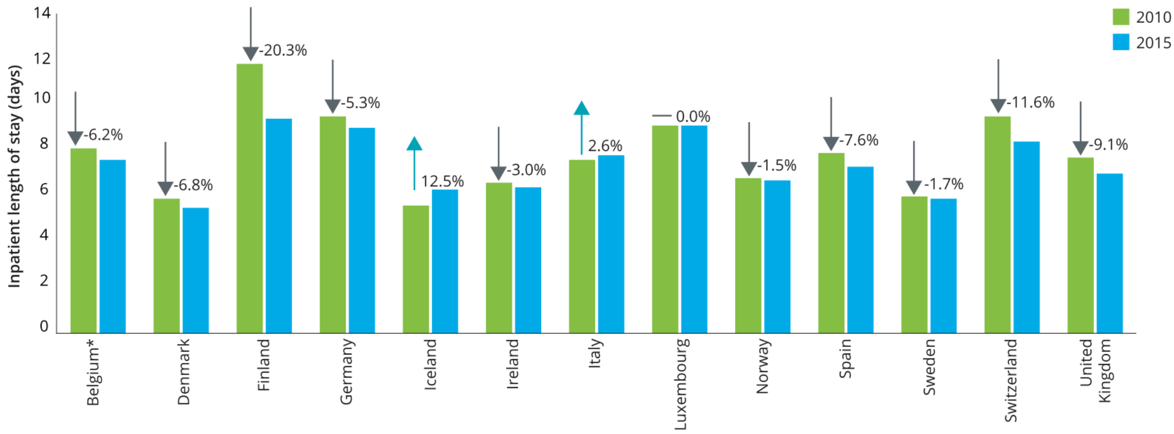

Figure 1.5: Changes in average length of stay in hospitals, per 1.000 population, from 2010 to 2015 (or nearest year).*Belgium data of 2014, Netherlands is omitted due to country-level data for length of stay only available for 2006, *Source: OECD, 2017*

workload over time to be very difficult to manage (2012-2017), resulting in the highest perception of workload and least manageable of all of Europe. 78 % of Germany's nurses perceive their work as *quite* or *very difficult* to manage. This percentage has increased by 31% over the last five years [11].

This big increase is remarkable since most other countries where also able to reduce their number of beds and LOS but the perceptions did not change that much. These reductions came above the reduction of the LOS between 2001 and 2010, when the length was much higher [5]. Reducing the LOS is definitely possible without increasing the workload, but the relatively low reduction could indicate that Germany needs another way of reducing their number. This could be achieved by using another way of thinking to minimize the duration of patients' stay, lowering the need for beds and reducing the amount of work for the doctors and nurses.

Germany is the largest country in Europe, with the highest total spending on health care (OECD 2017). This implies a big amount of potential savings, if an appropriate solution can be found. This is the first operational research that is performed in the MHK. Before determining the research objective of this thesis, it had to be clear how this project could contribute directly to increase the performance of the MHK. In the end, this thesis should show how operation research can be used in medical institutions and why this is so important. Improvements, that fall out of scope, can be performed by the personnel or should serve a basis for further research for MHK and other Hospitals.

1.3 Problem description

In order to help as many patients as possible, the MHK has a full planning, resulting in a high daily demand for beds. There are a lot of patients in the hospital, but not everyone can be treated at the same time. Most patients are admitted around 7 AM, but the majority of discharges occur after 11 AM, creating a deficit in bed availability. Patients have to wait for their treatment, creating a high occupancy rate and a scarcity in available beds. The waiting times result in a longer LOS than prescribed by the DRG. The additional cost are not reimbursed by the health insurance agency and the bed cannot be used by another patient, obstructing additional revenue. To account for these patients, the MHK applies an interdisciplinary bed division, where patients are not only assigned to a designated ward, but can also be placed in a different one. This widespread of patients causes a lot of walking for the surgeons and a loss of overview. Sometimes patient are *forgotten* and just lie in their bed waiting for treatment that is not coming. In addition, the nursing staff is specialized for a certain medical procedure, but if there are patients requiring different medical procedures, the nurse with that particular specialization is not always available at the ward. Making the quality of care is not optimal.

As a result of the merger into the KKLK and without any capacity analyses, a part of the MKA was relocated from Kleve to Kevelaer in 2017. A new cardiac catheterization laboratory was built in Kevelaer, patients started coming and needed to be accommodated. Since ward M4 was usually the least occupied, most MKA patients were sent to this ward. But in almost half of the cases, M4 turned out to be full, so patients started to settle other wards wherever there was a free spot. As a result, other specialties could not treat their patients in *their own* ward, moving them all over the hospital. This created a vicious circle, patients had no place in the specialized ward due to *Fremdlieger*, causing them to become*Fremdlieger* themselves.

The additional MKA patients also occupy some beds in the intensive care unit (ICU), but the ICU was already short staffed. This resulted in even longer LOS, since patients that needed an ICU bed after surgery could not be operated and had to wait.

Due to the high number of *Fremdlieger*, specialties cannot treat their own patients. So if a bed becomes available, it is immediately claimed by another specialty. As a result, doctors only discharge a patient, if they already have a new patient that can be placed in the same bed. The cured patient serves as a placeholder, increasing his LOS and the overall problem even further.

To make up for the missing revenue, more patients get planned since they bring in the money. This results in even fuller schedules and long workdays for the employees, which are already understaffed.

Due to the principles of the German health care system, the length of stay is key. Financial reimbursement is mainly based upon this LOS. The Marienhospital Kevelaer has substantial problems when it comes to absorbing the flow of patients and wants to know if they can reduce the LOS by using their Bed and OR Capacity more efficiently. The goal of this thesis is to provide some first steps towards an easy to understand model that can help the hospital to become more profitable.

There are already a lot of possible solutions in the hospital, even for decreasing the LOS, of which some are already (partially) used within the hospital. There may not be a great need for a complex revolutionary model. Rather, this research aims to provide the hospital with insight into the importance of taken measures and an outlook on the hospital's need for increasing bed or Operating room capacity.

1.4 Research objective

The goal of a hospital is not to maximize the usage of the hospital's bed and OR capacity in itself, but to help as many patients in an as cost efficient way as possible. Due to the nature of the German health care system, reducing the length of stay helps achieving this for both aspects. Although possible solutions are known, experience shows that its execution remains difficult. By using literature study, data analyses, mathematical models and human interaction within the hospital, this thesis tries to provide a strategic basis for the hospital by providing a substantiated answer to the question:

"How should MHK assign its beds to generate an optimal patient flow in the hospital and to the OR in particular, such that the average length of stay is reduced in the current environment?"

Since the MHK is part of the KKLK, optimizing should in the end be done over all the departments. The solution should be easy to understand and also applicable outside the MHK, such that it can actually be applied in any hospital.

1.5 Research questions

In order to fulfill the research objective, four sub categories are defined. Since the specialties cannot cope with the interdisciplinary bed division and changing this is presumed to be not possible. An intermediate solution is needed as a basis such that processes can be improved and trust in using scientific models can be gained.

1.5.1 Optimal patient flow in hospital

The goal of a hospital is to treat patients as good and quick possible, without unnecessary waiting times. This will limit the LOS to a time the patient actual needs in order to be cured. Due to the importance of the LOS in the German health system, reducing the LOS will improve the cost efficiency of the hospital. The pace of treatment gets determined by the capacity of doctors, nurses, OR capacity and number of beds. To use this capacity to its best, it is important to know how many patients can be allocated to the capacities while a smooth throughput and manageable workload can be guaranteed. This can be summarized into the following question.

At what utilization level is the usage of capacity optimal, while waiting times of patients are kept to a minimum? (utilization of occupancy?)

1.5.2 Determining appropriate bed division

Since the interdisciplinary bed division results in a lot of problems, the MHK wants to assign a fixed number of capacity to each specialty to plan their activities. The following question should provide the hospitals with numbers to split up its capacity:

How should the beds be allocated over the different specialties, and how should the specialties be allocated over the wards?

The capacity and division of the ICU will not be covered in this thesis since this involves additional complications and requires its own in-depth analysis.

1.5.3 Planning of the new bed division

Once an appropriate division is introduced, the specialties need to know how to use this capacity. An overload of patients will result in inefficiencies within the hospital. How much capacity should be kept unplanned in order to handle the arrival of emergencies and other disruptions in the planning. It is therefore important to know how much capacity should be kept unplanned. Therefore, the following question is drafted:

What is the optimal bed occupancy level, including how much slack should the OR and bed schedule have to take in Emergencies?

1.5.4 Sustainable solution

In the end it is important that the proposed solution will indeed be used and can be maintained under new circumstances. The goal is to reduce the LOS, which will change the demands for certain capacities. The first solution will be based on *non optimal* performance, using this solution will improve the non optimal performance. But in order to really improve, the proposed divisions should be able to be evaluated. To do so, the solution will need to be actual used, making it possible to analyze the results and optimize the system. The real benefit will only come if this process is actual applied. Since other good options to improve the performance of the hospitals are neglected, this thesis should provide a solution will be adopted. This may be the most challenging part of the thesis and needs to be assured by the following question:

What is a simple yet effective way to ensure that the results can be maintained and actually will be used?

1.6 Report organization

The remainder of this thesis is organized as follows. In Chapter 2, a context description is drafted to give insights in how the hospital operates. Chapter 3 provides a review of the most relevant literature for theoretical background. The solution design is described in Chapter 4 and the results of testing the designs are discussed in the subsequent Chapter 5. Finally, in Chapter 6, conclusions and a short term roadmap are given to improve the easy to harvest *low hanging fruit* which make a direct impact. Lastly, a long term road map is given which includes aspects that were encounter during the process of this thesis, but fell out of scope.

Chapter 2

Context analysis

The goal of operation research in general is to maximize added value, reduce variability and minimizing complexity. But in order to do so, the system needs to be understood first. This is not achieved by looking at the OR and wards directly, but by focusing on the patient. He is involved in the whole process and only resolving problems partially will displace these problems elsewhere and postpone the corresponding waiting times or other losses. In the end, the LOS of the patients will not decline, not solving the actual problem.

To give some context, the process will be described first. Followed by how these processes can be organized. Then, the performance of these processes will be examined and compared to other hospitals. At the end, the most important insights will be summarized.

2.1 Process description

In this section the current practices processes in MHK are described. Since by definition, the patient is involved in the entire care process from start to finish. Optimization must address the entire care process, which means that the performance must be measured over the entire care chain, not merely the individual components within the chain [12].

In order to understand the consequences which planning a hospital causes in-depth, the full path of the patient was followed. On the road, all the processes were observed multiple times, while interviews could be conducted and the work continued. The stops usually covered a big part of the day, such that a representative impression could be obtained. Existing reports of previous students were analyzed and the available software was inspected. Next, different sources of data were analyzed together with a benchmarking report. Due to the changes in the hospital (e.g. arrival of the specialty MKA), most calculations are based on the year 2017. Since the new division brought new challenges with it. Although these calculations are also checked on consistency for the previous years and 2018 if available. Especially new data is relevant since the arrival of MKA has a big impact on the overall flow in the hospital.

2.1.1 Care Pathway

This thesis focuses on the patient, since we want to reduce their length of stay. Treatments before the hospitalization, along with the planning of these processes, are outside the scope. The first time patients are considered is when they arrive.

Reception

The most general way for a patient to arrive is when he has an appointment of hospitalization. If so, he will come to the hospital to his planned time. The reception will take the patient in and makes sure all the paperwork is done and print the patient stickers that will be used throughout the whole hospital. The patient will be given a red folder containing all his information. If everything is cleared and all the required paperwork is signed, he can make his way up to his assigned ward.

Outpatient clinic

If for any reason a patient visits the outpatient clinic, the doctor can decide that the patient needs to be admitted. How the patients ended up in the hospital does not matter since this thesis considers only patients that arrive at the hospital who will need a bed and maybe require surgery. Planning of regular follow-up consultation are out of scope since these patients may occupy a doctor, but do not require a bed (yet). Due to the German health system, patients can come by referral from a doctor but also on own initiative.

Transfer

Patients also arrive at the hospital when they are transferred from another hospital. Within the KKLK, patients can be transferred if one of the hospitals is for example full. However due to the expertise within the hospital, sometime patients also get transferred from other hospitals. The available data distinguishes transfers between a LOS of under 24 hours and above. Within this thesis both transfers are considered *elective* patients since they can be foreseen and planned. If there were no room in the MHK, the patient could be transferred to another hospital.

Emergencies

Since there always will be emergencies not all patient arrivals can be planned. No one knows exactly when they will arrive, but from experience it is known that eventual they will. Capacity for emergency patients therefore needs to be reserved in the planning. If on entry, the patient does not have a referral, he will be marked as an emergency since he was unforeseen. A doctors referral may also come unforeseen, but usually these case do not require direct admission. If this is the case, the doctor will contact the hospital in the meantime.

Discharge

On time discharges are important since the admission and discharge day together are seen as one day according to the DRG. If a patient has an early admission and a late discharge, the patient has stayed longer in the hospital as will be reimbursed.

In order for a patient to leave the hospital, the doctor needs to decide that the patient is allowed to be discharged. If possible, the doctor will consult the patient about his intentions one or two days in advance. He then prepares the discharge letter and instructs the nursing personnel about the drugs the patient will be given home. At last, the doctor has to inform the patient about the drugs the patient will be given home. The nurse will have to inform the patient that he will be subscribed as a patient. If needed the nurse will arrange transportation, informs the housing accommodation and fill out transfer papers. The nurse will then remove the patient from the ward plan in the computer system. If the patient has left, the nurse will clean near-patient surroundings and bring the bed to the central bed station, in German: Bettenzentrale (CBS). This process is documented under number D-006374 in roXtra and agreed on by doctors and executive nurses.

2.1.2 Wards

The hospital has seven wards: M1, M2, M3, M4, M5a, M5b and M7, leaving number six open. Ward six is located in the old building and when connecting the ward to the new hospital. Some stairs had to be added to the corridor, which was no longer acceptable by emergency regulations in 20XX. Ward six therefore remains empty, but there are thoughts of building offices there. The hospital also has a Intensive care unit, in German: Intensivstation (MINT) with a potential capacity of ten beds.
M1 and M2 are located at the ground floor of the hospital. M3, M4, M5a, & M5b are located on the first floor, on which also the ORs are located. Patients that reside on these wards do not require an elevator to be brought to the OR, which saves time. Ward M5 is primary for PHI patients and used to be one ward. But since the corridor has a 90 degrees angle in the middle which makes it hard to oversee, it was split into a part A and B. Since both wards are considered as a ward on their own, PHI patients are allocated to one of the two. M7 is located in the top level, where mostly offices are located.

Table 2.1 shows the numbers of beds that are planned per specialty for 2017 and 2018. These beds include NHI and PHI patients. For the year 2018 there are some small changes, but the biggest change is the removal of planned beds for MHH in 2018, which were partially needed to accommodate the new arrived MKA.

Every ward has a whiteboard where all the patients are listed. This information can also be found in the computer system, but the board gives a quicker overview. The prescribed ALOS by the DRG are not considered by the nursing personnel since they see this as a task of the doctor.

	2017	2018
MCHA	15	15
MCHG	40	30
MCHU	35	24
MIM	75	71
MKA	—	30
MNEU	35	40
MHH	18	—
MHK	218	210

Table 2.1: Number of assigned beds in MHK per specialty in 2017 and 2018. source: 20180205_Zahlen_Daten_Fakten.xls

Beds

The hospital has a total of 218 Beds, of which 60 electric. The electronic beds (e-beds) are assigned to the private patents, but are also needed in the ICU (7 to 10 beds) and for special cases.

If there is no e-bed available, the patient gets a *normal* bed and is switched to an e-bed, if one becomes available.

Next to the *normal* beds, there are also beds that can be extended for longer people (>185 cm). All the e-beds can be extended, which makes them high in demand and always have first priority. If no extendible bed is available for a tall person, he will be given a e-bed, which will be switched if a *normal* extendable bed gets available.

If a patient is transferred to bed he is entitled to, the old bed needs to be cleaned. These beds are called *Tauschbetten* (exchange beds).

The regular beds are for people up to 150 Kg. If a person exceeds this weight, a special bed is needed, but this is barley the case. In order for a patient to stay in hospital, his bed need to be available, which has to be ready on time. So it needs to be brought to the CBS on time, so the nurses need to have the time and the patients need to be discharged on time, so the discharge papers need to be ready on time.

Central Bed station

The beds get cleaned by the central bed station, in German: Bettenzentrale (CBS), located in the basement of the hospital. On arrival the dirty laundry gets removed and the bed gets fully cleaned. Due to Hygiene rules, the bed needs to dry for about ten minutes to let the alcohol evaporate. Next the bedding is made and the bed is sealed with a plastic sheet. It takes nine minutes to clean a *normal* bed and twelve minutes to clean an e-bed (excluded drying time), whether a bed is extendable does not differ.

Nurses have no time to bring a bed down after a discharge. So the supply to the CBS is not evenly distributed, so the outflow also has a high variation. Since the CBS is not staffed 24/7, beds pile-up. If a patient is discharged *to late*, the bed will be ready the next day. The

<table>
<tr><th colspan="2">Planning</th><th colspan="4">Operating room</th></tr>
<tr><th>Day</th><th>time slot</th><th>MOP1</th><th>MOP2</th><th>MOP3</th><th>MOP4</th></tr>
<tr><td rowspan="2">Monday</td><td>08:00 - 12:00</td><td rowspan="2"></td><td rowspan="7">MCHG</td><td>MCHG</td><td rowspan="3">MCHU</td></tr>
<tr><td>12:00 - 16:00</td><td rowspan="2">MCHA</td></tr>
<tr><td>Tuesday</td><td>08:00 - 16:00</td><td>Augen</td></tr>
<tr><td>Wednesday</td><td>08:00 - 16:00</td><td></td><td>MCHG</td><td rowspan="2"></td></tr>
<tr><td rowspan="2">Thursday</td><td>08:00 - 11:00</td><td>MHH</td><td rowspan="3">MCHA</td></tr>
<tr><td>11:00 - 16:00</td><td rowspan="2"></td><td rowspan="2">MCHU</td></tr>
<tr><td>Friday</td><td>08:00 - 14:30</td></tr>
</table>

Table 2.2: OR Division per week for the MHK as used in 2017 and 2018.
Source: OP Statut MHK (D-007231)

CBS staff are relative flexible, and work until no work is left, but if the go home the beds pile-up. When queued beds get processed, they pile-up at the end of the CBS, since not all Nurses bring beds back up to the room when bringing one down. This illustrates just one of the effects that late discharges have down the process.

2.1.3 Operating room

The MHK has four ORs of which MOP2, MOP3 and MOP4 are aseptic (surgically sterile). The other one (MOP1) is located outside the regular ORs and is used for smaller interventions. MOP1 is the OR that is rented to the Augen and MHH for one day of the week each. Next to these four ORs, the hospital has a new Cardiac catheterization laboratory (German: Herzkatheterlabor), primarily used by the MKA and its scheduling falls outside the scope of this thesis. However the MKA will be included in the division of the beds because this directly impacts the specializations under consideration in this thesis.

Patients can be planned in the OR schedule by various people up to 14:30 one day in advance (13:30 on Friday) in the program iMedOne. The operating room coordinator (ORC) then closes the planning and checks the planning. Surgeries that come up after this deadline can be added to a separate field and only the ORC can plan them in the schedule. Changes to the planned sequence should be avoided, but occurs often and causes a lot of problems. This can be due to on hand changes resulting from practical events, such as an emergency or a no show of a patient. But often also the Surgeons change the sequence because it suits them better or just because they feel like it.

Surgeries that have a higher approximate duration then two hours are scheduled in the beginning of the day. Hence these are often big surgeries that require more preparation and if they run out of schedule, no overtime is required for that surgery in order to finish it.

Table 2.2 shows the OR division of 2017 and 2018. The septic MOP1 is only used for the external specialties, but in practice some surgeries of the other specialties are also performed in this OR. Most of the time only three ORs can be used at the same time since there are only three operating teams to assist. Tuesday is the only day where all four ORs are used since Augen bring in their own operating team. On Thursday, MCHU can only start after MHH has finished its surgeries. Since these are all small interventions, with low variation, they usually finish on time for MCHU to start at 11:00. MCHG is the only specialty that OR time scheduled on every day, fully use MOP2. On Wednesday, they are the only scheduled specialty, using also MOP3, which is also used on Monday morning, before MCHA arrives. The availability of the specialties is influenced by the presence of specialties in other hospitals of the KKLK.

For emergency surgeries distinguishes in emergencies that need to be treated within 24 hours and emergencies with a lower priority. If the patient does not require immediate care, the current surgeries can be finished. Since the arrival of an acute emergency is still known minimal half an hour in advance, the ORC decides what surgery can be finished or needs to be stopped. He then also adjust the schedule to the new situation in consultation with the surgeons.

Anaesthesia

The Anaesthetist requires some time the prepare the patient, but these planning are made in a separate program. They will not be directly looked at during this thesis, but since the anaesthesia is part of the OR process and can cause delays, they need to be mentioned. The anaesthesical equipment used in MHK is very old and outdated, which contributes to frequency of delays suffered during the anaesthesical preparation of the surgery.

Recovery

After surgery, a patient is usually still numb due to the narcosis. Since the OR is an expensive resource and other patients need to be treated too, the patient is brought to the recovery (German: Aufwachraum) if he is capable of being transported. Here the patient can slowly recover from his surgery where after he can be transported back to his ward if he is in stable condition. The recovery is located right outside the aseptic ORs and across from MOP1. The recovery usually opens at the same time the OR plan start, but usually do not have much to do in the first hours of the day because the longest surgeries are planned first.

2.2 Process planning

Already in 1985, Vassilacopoulos (A simulation model for bed allocation to hospital inpatient departments) demonstrated that, while keeping the same bed allocation, a hospital could achieve higher levels of operating efficiency by smoothing patient admissions and discharges. However, health care planning and control is far behind manufacturing planning and control [13].

Planning an organization is a multiple stage process and consists out of decisions made on different hierarchical levels and management areas. The first of three stages involve

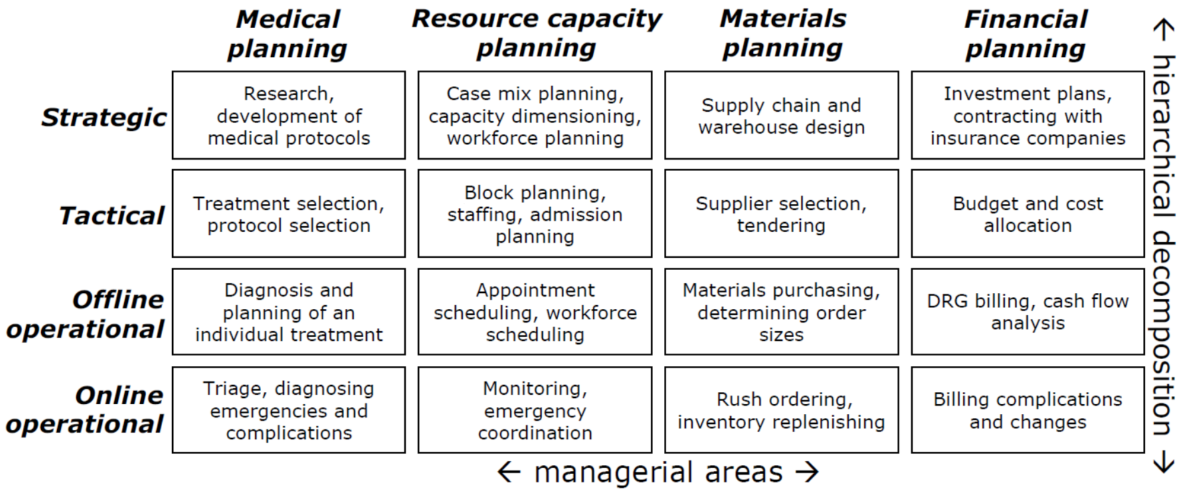

Figure 2.1: Framework for health care planning and control by Hans et al. (2012) [13]

strategic (or design) decisions, these are long-term decisions that determine the main structure of an organization. Tactical decisions are medium-term decisions related to how patients as a whole are scheduled, or how groups of patients are processed. Operational decisions are short-term and are concerned with efficiently scheduling individual patients [14].

Hans et al. [13] combines the three levels and all managerial areas involved in health care operations in Figure 2.1. Hans divides the operational level into off-line (in advance) and online (reactive) decision making. This thesis focuses on the resource capacity planning. Strategic decisions are the first stage in planning, where the capacity is allocated over the different specialties. Tactical decisions are about how this capacity should be used over a smaller period. The operational planning of the various patients is done on a daily basis. Individual appointments get scheduled in advance (offline), which can change due to real time events like emergency situations or other changes in available capacity (online).

The framework can be applied anywhere from the department level (for example OR) to organization-wide, or to a complete supply chain of care providers. Depending on the context, the content of the framework may be very different. The figure shows the content of the framework when applied to a general hospital as whole. The inserted planning and control functions are examples, and not exclusive [13].

2.3 Performance

In Operations research, analyzing data is an important first step in *process optimization*. This term implies that something is going to be *improved*, but first one needs to know *what* the actual *performance* of the process is [12]. The performance is split up into patient flow, wards, OR, (financial), benchmarking and in the end captured by key performance indicators.

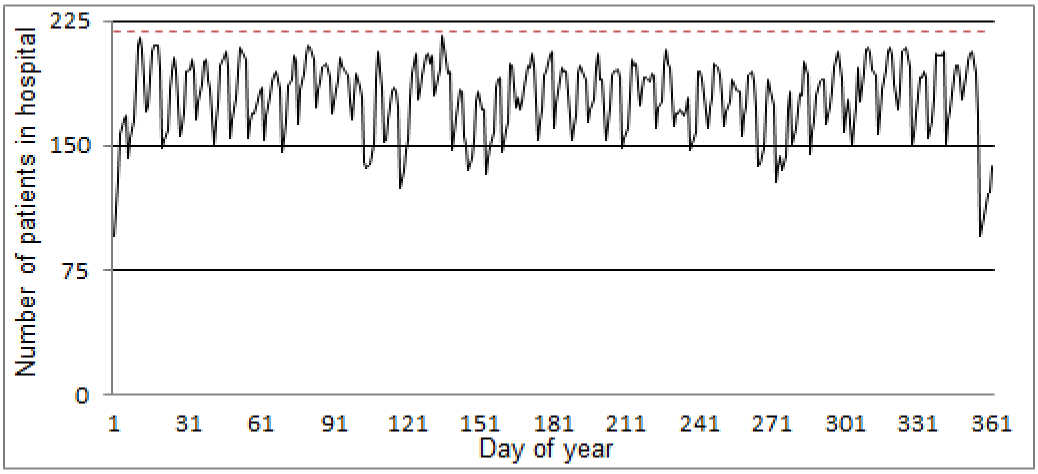

Figure 2.2: Number of patients that stayed over night in MHK in 2017.The red line indicates the maximum bed capacity measured every day between 08:00 and 08:30. Source: Anwesenheitstage KKLE 2017

2.3.1 Care Pathway

Since the availability of beds for arriving patients depends on the occupation by the other patients, only new beds become available after discharge. Figure 2.2 shows the number occupied beds per day in 2017 measured between 8.00 am and 8.30 am. The figure shows certain patterns of a build-up of 50 peaks. These peaks correspond to the number of weeks in the observed period. On Monday the line starts roughly above 150 patients, which increases toward the maximum capacity, where after it declines back to roughly above 150. The maximum capacity in the figure is a monotonous line, which in practice could be lower due to specific circumstances. However, the actual maximum capacity per day could not be retrieved from the available data.

At new years day, only a few patients are in the hospital. The same counts for Christmas at the end of the year. Outliers below the 150-mark are usually the result of other Christian holy days, like the Eastern weekend on days 105 and 106. Day 276 is October 3rd, which is *Tag der Deutschen Einheit*. There is a clear trend that is repeated every week, which could be explained by having every week the same OR schedule, like seen in Table 2.2.

Figure 2.3 gives further insights in this trend, by showing the average patient flow of 2017 on a weakly level. For every day the number of elective and emergency admissions are given along with the discharges. These are no surgical emergencies, but represent the arrival of unplanned patients that require a bed. The urgency of the surgery of this emergency patient will be covered in Section 2.3.3. Since a bed can only be used for a new patient after the previous patient is discharged, the difference between these moments is calculated by subtracting both ways of admission from the number of discharges.

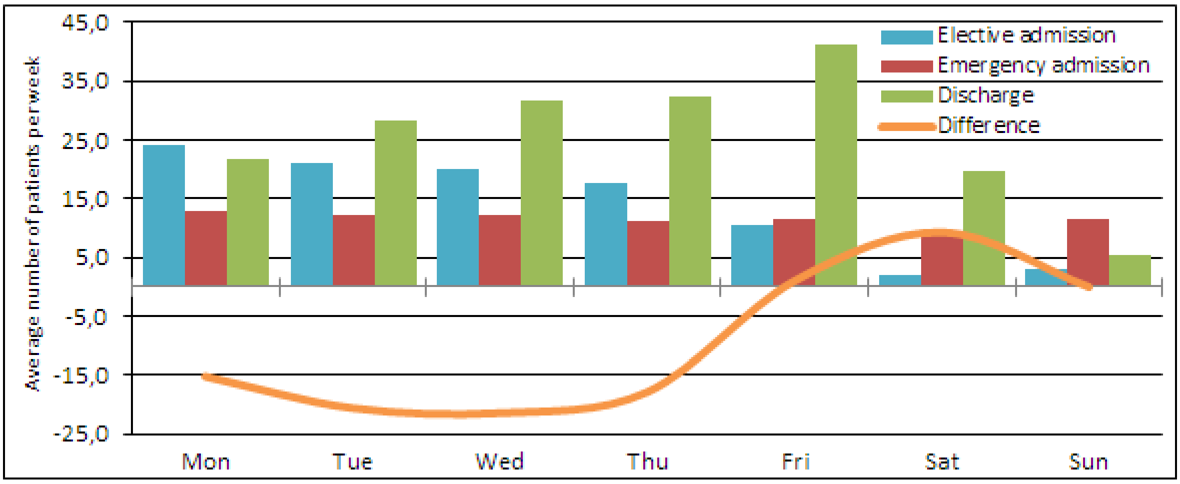

Figure 2.3: Weekly average elective + emergency admissions & discharge of all patients per day and accumulated difference in MHK over 2017.
Source: source: MHK Fälle 2017 - Wahlleistung und DRG.xls

Admissions

In order to plan the stay of the patients, the arrival of the patient needs to be scheduled. Figure 2.3 shows that on average, most elective patient will arrive on Monday. Down the week the number of elective admissions gradually decrease until the start of the weekend, where the amount is brought back to a minimum. This can be done since there are no scheduled surgeries in the weekend and since all admissions are planned in beforehand, no admissions are planned during the weekend. There no Sunday admissions for Monday surgeries, even though Monday has the highest number of elective admissions.

Next to the planned patients, a hospital also has to cope with emergency patients. Since the arrival of an emergency is stochastic, it is unknown when these patients will arrive. But Figure 2.3 clearly shows that *on average*, roughly the same amount of emergency patients arrive, with a small decrease in the weekend. It is clear that the exact moment of occurrence and arrival of an emergency is unknown, but *on average* twelve emergency patients will arrive on a weekday. Which makes sense if one would model the arrival of the emergency patients as a Poisson process, where the arrival rate λ is constant over t, assuming that different emergency are independent.

Discharge

Like previously mentioned, a patient needs to be discharged before the bed can be used for another patient. The week shows a build-up in number of discharges in Figure 2.3, ending with a peak on Friday. From Figure 2.2 it is known that on Monday there is some room to accommodate additional patients. But one has to wonder if all these patients can be treated during this day. In general, this pattern can be expected due to the way of admission since patients need to stay a view days in the hospital before they get discharged.

Difference

The accumulated difference, indicated in Figure 2.3, gives insights in the course of the flow. The difference is based upon circulation starting on Monday, making the numbers a bit subjective since starting on another day will change the accumulated differences, but the pattern will stay the same. Having a difference is not bad on its own, as long as there are enough beds for new patients. A big difference indicates huge fluctuation between the occupied beds. This means that the full capacity is not always needed. If both patterns would be more in sync, the difference would be smaller and smother divided over the week. Since total capacity is only partially uses, smothering this distribution over the whole week would require fewer capacity. Looking at the whole week we encounter a slow decrease of elective admissions and a build-up until Friday of discharges. The increase in negative difference until Thursday shows that on the first three days of the week more patients are admitted then discharged. This negative difference is event out on Friday, when the most patients are discharged. Meaning that during the whole week there is a backlog due to which the occupation level is not constant. This means that there is a dis balance upon workload for the nursing personnel.

Flow per hour

In terms of data needs, a hospital's midnight census data is commonly viewed as the surrogate for demand for inpatient units. [15]. Previous research demonstrates that using midnight census can be unreliable because demand variations within a day are not statistically captured [15]. From Figure 2.3 it has been shown that there is a backlog in bed availability per day. This pattern can be studied further by looking at the flow per hour. This shows more precisely at what time beds are needed and what kind of backlog is created due to the difference in admission and discharge times. Figure 2.4 shows the flow per average day in 2017. Since this shows an average day, the actual pattern can vary per day.

It is obvious that on the first five hours of the day almost no activity is shown. The first peak of the day starts with the elective admissions in the sixth hour of the day. Most patients are planned before 7 am. for surgical specialties. In the next three hours we see an increase after a small drop from the sixth hour. The emergency arrivals are roughly evenly distributed over the day, with a peak between nine and ten, right before and during the start of the discharges. The real peak of discharges starts after 10 am and continuous the whole working day, despite discharges should be processed before 11 am. This gap between admissions and discharge results in a huge difference. If this difference exceeds the amount of available bed, patients have to wait. Moreover, if a patient is discharged, the bed is not immediately available for the next patient. The bed has first to be brought to the CBS, get cleaned, dry, made and brought back to the ward.

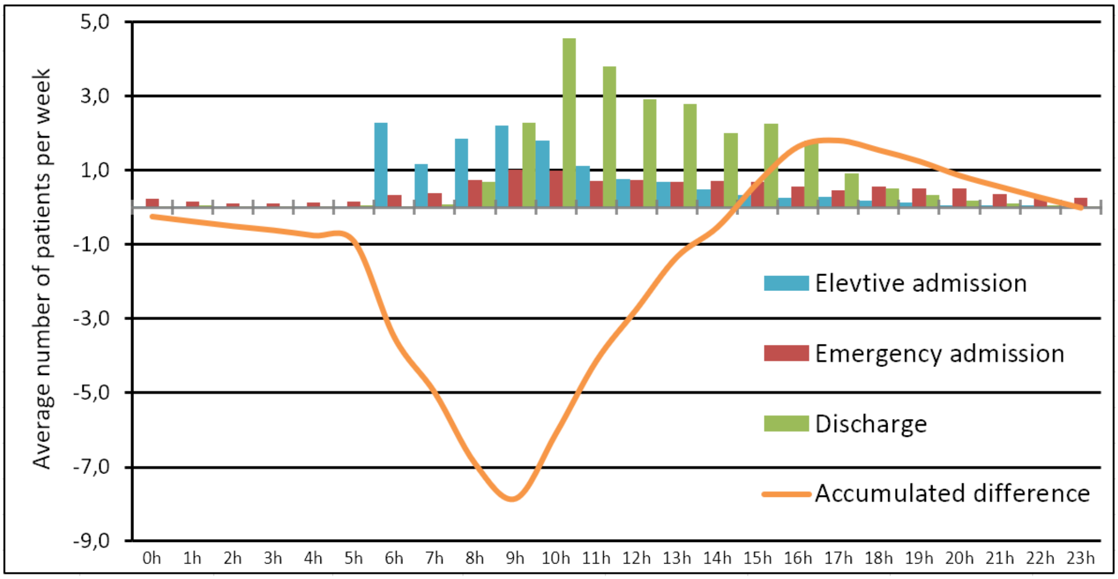

Figure 2.4: Time of admission (elective + emergency) & discharge of all patients per day and accumulated difference in MHK over 2017.
source: MHK Fälle 2017 - Wahlleistung und DRG.xls

2.3.2 Wards

Table 2.3 shows an overview of the care days per specialty, divided per ward over 2017. This is done in both absolute numbers and as a percentage of the total care days of that specialty. In order to let the table fit the page, the specialties are placed on the horizontal view. The table shows over which ward the specialties divide their patients. MCHA and MCHG have most of their care days on Ward M3 (NHI) and M5A (PHI). MCHU mainly uses M4, together with MKA who, however, have about 5% divided over the first three wards each. The ground floor (M1 and M2) are used for the NHI patients of MIM, the PHI patients are in M5B. MNEU uses almost exclusively the top floor (M7).

It has to be noted that the capacity differs per ward.

Occupancy & Utilization

MHKs estimates the required bed capacity based on the amount of 300 care days per year. Table 2.3 shows the amount of care days per ward, the amount of planned beds for the year 2017, the number of beds per 300 days of the year and the utilization as defined by the hospital. The table clearly show a high utilization, which exceeds 100% for the whole hospital. This of course has partly to do with the way utilization is defined. In addition, it is possible to put more beds in a room as planned. This is not only undesirable for the patients but also increases the workload of the personnel, which is planned based on the planned amount of beds.

	MCHA	MCHG	MCHU	MIM	MKA	MNEU	MHK
M1	6 0%	13 0%	25 0%	9283 38%	372 6%	125 1%	9824 16%
M2	0 0%	27 0%	12 0%	8558 35%	295 5%	142 1%	9034 14%
M3	2682 64%	6733 79%	539 8%	77 0%	366 6%	65 0%	10462 17%
M4	15 0%	36 0%	5653 87%	83 0%	4354 75%	78 1%	10219 16%
M5A	1188 28%	1508 18%	155 2%	1845 7%	113 2%	104 1%	4913 8%
M5B	209 5%	136 2%	32 0%	4624 19%	126 2%	37 0%	5164 8%
M7	1 0%	0 0%	0 0%	11 0%	4 0%	12721 95%	12737 20%
MINT	104 2%	110 1%	46 1%	252 1%	212 4%	144 1%	868 1%
MHK	4205	8563	6462	24733	5842	13416	63221

Table 2.3: Care days per specialty per ward in MHK over 2017.
source: MHK Fälle 2017 - Wahlleistung und DRG.xls

Ward	M1	M2	M3	M4	M5A	M5B	M7	MHK
Care days	9.927	9.187	9.835	9.703	4.610	5.120	12.474	63.065
Beds	31	32	37	34	17	16	35	202
Care days/300	33,1	30,6	32,8	32,3	15,4	17,1	41,6	210,2
Utilization	107%	96%	89%	95%	90%	107%	119%	104%

Table 2.4: Utilization based on 300 care days per year for the different wards in 2017.
source: MHK Fälle 2017 - Wahlleistung und DRG.xls

Length of stay

When calculating the LOS in Germany, the admission and discharge day are considered one day. When a patient gets discharged on the same day as he was admitted, the LOS is one. But if the patients stay one night in the hospital and is discharged the next day, this still counts as one day. Every further night counts as an additional day spend in the hospital.

In Figure 2.5 the ALOS is given per specialty, together with the LOS defined by the DRG. For most specialties (MCHA, MCHU,MIM and MNEU), the actual LOS is exceeding the prescribed length by the DRG. MCHG is just above the prescribed value and MKA manages to go just under this value. For the whole hospital, there LOS is way above the prescribed value. The desired value would be about one day below the DRG. This surplus is most influenced by MIM and MNEU, who treat the most patients. This does not directly

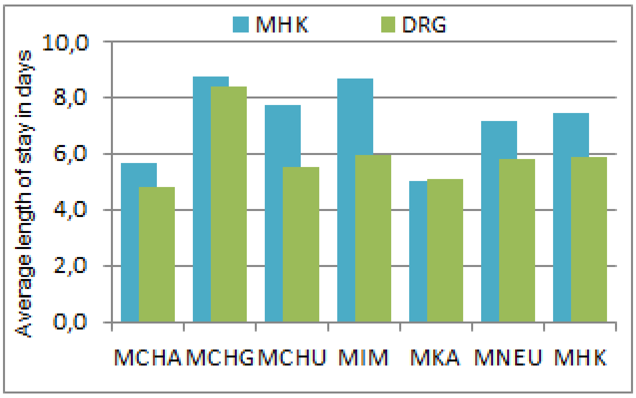

Figure 2.5: Average length of stay in MHK per specialty and according to the ALOS prescribed by the DRG over 2017.
source: MHK Fälle 2017 - Wahlleistung und DRG.xls n=9669

say something about how remunerative these specialties are since LOS is not the only cost driver, but it gives a quick and good impression.

Figure 2.6 the frequency of days in numbers along with the cumulative percentage. About 50% of all the patients stay five days or fewer in the hospitals, which fits in one work week. More than 85% of the patients will leave the hospital within 12 days, which are two work weeks and one weekend. The figure shows that 95% of the patients LOS is under 20 day. One has to keep in mind that the LOS of the remaining 5% can be way longer, keeping the bed way longer occupied.

2.3.3 Operating room

Number of surgeries

The flow of patients through the OR has a huge influence on the overall flow of the patients. It indicates the number of patients that have to be processed during the admission and for which a bed is required afterwards. The total number of surgeries per OR per day are given in Figure 2.7 with the accumulated number for the whole day. Most ORs process the same amount of surgeries per day, only the surgeries of M1 vary per day, showing a big peak on Thursday when MHH operates. The surgeries of Augen on Tuesday are not included in the data. But both external surgeries have no impact on the general flow since these surgeries do not require a bed afterwards. The number of surgeries in M3 on Wednesday are a bit higher compared to the other days since this is the day when varicose veins get operated. This is done by a retired doctor who is specialized in this procedure. Figure 2.8 specifies the number of surgeries per specialty. The influence of the OR division (Table 2.2) can be traced back to the usage. On Wednesday only MCHG have assigned capacity, but they achieve to process the maximum of patients per week (if the MHH surgeries are not considered.)

Both figures show that there are almost all surgeries take place during weekdays and not during the weekend.

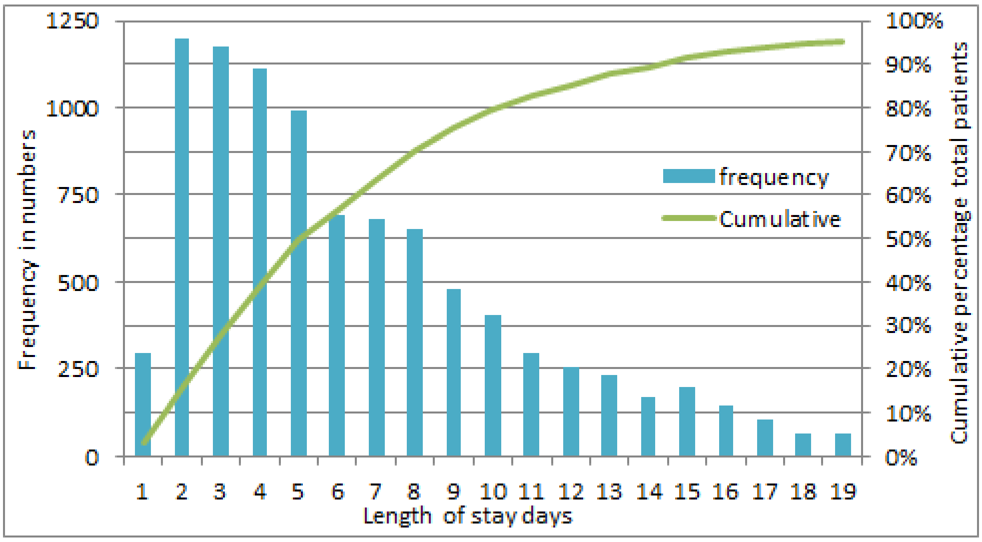

Figure 2.6: Frequency of the length of stay in MHK in the year 2017 for the first nineteen days and cumulative percentage over those days. If a patient is discharged the same day as admitted, this counts as one day, but also the stay of one night will count as one day.
source: MHK Fälle 2017 - Wahlleistung und DRG.xls

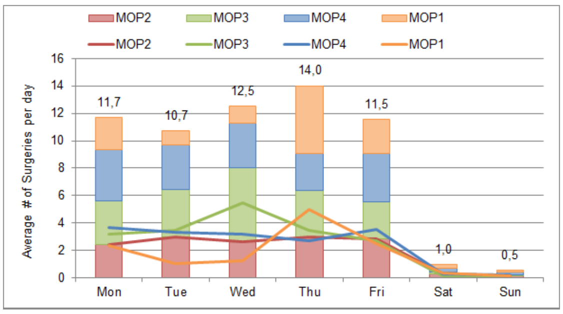

Figure 2.7: Number of surgeries per OR and cumulated in 2017. MOP2, MOP3 and MOP4 are fully functional and inside the main OR area. MOP1 is aseptic. In the weekend only emergency surgeries are performed. source: MHK Fälle 2017 - Wahlleistung und DRG.xls n = 3323

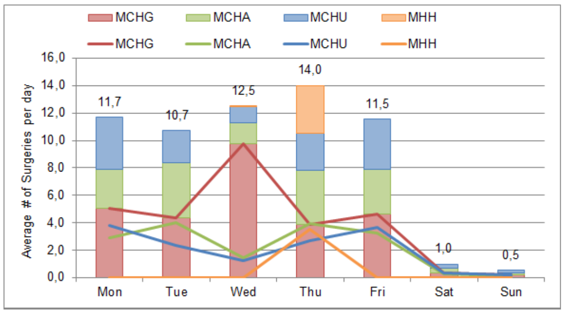

Figure 2.8: Frequency of number of surgeries per day, and total frequency in 2017. It has to be noted that MHH is no part of MHK or KKLK, but rents OR Capacity. There is no data about the AUGEN specialty (use MOP1 on Tue).
source: MHK Fälle 2017 - Wahlleistung und DRG.xls n = 3323

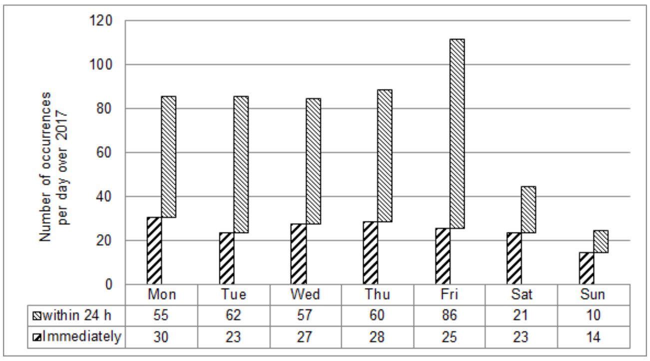

Figure 2.9: Total number of emergencies per weekday, divided in emergencies require immediate treatment or within 24 hours, over 2017.
source: MHK Fälle 2017 - Wahlleistung und DRG.xls

Emergencies surgeries

The figure shows that it is wise to expect at least one emergency per day an incorporate this in the planning.

In Figure 2.9, total numbers of emergencies that need surgery per day are given per year. It can be seen that the amount of patients that require immediate care are roughly the same over the week. The same can be seen on Monday to Thursday for the lower priority, but with an increase on Friday. A reason for this increase could be that GP's send the patients to the hospital more often, just to be sure nothing will happen during the weekend. Since the amount of emergency patients is higher on Friday, fewer elective patients should be planned compared to the other weekdays in order to treat all patients with the available capacity. Since the OR closes earlier on Friday anyway (Table 2.2), even fewer elective patients should be planned. On weekend days the demand for low priority emergency surgeries decreases.

OR Waiting time

It is possible to document OR Delays in planning tool iMedOne that the hospital uses. Since November 2017 it is possible to access this data. For the MHK, this is shown in Table 2.5 in number of occurrences and total minutes. The biggest amount of time is wasted due to organizational delay. This option however is used since the software only allows the entry of one reason per surgery, but there are often multiple combined reasons for a delay. Overall the biggest delay comes from waiting for personnel, of which waiting for the surgeon happens the most, especially for MCHU. This is also the main driver for the total percentage of surgeries that encounter delays. On average, every surgery encounters almost four minutes of delay outside the time of the surgery.

Since the core problem of the organizational delay could not be withdrawn form the data, two 'nurses in training' gathered more detailed information for an education practicum during the August 2017. In addition, they also tracked the delays during the surgery. The results are summarized in Figure 2.10. All the causes are subdivided into six categories and in every

Delay	Number				Minutes			
	MCHA	MCHG	MCHU	Total	MCHA	MCHG	MCHU	Total
Without further reason		1	4	5		5	146	151
Failure technical devices				0				0
Organizational delay*	10	12	8	30	263	350	363	976
Patient preparation incomplete	1	2		3	30	60		90
Difficult anesthetic induction	5	3		8	170	95		265
Preparation time anesthesia	3	2		5	70	105		175
Waiting for assistant				0				0
Waiting for sterile supply		3	1	4		50	35	85
Waiting for anesthesia	5	5	7	17	130	103	263	496
Waiting for surgeon	8	7	20	35	110	135	525	770
Waiting for patient	5	6	1	12	90	120	30	240
Total delays	37	41	41	119	863	1023	1362	3248
Total number of surgeries	263	450	221	934	263	450	221	934
Fraction (per # / min)	14,1%	9,1%	18,6%	12,7%	3,28	2,73	6,16	3,48

Table 2.5: Documented OR delays in MHK, numbers and minutes, from November 2017 to February 2018. *The system permits only the entry of one reason. If multiple reasons occurred, organizational delay is used to mark this. Source: iMedOne.

category we have a clear *winner*. Delays before entering the OR are mainly occur if the patient is brought to late OR. During entering of the OR, most of the time is lost if the sterile gate is already used by another patient. Trouble getting the patient on time under narcotics is the main driver for pre-surgery delays. Waiting for the surges costs the most time before the surgery can start. The longest delay is due to underestimations of the surgery time. Sometime a patient has to stay in the OR after the surgery, before he is fit enough to be transported, this is the final delay.

First Operation / start of the day

Most of the delays encounter during the first surgery of the OR. This has also the most influence on the rest of the schedule since every following surgery will be delayed. Figure 2.10 show the delays of the first surgery in the August 2017.

2.3.4 The importance of financial aspects

In the end, the hospital needs to be financial stable in order to survive. Financial planning is a separate managerial area in the framework for health care planning as seen in Figure 2.1. Although there was a lot of useful (sensitive) financial data available, it was decided to keep this outside the scope of this research. It requires knowledge and time to allocate the different cost to the specialties, especially if the patient was treated by different specialties. Financial data make the problem more complex and this thesis thrives towards an easy to implement solution. Since it is believed that this impact can be already created without financial analysis, which require no difficult mathematical models or tools and the knowledge

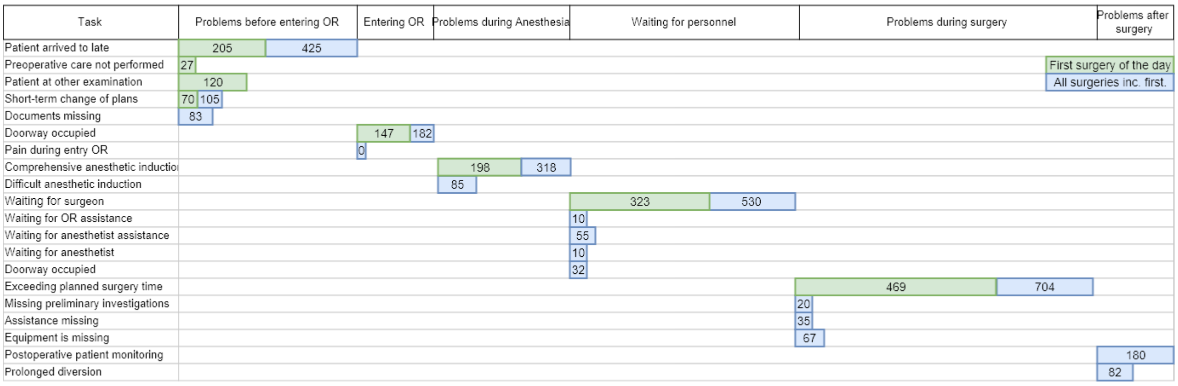

Figure 2.10: Gantt chart of all the waiting times in the OR in minutes in August 2017. The delays of the first surgery are shown green and the cumulative total in blue. For the smaller delays only the total time are given.
Source: Projektabschlussbericht Pia Aderian und Bastian Grütter.

is available within the KKLK, it was decided to keep these aspects for further research.

The hospital is already investigating this data, but should also openly communicate these numbers towards its personnel. Doctors should know on which treatments they make money and where the margins are thin, in order to improve their performance.

2.3.5 Benchmarking

Considering only the own performance can result in a distorted picture. Improving a bad performance will still result in a bad performance. Therefore, it is important to compare the performance to other hospitals. A bad performance compared to worser performance does not make the bad performance good, but it will give some more insight on how the hospital is performing in its research field.

The KKLK is member of the Krankenhauszweckverband Rheinland e. V. (KHZV), which is a big association that supports 164 hospitals in the area. Working together with these hospitals, the Krankenhauszweckverband Rheinland e. V. (KHZV) provides all kinds of reports to help their members improve their business. These include DRG -evaluation with CM -trends, quality indicators from routine data, Clinical performance groups, process- and encoding-quality (of the DRGs), management key figures, comparison of downtime differentiated by occupation and OR -benchmarking.

The OR -benchmarking report was key in finding the performance of the MHK and the room for improvement. During the start of this thesis, February, not all the data was processed by the KHZV, but the available data was enough to gain useful insides and if needed, information from 2016 could be used. Figure 2.11 shows the difference between actual and planned first cut of the first surgery per day in minutes. The benchmark shows that the average top 5 hospitals start their days on time. The starting times of the average hospitals in 2016 show a wider distribution and was shifted to the right. The figure clearly shows that on average, the surgeries in MHK start too late. These graph can be further specified per OR

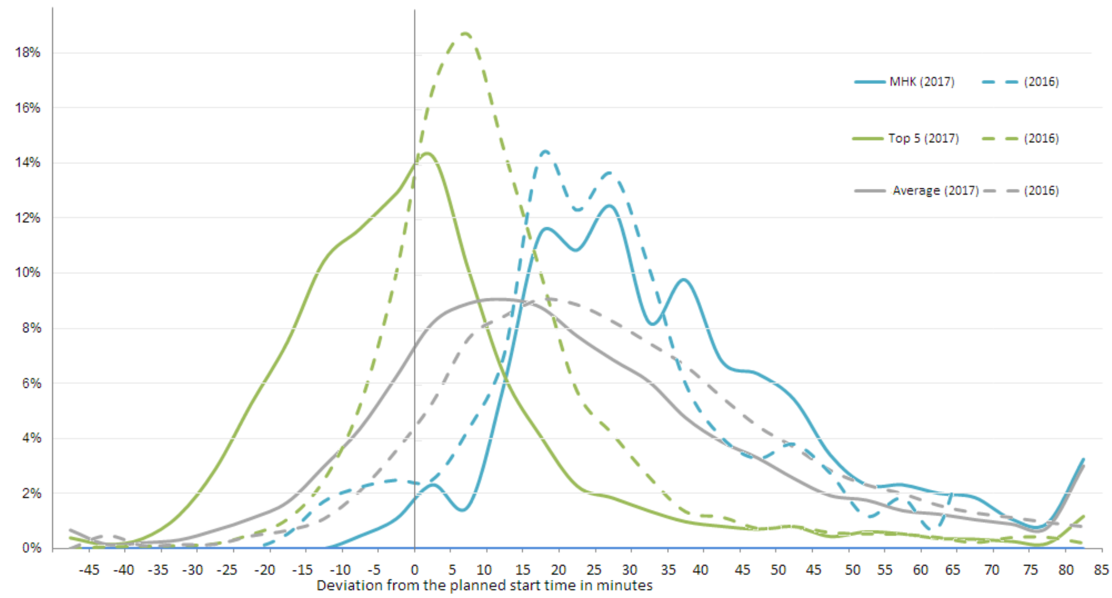

Figure 2.11: Start of the OR day, benchmarked over all hospitals, the top five and the MHK over 2016 and 2017. Source: 84_opbenchmarking_algemein.xls

and specialty, these figures are however not included in this report since, first they would require a lot of space and second because these graphs can be quickly generated by using the 84_opbenchmarking_algemein file. Self generating these file has also the benefit of having the most up to date information, with further information about this selection in the other tabs.

The KHZV also provides insights in the performance of the CM, case mix index (CMI) and the LOS of the hospital. Figure 2.6 shows the performance of all the specializations except for MCHU. Since the weight of the CM represents the difficulty of the specific surgery, it influences the LOS. To compare the performance of the MHK to the benchmark, the LOS per CMI ratio was defined. It shows that all the MHK specialties achieve a higher ratio compared to the average hospitals. Since revenue is based on the CM, it is optimal to have an as low ratio as possible. So the LOSs in the MHK are too long, compared to their CM. This once more shows the need of reducing the LOS in the entire hospital. Other hospitals show that it should be possible.

Within the MHK, the people where not aware of the existence of this benchmark report. This report was found during the literature search, where after the controlling department in Kleve could provide the requested files for the hospital.

2.3.6 Key Performance Indicators

In order to be able to manage something, one needs to be able to measure it. This means that factors that are critical to success have to be linked to project success measurements. Critical factors are the factors that contribute to achieving project success. On the other

	MHK				Benchmark KZR e.V.			
	n	CMI	LOS	LOS/CMI	# of participants	CMI	LOS	LOS/CMI
MCHA	1.749	1,008	5,81	5,76	133	1,311	6,32	4,83
MCHG	947	1,758	8,45	4,80	39	1,950	8,77	4,50
MIM	3.142	0,949	7,62	8,03	123	0,837	6,30	7,54
MKA	1.338	0,704	4,05	5,75	17	1,350	5,76	4,26
MNEU	2.082	0,900	6,16	6,84	35	1,120	6,73	6,01
MHK	9.259	0,996	6,51	6,54		1,057	6,20	5,87

Table 2.6: Comparison of MHK compared to the benchmark performed by the Krankenhaus Zweckverband Rheinland e.V. in 2017, MCHU was not included in the benchmark. Source: OP Benchmark

hand, success criteria are measures for determining whether a project is successful or not. The factors that make up success criteria are called Key performance indicator (KPI). They represent a set of measurable data used for evaluating and measuring performances in implementation phase [16].

It is not for the researcher to determine the desired performance of the care process. This is a matter for the organization itself. KPIs should be developed by the organization, but the organization is fully focused on care for the patients. The patient should be free of pain (as soon as possible) or should have a pleasant stay and a quick recovery and personal think he is treated well. So the personnel think its important that they have done everything within their power to help the patient. For this good communication within the team is needed. Everyone needs to be able to speak freely and without holding back. Especially for the safety of the patient, no one should be afraid to say something, which could have prevented an accident. A nice indicator for the secretary is the number of calls she gets during a day, if there a few calls, then everything is clear and she has done a good job [12].
Within a hospital there are three groups of stakeholders for which success depends on different things. Key performance indicator (KPI) should measure the kind of success for all these groups, which will be elaborated in the following sections.

Board of management

A hospital wants to help as many people possible. The hospital has the obligation to help all the patients today, but also in ten years. In order to survive, it needs to operate on a financial positive level. If the hospital does not survive, none of the other KPIs matter. Money is therefore an important criterion, like in all companies. But it should never be the main goad, in the end the emphasis should always be about what is best for the patient. He can only be discharged if he is in a medical good state. So the objective can be described as quality under minimum amount of resources, which is *efficiency*.

In Germany, the DRG has a big impact on the financial results of a hospital since primarily the ALOS will be reimbursed. Therefore, it is clear that the ALOS, or the days above the ALOS, are key to the financial and overall success of the hospital. The LOS can be seen as the product that comes out of the process.

Personnel

Quality of labor
According to the mission of the MHK one of the vertices of the hospital is *Mitarbeiterinnen und Mitarbeiter sind unser wichtigstes Potenzial* (ENG: Employees are the biggest potential of the hospital). The employees do not see the big workload as a problem, but only if it is known in advance. A key point in avoiding this is accurate planning, which requires minimal differences between planned and actual planning. This also presumed little waiting time all over the hospital.

Patients

Patients only care about one thing and that is to be cured. But also the quality and duration of this process are important to them. Patients have to come in early for admission and have to wait a long time before they get a bed in a room. Due to the high utilization and full planning, surgeries get moved to the next day. This is an additional day in the hospital, where they have to keep a sober stomach and is not allowed to eat something. Like mentioned before, the patient is involved in every step in the hospital, so to truly help him, the hole chain needs to be improved. All the other improvements will, in the end, benefit the patient.

KPIs

The interests of all three stakeholders should be represented by the KPIs. The overall goal should be to have a LOSs that is between the lower limit residence time and the ALOS prescribed by the DRGs. If the LOSs is smaller than the lower limit, revenue gets deducted, but also fewer costs are made. In addition, the free bed can be used for another patient and generate additional revenue. So it is in all cases better to have a LOSs below the ALOSs.

The goal of this thesis is to generate an optimal flow within the hospital and requires minimal waiting times. This cannot be achieved if there is a mismatch between capacity, in this case personnel and ORcapacity in relation to the number of people in the hospital (capacity of the wards). The occupancy of these resources should be balanced at a to be determined ratio. This ratio is influenced based on the smoothness in distribution of the workload. Once a good workload is planned, it should also be achieved. Therefore the difference between planned and actual surgery time should be minimized.

The KPIs that the MHK should measure are shown in Table 2.7.

Optional:
Profit per Case mix point enables the hospital to compare the difficulties of every specific treatment that could justify a longer LOS since it is compensated for, making the CM a *fair* indicator. In addition, profit per day of stay can reflect directly the profit of the bed the patient occupied. It has to be shown if these can be combined, in any case both indicators need to be maximized.

KPI	Defined	Objective	2017
LOS	Actual LOS / prescribed LOS	ratio t.b.d, <1	1.1
On time discharges	% of discharges before 11.00	maximize	45.5%
Occupancy rate	(Used capacity / available capacity)*	ratio t.b.d	104%
Accuracy in planning	Actual surgery time - planned time	minimize	

Table 2.7: KPIs as they should be used in MHK, how they are defined, their objective and the value in 2017. *Used capacity is considered the time between admission and discharge.

Chapter 3

Theoretical framework

The previous chapters served to understand why the hospital has a problem. The next step is to investigate how these problems can be solved. In order to find a solution that works, this research relies on the work of others, of which is to be believed that their solution can help in the current situation. There are various amount of theories and models available in literature.

The process of finding this literature is stated first. Next the influence of variability in health care planning is elaborated, where after this theory can be used to plan processes. At the end a small section treats the possibilities of using spreadsheets.

3.1 Search method

The starting point of this literature search was done in the search engines scopus and google scholar. This process is further explained in Appendix A. After finding promising articles, the snowballing approach [17] was used by using the citations of the papers and searched for papers that cited the original paper, (so-called forward and backwards snow bowling).

In order to obtain recent results and up-to-date literature, it usual that literature should not exceed an age of 10 years. But the core principles of how hospitals should be planned date back further. Since these principles are not used by now, they can still be beneficial to the hospitals. Therefore also older literature was accepted. However, most found literature was from the last 10 years.

3.2 Influence of variability in health care planning

Health care management is essentially about matching supply and demand in a way that the available capacity is optimally used. If all patients were identical and the arise of a medical condition could be exactly predicted, the planning of care processes would be considerably easier. But due to variability, it is possible that comparable events do not give similar results, making planning extremely complex. Also on the hospital side, there is always a way of uncertainty, staff may be absent due to their own illness, equipment goes missing and errors are made. Many of the unknowns are due to natural variability: no one can predict when an injured patient will arrive in the emergency room. But there are also organized factors that cause predictable, so-called unnatural, variability. Access to doctors and diagnostic equipment for example is generally limited to certain periods during the day. This creates considerable variation in processes elsewhere in the chain [12].

Without these fluctuations, it would be hypothetically possible to align all processes once and use 100 % of the capacity. In other words, without variability, there is no logistical problem. This does not mean that processes cannot be planned, only that the variability has to be measured and dealt with in an adequate way. Flexibility is needed to even out the effects of variability as much as possible. Health care can be planned to a certain extent and that degree is closely related to the uncertainty of the demand. *Uncertainty is the information that is not available at the moment, but yet required [18].* If the demand or supply is uncertain, it is hard to match the two, but even if both are known, it can be hard to use the capacity in a flexible way. The degree of uncertainty and flexibility usually declines over a decreasing period of time.

Delays are the result of a disparity between demand for a service and the capacity available to meet that demand. Usually this mismatch is temporary and due to natural variability in the timing of demands and in the duration of time needed to provide service [19].

Bed management has to solve optimization problems in a context with a high level of uncertainty: the outcome of a treatment cannot be predicted fully, and emergency patients need to be treated immediately [20]. Gallivan et al. [21] investigate the variability of the patients' LOS in ICU after cardiac surgery. Their results indicate that variability has a considerable impact on the ICU capacity requirements. They conclude that a booking admission system should be treated with caution regarding inpatient admissions if there is a high variability in the LOS [21].

3.2.1 Revenue Management

A hospital can use its ward division to reserve beds for high-utility (lucrative) care types, capturing more of their demand, and also restrict access for low-utility (but non-critical) types, causing more of their demand to go elsewhere [22]. For hospitals, Chapman and Carmel [23] recommend this so called quantity-based revenue management over pricing-based revenue management, which they label as less feasible or influential since third parties pay for most inpatient care at fixed rates. So higher price equals higher costs. The hospital should focus on the types they perform best and not on what brings initial the highest revenue. But in the end it should be up to the hospital to decide on what criteria they will prioritize the actual scheduling of the individual patients.

3.2.2 Little's Law

Little's law (or formula) is a theorem discovered by John Little in 1954. It states that the long-term average number of patients L in a stationary system is equal to the long-term

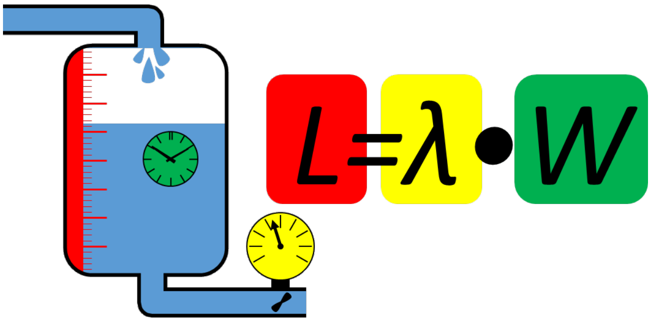

Figure 3.1: Illustration of Little's law using a water tank. The colors indicate green W for waiting time or lead time, yellow λ for throughput in quantity per time, and red L for Inventory or current fill level. Source: Christoph Roser at AllAboutLean.com under the free CC-BY-SA 4.0 license.

average effective arrival rate λ multiplied by the average time W that a customer spends in the system. Algebraically the law/formula is expressed as: $L = \lambda W$ [24].

Figure 3.1 illustrates Little's law using a water tank. The current fill level of the tank can be calculated by the multiplying the arrival rate or throughput per time through the pipes with the waiting time in the tank.

The goal of this research is to reduce L, the patients *in the system* (not overall). This can be done either reducing λ or W. If W is reduced, one can increase λ while L stays the same. So with the current capacity, the system can treat more arriving patients (with increase the throughput rate) if the LOS is reduced. So if the goal is to treat more people, the throughput rate must be increased if the capacity stays the same.

3.2.3 Queueing theory

Queueing theory was developed by A.K. Erlang in 1904 to help determine the capacity requirements of the Danish telephone system. It has since been applied to a large range of service industries including banks, airlines, telephone call centers as well as emergency systems such as police patrol, fire, ambulances and in various health care settings. Queueing models can be very useful in identifying appropriate levels of staff, equipment, and beds as well as in making decisions about resource allocation and the design of new services [19].

One can view the health care process of a hospital as a queuing system in which patients arrive, wait for service, obtain service and then depart. Different health care processes vary in complexity and scope, but they all consist of a set of activities and procedures (both medical a none-medical) that the patient must undergo in order to receive the needed treatment [25].

In queueing theory, utilization, defined as the average number of busy servers divided by the total number of server times 100, is an important measure. But determining bed capacity based on occupancy levels can result in very long waiting times for beds [19]. In all queueing systems, the higher the average utilization level, the longer the wait times. Figure 3.2 illustrates the Pollaczek-Khinchine formula [26] and shows that the average delay

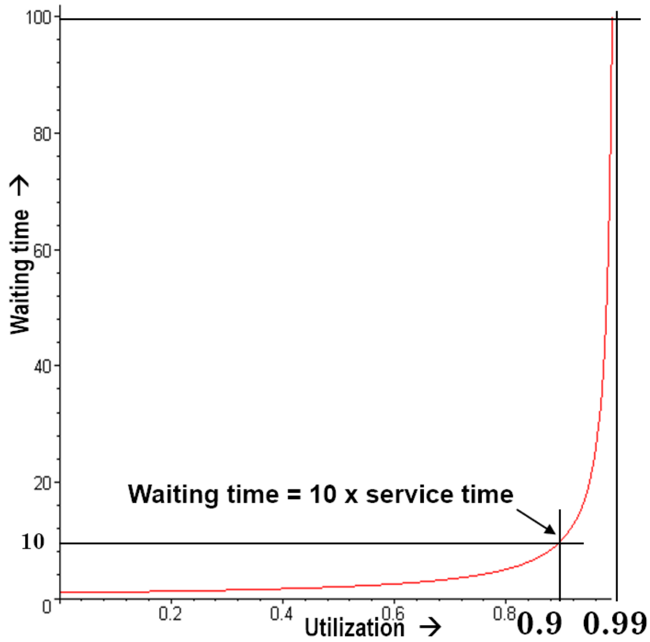

Figure 3.2: Illustration of the Pollaczek-Khinchine formula [26]: Service time grows exponentially when utilization approaches 1. At a utilization level of 90%, the waiting times is ten times the service time. At a utilization level of 99%, the waiting times increases to hundred times the service time. Source: [12]

grows exponentially and approaches infinity as utilization approaches one. Maximizing the utilization of doctors, nurses and beds will result in also maximizing the variability of waiting times.

Based on clinical experience, Horrocks [27] suggested in 1986 that 15 % bed emptiness was needed. Bagust et al. [28] showed that regular bed crises occur when medical bed occupancy is greater than 90 % and a discernible risk of failure to admit occurs at occupancy rates above 85 %. McQuarrie [29] used queuing theory in 1983 to conclude that hospital utilization rates approaching 100 % are not practical, if quality health services are to be maintained. Pressuring hospital utilization above 90 % could produce waiting lists for elective care measured in years, marginal availability of emergency beds, longer LOS and more expensive care. Queuing theory has proven that due to stochastic arrival and services processes, 10% emptiness should be maintained in order to run efficiently [15].

The greater the variability in the service time (LOS), the longer the delays at a given utilization level [25]. High utilization (starting at full planning) will lead to more delays which will lead to more cancellations which have to be rescheduled, in an already thigh program.

The usage of an appointment system can be an effective way to minimize or eliminate variability in the arrival stream of a service system and therefore minimize delays. If provided by accurate patient arrivals in appropriate time slots, there is little or no likelihood of congestion, eliminating the need for Queueing models. However, the difficulty of managing many health care facilities is that the demand for resources is unscheduled and hence random, yet timely care is important. This is the case for many parts of a hospital that deal primarily with non-elective admissions. In these cases, queueing models can be very helpful in identifying long-term capacity needs [19].

First, a queueing system could be used to determine the required capacity of emergency patients. In addition, accurate planning of elective patients should avoid the need for a queueing system for those patients, minimizing the uncertainty enabling a high utilization for elective patients. In order to minimize the delays, the variability of the LOS should be minimized, so the actual LOS should be close to the LOS prescribed by the DRG. If the variability is too high or shows frequent revisions, discrete event simulation can be applied to situations where queuing models cannot be used accurately [30]. Queuing models and simulation each have their advantages. Queuing models are simpler, require less data, and provide more generic results than simulation [19]. However, discrete event simulation permits modeling the details of complex patient flows [25].

Queuing theory provides an additional framework to help clinicians and managers more effectively plan in the future. Their advantage is that they are relatively straightforward to build, require no additional software other than a spreadsheet, and are relatively low on data requirements. Boulton et al. recommend that such modeling techniques should use more widely in health care planning.

3.2.4 Erlang B - formula

In order to make a well-found decision about the number of beds a hospital should have, it is good to know how these numbers will influence the hospital. There will be a trade-off between a certain number of average empty beds (to manage peak capacity) and how often people have to be rejected when full capacity is reached. The Erlang B formula calculates the average number of empty beds and rejections based upon the demand for care, the duration of the care and the number of beds available. The number of rejections is an interesting number since it is not registered by most hospitals and can be decisive by determining the final capacity. The formula provides in particular good results for emergency admissions. Due to the great variety in elective admission, the Erlang B formula provides good estimations for both kinds of admissions, which makes it a widely used tool [31].

Example *[31]: A ward has an average demand of 4 patients per day with an average LOS of 4 days. Little's law shows that the required capacity of 4 x 4 = 16. But when applying the Erlang B formula to evaluate an average demand of 16 beds, this results in an refusal rate of 17.5 %. If a lower rate is desired, more capacity will be needed. To achieve a refusal rate of only 5 %, a capacity of 21 beds is needed, which results in an occupancy rate of 72.6 %.*

3.3 Planning and scheduling of capacity

Chapter 2 showed that patterns in patient flow occur over time. These returning patterns can be directly related to the way of planning, which follows the same MSS every week (Table 2.2). The exact number will differ every week, but varies only by a small amount.

This pattern, with its accompanying probabilities, can be used to predict new patterns in the future and to see what influence changing these patterns will bring along.

3.3.1 Surgery Scheduling

In order to decide how much capacity should be assigned to what specialty (at what time), it is important to know when these patients arrive at the ward. Section 2.3.1 already covered the arrival of the patients to the hospital, but the most important factor for surgical specialties is the moment of surgery. These moments are determined by the MSS, since a surgeon can only operate if there is OR capacity available. It is based on this schedule how patients are expected in the hospital, are planned and arrived at the hospital.

Figure 2.2 showed that there is a certain trend over a year that can be translated back to the number of weeks. Since the MSS is the same every week, the number of surgeries are roughly the same and therefore the required capacity on the wards will see the same pattern over and over again. Changing the MSS, will change the arrival rate of patients and therefore the required capacity. Vanberkel et al. [1] developed a model to evaluate the results of a MSS and lets the user find better solutions by adjusting the MSS, such that the outflow to the wards is spread out over the wards, reducing the peaks in the planning. The model assumes the LOS to be multinomial distributed. This distribution can easily be obtained from historical data, which makes it highly applicable within the context of this thesis.

Variability in bed demand is best reduced by smoothening out weekly admissions [32]. In order to generate a smoother patient flow and reducing overall waiting time, it is better to give priority to patients with a shorter LOS. However this is cannot always be medically justified [31].

3.3.2 Discharge Management

Ideally, a patient should be hospitalized only until the benefits of hospitalization no longer justify the expense. At some point the risk of complications requiring immediate detection and treatment will be so low that continued hospitalization cannot be justified. Also, once this point has been reached, a patient is likely to benefit emotionally by returning to his family and physically by resuming his normal activities [33]. But finding the right time of discharge is subjective and according to Madsen et al. [33], the only reasonable basis for deciding the appropriate discharge time of an individual patient is an estimation of the risk of death and severe complications.

Berk [34] models a patient's stay as two distinct (meta) stages for critical (primary) and non-critical (secondary) care. After receiving acute care in the first stage, the patient's condition is stabilizes and enters stage two. The patient resides some time here and if no complications develop which relapse him to the first stage, he will be discharged. A new arriving patient will benefit more of the hospital care than the patient with the shortest remaining expected LOS, who is assumed to be best able to tolerate early discharge (§3.3.2). Usually, these discharges are patients with a remaining LOS of one day or fewer remaining.

These decisions based on the LOS are the most appropriate when the patient follows a predictable course of recovery.

This way of early discharge option improve system accessibility significantly and does not jeopardize care equity among patients. In addition, early discharges have more pronounced effects on increasing capacity than addition of beds [34].

3.4 Spreadsheets

There is a lot of literature about how health care can be improved and for example the LOS can be reduced. But most involve complex mathematical solutions that are not easy to understand. Cochran and Roche believe that widespread application of solution techniques in hospitals require a simpler and faster scientific foundation than for example simulation. The propose the use of spreadsheets in hospitals [15].

3.4.1 Benefits

Spreadsheets provide an easier and more rapid access to model development for the non-technical student by raising the algebraic curtain. There is a trade off between how simple and how realistic the outcomes of the model are and the usability compared to the performance [35].

Distributing these models to people with minimal experience with OR techniques and no resources for acquiring and learning new software. Because discrete-event simulation models require specialized software that public health officials do not have, we decided to develop analytic capacity planning a queueing network models and to implement them as spreadsheets. Because most public health emergency preparedness planners already use Excel, they do not have to buy new software. Moreover, the spreadsheet concept is so familiar that users can learn the software quickly [36].

Management engineers, planners, and finance analysts need an easy to use planning tool and Excel is simple and universal in health care. Use of the Excel tool is basically 'turning knobs' facilitation scenario analysis in real time. This ease of use can be appealed by applying queuing theory, since it uses analytic expressions rather than statistical experiments to evaluate hospital patient flows and determine bed allocation [15].

Thiriez [37] praises the ease of use, transparency, need for no additional software and reduction of development effort.

3.4.2 Structure

Excel is characterized by the lack of structure. This enables the user to perform complex calculations quickly, without being compelled to do this in a certain pattern or for programming. But spreadsheets can be hard to use by others and errors are difficult to detect. And since most spreadsheets are not developed by professional programmers, but are largely self-taught, about 1 % of all formulas contain errors. Literature shows that many errors have no quantitative impact on the spreadsheet, but if they do they sometimes can have far reaching consequences [38].

Chapter 4

Solution design

The first three chapters provide insights about the current way of working within the MHK. To improve these processes and to monitor the effects of these changes, a tool is needed that can analyse new scenarios and can predict future outcomes.

In §4.1, the model of Vanberkel et al. [1] is used to analyse the influence of the weekly surgical schedule and optimize the schedule. §4.2 will explain how the proposed solution will actually be implemented and used by the hospital. In §4.3 will describe a way in which the KPIs can be evaluated. §4.4 explains how the capacity design should look like and §4.5 will tell what data is needed to perform all these actions.

4.1 Surgical schedule

There are two types of specialties, surgical and non surgical. The starting point of this thesis was to improve the usage of OR capacity. Planning improvement will probably result in a different MSS. To see if the surgical specialties indeed needs to be optimized, it should first be clear *what* should be improved or optimized. A patient requires a bed after surgery, so the surgical schedule impacts the bed capacity due to the amount of surgeries that are performed on that day. With respect to the discovered bed capacity bottleneck, two ways of improvement are considered. The maximum required beds per period can be minimized, or the difference between the maximum and the minimum beds needed over a given period can be minimized.

A new schedule can be created by swapping two of the three specialties, or swapping one specialty with an empty slot in the schedule. The two external specialties are left out of scope, since they are not part of the hospital and do not require a bed after surgery. The possible number of swaps between three specialties are not that high, but the schedule can test if the hospital should operate all four ORs at a day, or should create a schedule over a longer period of time. The current schedule is repeated every week (see Table 2.2), so the model will test if considering a longer period will improve the usage of bed capacity needed.

To determine the improvement potential of the surgery schedules, this thesis uses the model of Vanberkel [1] and the additions provided by van Essen [39] along with the work from Master thesis of students of the University of Twente. In particular, there will be close collaborated with Wopereis, who used this model in a Dutch hospital to reduce the maximum beds needed. The program is written in the programming language Delphi[1] and uses the model of Vanberkel et al. to evaluate further improvements on the MSS. The model is stripped down to apply to the goal of this thesis. The model only considers working days with the same length, but on Friday the MHK only schedules its surgeries until 14:30 instead of 16:00. On Monday, the first part of the day, MOP3 is used by MCHG where after MCHA uses it the rest of the day (see Table 2.2). This can be modelled by assigning both specialties a whole OR for the day and will result in an upper bound. If both specialties do use MOP3 that day, this will result in a lower bound, which can be compared to the upper bound. For a detailed description of the models of Vanberkel et al. and Wopereis please see their own work [1], [40].

There will be some practical limitations to potential solutions. Not all surgeries can be performed in the septic MOP1 and personnel has to be available. Since some surgeries also operate in other hospitals within the KKLK, this might be hard to realize. All these aspects will be neglected for now to determine the theoretical improvement potential by rescheduling the OR planning. If this will turn out to be a minimal improvement, the optimization should focus on the non surgical specialties to generate the *"Biggest bang for your buck"*.

4.2 Sustainable

By applying mathematical models, complex problems can be solved, possible outcomes can be precisely predicted and near optimal solutions can be found. But these models require a lot of time and skills to develop, use and maintain. In addition, most of the models are hard coded and require expertise in order to implement them in another situation and expensive software license are needed in order to run these programs.

The context analysis in Chapter 2 showed that improving the surgery schedule was not the biggest problem of the MHK. If patients or surgeons still arrive late for the surgery and the planned surgery time is most of the time incorrect, a new way of scheduling has no big impact. Reliable data input is key to make a planning tool perform optimally.

All these things lead to the conclusion that using a mathematical planning tool would not bring the desired results for the MHK. A more basic and more accessible tool would be required. In order to ensure that the tool will be used, it should:

- Be easy to understand
- Be easy to use
- Be easy to maintain
- Be easily adaptable to new situations
- Have low costs to use

These things can be done using a spreadsheet. In this case, Microsoft Office Excel will be used, since it is widely known and the hospital is already using this software, has the required licenses and the data exports are saved in excel files.

[1] www.embarcadero.com/products/delphi

4.3 Key Performance Indicators

To track down the biggest challenges, measure and evaluate the performance of the MHK, KPIs were formulated in § 2.3.6. In order to use and control these indicators, the hospital should be able to keep measuring them in the future using the spreadsheet solution. Each KPI will be addressed in a separate section.

4.3.1 Length of stay

The planning tool *iMedOne* has an option that shows the current patients' LOS and the prescribed length by the DRG. This, however, is a tool to influence the current LOS, in order to analyse trends, an overview will be made comparing the actual LOS to the prescribed length.

Every LOS will be evaluated against the length prescribed by the DRG. These values need to be looked up in a DRG table. The average LOS should be available for every DRG, specialty, ward, and the overall hospital. To keep using the application in the future, the new DRG table will need to be provided by the user. This can be done in a separate worksheet.

4.3.2 Occupancy rate

For every day, a list will be created containing the patients that occupy a bed at the begin of the day. The summation of this list will be the number of patients in the hospital at the beginning of the day. In chronological sequence, admissions and discharges will be added to the list along with the new number of patients of that moment in time. This will result in a number of occupied beds between events (admission or discharge). The maximum number per day, is the maximum number of beds needed on that day. Not only the maximum number of beds, but also the time span can be of interest.

4.3.3 On time discharges

In the current practice, a patient is considered discharged on time if he has left the hospital before 11 AM. The KPI is measuring the percentage of all patients that are discharged before 11 AM over all patients. To calculate this, only the discharge times are needed. This can be specified per specialty, ward or day of the week providing some deeper insights. The list generated to evaluate the occupancy rate has already all this data in it, so determining the percentage of on time discharges can be done using this list.

4.3.4 Accuracy in planning

To achieve an accurate planning, planned times should resemble the true surgery times as close possible. Due to unforeseeable events, it is not possible to achieve an exact resemblance, but the goal is to approach these times when making a plan.

A surgery is built up from different processes that all require a certain amount of time. These have to be taken into consideration in order to create a planning. This requires a lot of data points of every surgery. Luckily, the planning tool *iMedOne* already has an option to perform just these actions. In the system, this option is called "*OP-Profilzeiten und aktuellen OP-Zeiten*. To use this option, only the right "*Profil*" needs to be available in the input. The system needs to know what comparable surgeries are, from which the average and variance should be considered.

The planning will be as close to the actual situation, if the average surgery times are used. The more these values are adjusted, the more difficult it will become to forecast the outcome. This will result in a bigger variance which will create an overall worse planning. If the surgery is performed on an obese patient, the surgery time will probably be longer. This would be a case when surgery forecast is usually adjusted. But these patients are part of the average, so they are already considered to a certain degree. If the surgery times are adjusted, these patients should be excluded from the average.

To evaluate this KPI, the benchmarking report of the KHZV can be used.

4.4 Capacity design

To allocate capacity over the different specialties, first the patient mix needs to be determined. It will show what percentage of the patients are elective or an emergency. The variance will have a big impact on the capacity required. Once this is known, the actual capacity division can be allocated for beds and the OR.

4.4.1 Arrival pattern of emergency patients

To know how much capacity should be left open for emergency cases, the arrival pattern of every specialty needs to be determined. For this, the number of arriving patients is needed at a given time. In this case, a period is considered to be a day. Next, the statistical distribution of the inter-arrival times need to be calculated. This pattern indicates the time between the arrival of the patients. This may differ per specialty and could require different strategies. For the actual bed capacity, the inter-arrival times are not that important. It is known *that* the patients are coming, *when* is not that important since they will all require a bed for the night.

4.4.2 Bed capacity division

When assigning fixed capacity to a specialty, we must know how often the specialty needs less or more capacity. If a specialty should accept every patient, it will need infinite capacity (see Figure 3.2). Since this is not possible, there will always be a chance that a specialty needs to decline a patient. On the other side, it is desirable that the assigned capacity is used as much as possible. In particular since other specialties will need to decline patients, while there would be still room available.

Applying Little's law (§3.2.2), the number of patients in a stationary system (L) is equal to the long-term average arrival rate (λ) multiplied by the average length of stay (W) that a customer spends in the hospital. The excel file *QtsPlus.xls* [2] will be used to calculate the effects of the assigned capacity using the Erlang B (§3.2.4) formula. Like described in the section there is a trade off between the expected utilization rate and the chance of patients that have to be declined.

Not every bed needs to be filled at every moment, it could be needed in a couple of hours. So claiming every bed might not be a good idea.

4.4.3 OR capacity division

Once the arrival pattern of the emergency patients is known, the OR can anticipate on how much capacity should be reserved during a day due to unexpected arrivals of patients. For this, the average surgery time of these patients is needed. The hospital distinguishes three types of priorities. Surgeries with priority 3 need to be operated as soon as possible, priority 2 need to undergo surgery within a day and priority 1 have no direct need and are most of the time elective surgeries. For each priority, the expected number of surgeries per day and per week are required. Together with the length of these surgeries, the required capacity per priority can be determined. If the required capacity for patients that need to get surgery within 24 hours are known, this capacity needs to be reserved up to 24 hours before the start of that day. On the day itself, this capacity can be used for changes that happened during that day.

4.5 Data

To perform all these actions, the user will have to provide the data of the hospital. This can be gathered in one list containing the following data points:

- Patient number (this can be a unique identifier without any relation to the real patient)
- Case number
- Specialty
- Ward
- DRG
- Way of entry (normal admission or emergency)
- Length of surgery (in - out times)
- Day
  - Admission day
  - Surgery day (if available)
  - Discharge day

[2] http://www.oocities.org/qtsplus/DownloadInstructions.htm

If multiple surgeries are carried out, a new case number will be assigned. Therefore, only unique patient numbers are considered in determining the occupancy rates, LOS and times of discharge.

Chapter 5

Solution results

This chapter provides the results of the designed solutions in Chapter 4. First the results of changing the surgical schedule will be shown in Paragraph 5.1. Paragraph 5.2 will show the results of the spreadsheet solution. This involves the KPIs and the capacity division.

5.1 Surgical schedule

The model evaluated a schedule that minimizes the maximum capacity needed (§5.1.1) and a schedule that minimizes the difference between the minimum and maximum required capacity (§5.1.2). These results only cover the surgical specialties of the hospital since they are directly affected by the surgical schedule.

5.1.1 Minimization of maximum capacity needed

To see the improvement potential of the current MSS, the model was used to evaluate the current version of the schedule. The output is given in Figure 5.1, the orange area indicates the average required capacity and the blue line represents the 90% percentile of the required capacity. So in 90% of the time, the blue line shows sufficient capacity for all the patients. On average a capacity of 71 beds is needed and 85 beds to realize the 90% percentile.

The maximum capacity is left out of scope since it is an enormous number that almost never is needed. Basically infinite capacity is needed, which is impossible and does not give good information. Since the schedule is the same every week, the same pattern is shown in the four weeks. A four week period is chosen to see if a broader horizon can improve the planning.

The model objective is to minimize the maximum capacity needed, which can be realized by different schedules. The model does not allow to check for intermediate results. Only the schedule and graphs of the final solution are shown. Only the number of beds can be seen in the log. There are different variations in the schedules that result in the same minimization.

The outputs were checked for feasibility, since not every schedule can actually be applied in the hospital. Sometimes the optimization scheduled four surgeries of MCHG on Monday. MCHG do have not the personnel to perform four surgeries on one day and this would also

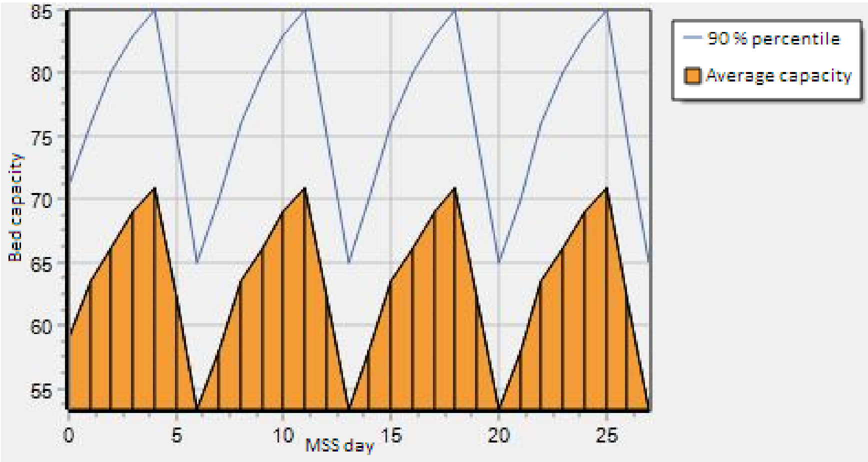

Figure 5.1: Capacity output of the original MSS over a period of four weeks. The orange area indicates the average required capacity and the blue line represents the 90% percentile of the required capacity. Source: Delphi model

require the septic MOP1. Based on various outputs, a schedule was manually created that used the divisions of specialties per day, but changed the OR. This does not effect the output of those surgeries and results in the same graphs. It is possible to rearrange the schedule in such a way that it only requires three ORs per day and respects the availability of the specialties. Using only three ORs has shown to be key in finding an optimal solution. This is logic since more OR time will result in more patient that can be treated.

An adjusted optimal solution is shown in Figure 5.2 and the corresponding schedule is given in Table 5.1. For the readability, the MCH of the abbreviations is left out.

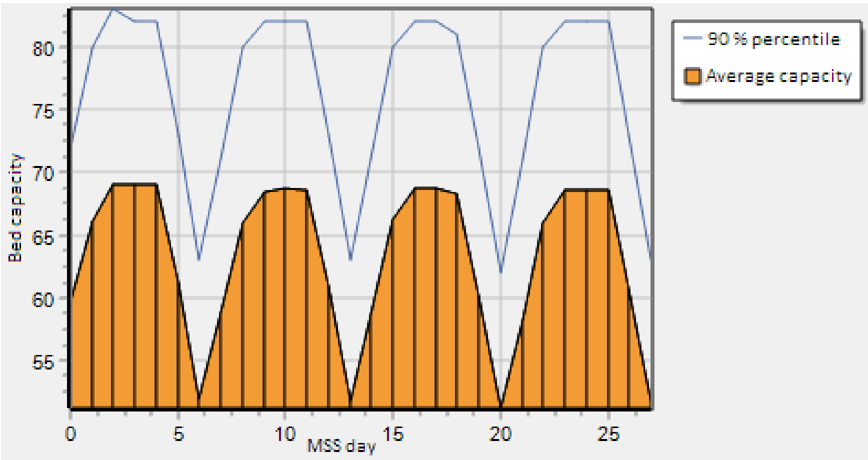

Figure 5.2: Optimization of minimizing the total beds needed (82/83) and the 90 % quartile (69). The orange area indicates the average required capacity and the blue line represents the 90% percentile of the required capacity. The schedule is given in Table 5.1. Source Delphi model

It has to be seen if this schedule is actually feasible, since it requires two ORs for the MCHU on Thursday. Every week the remaining OR day for MCHU is offset, except for

MSS	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	26	27	28
MOP1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MOP2	G	G	G	U	G	-	-	G	G	G	U	G	-	-	G	G	G	U	G	-	-	G	G	G	U	G	-	-
MOP3	U	A	A	A	A	-	-	A	U	A	A	A	-	-	A	A	A	A	U	-	-	A	A	A	U	A	-	-
MOP4	G	G	U	U	-	-	-	G	G	U	U	-	-	-	G	G	U	U	-	-	-	G	G	U	U	-	-	-

Table 5.1: An optimal schedule as seen in Figure 5.2. For the readability, the letters MCH where left out of the table. Source: Delhpi model

Thursday since then they have already two surgeries. This can lead to a capacity of 82 and the optimization therefore achieves a reduction of 3 beds. On Wednesday only the MCHU has only one OR, however this is their busiest day since they use one OR to treat varicose veins. This is done by a former surgeon who is now retired, but performs these surgeries ones a week. If he still wants to do these surgeries on a Wednesday, one of the sessions of for example Monday or Wednesday could be moved to the empty OR on Thursday. But this causes a big disruption and requires 88 beds. In that case the current setup would already be better. However, it could be possible to move the varicose vein surgeries to Tuesday, since most patients are checked one day before the surgery. This may be hard to change since *they have always done it this way.*

5.1.2 Minimizing difference between minimum and maximum capacity needed

When optimizing the original schedule with the objective to minimize the difference in capacity needed, the current schedule requires a 15 beds difference. After performing the optimization, a minimum of 13 beds is required. This is also the result of the optimal schedule in the previous paragraph. When determining the optimal manual, both aspects were taken into account when finding the optimal manual schedule.

The difference at the start of the first week is smaller, but some patients stay longer than one week. These patients are still in the hospital during the weekend and therefore at the begin of the week. In the following weeks, the same minimum patients can be seen. This shows that it is wise to look for a further planning horizon than one week when determining the effects of a schedule.

Since there are no elective surgeries during the weekend, the required capacity is lower during the weekend. This can only be further minimized if more surgeries perform during the weekend.

Before using the proposed schedule

It has to be kept in mind that the model is a simplified version of the possible schedule. Before the improved schedule is used, it would be wise to do some further research on making the model more specific. Since only a small reduction could be realized and other aspects promised bigger results, no further research was done at this point.

This model is based on the current LOS of the specialties, if these change, the model will also change.

5.2 Spreadsheet solution

To get an overview of all the functionalities, a *Dashboard* worksheet is created. All the KPIs and figures are summarized in a clear overview. The *Data* worksheet serves as input for all the necessary calculations.

5.2.1 Key Performance Indicators

Length of stay

For each specialty, the LOS can be calculated using the *Data* worksheet. The worksheet only provides the admission specialty and the discharge specialty. Based on the DRG these lengths are compared to the prescribed length of DRG. These values are looked up in the *Haubtabteilungen* worksheet of the DRG catalog[1]. This file needs to be updated every year to get the new LOSs.

The controlling department has their own ways to get preciser values on the LOS of the patients since they have more data available. This file only serves as a quick analysis tool which a manager can use to make his own calculations. He will only need the data described in section 4.5. These numbers are already shown in Chapter 2.

On time discharges

The desired discharge time can be set on the Dashboard. By default the time is set to 11:00 AM. In the *Discharge* workbook, the discharge times are subdivided per specialty and per day of the week.

	Mon	Tue	Wed	Thu	Fri	Sat	Sun	week
MCHA	86%	84%	71%	87%	79%	53%	39%	80%
MCHG	84%	82%	92%	73%	66%	53%	17%	80%
MCHU	60%	55%	44%	67%	60%	29%	34%	53%
MIM	52%	51%	49%	49%	37%	38%	32%	46%
MKA	52%	55%	56%	48%	43%	34%	28%	49%
MNEU	47%	57%	58%	51%	39%	27%	30%	48%
MHK	59%	61%	61%	58%	48%	34%	31%	**54%**

Table 5.2: Percentage of discharges before 11:00 AM per specialty and weekday. Source: excel file

Occupancy rate

Based on the discharge times, the occupancy rate can be seen over a whole day. They show the same pattern as can be seen in Figure 2.4.

[1] https://www.mydrg.de/myDRG_archives/tools_downloads_helferlein/index.html

Accuracy in planning

It was not possible to get the original planning such that it could be compared to the actual planning. *iMedOne* has an option to perform this analysis, but it was not available in the current license of the hospital.

5.2.2 Capacity

To help the hospital perform its process, a proposed capacity division was made.

Arrival pattern of emergency patients

Although the arrival pattern of the emergency patients differs per day, an average is used for the further calculations. The hospital is working with fixed number of capacities and the personnel is currently not capable of adapting to changes all the time. It was considered wiser to communicate one number that is clear for everybody. Over time, this pattern can be further specified, but considering emergencies at all in the planning were already a big step forward.

The average number of arriving patients is given in Figure 5.3. The table specifies the arrival of all patients and the emergency patients separately. MCHA and MCHG receive on average less than one patient per day. The higher number of emergencies for the MCHU is logic since they treat all the trauma patients. For the non surgical specialities, the emergencies make up almost half of all the patients.

	MCHA	MCHG	MCHU	MIM	MKA	MNEU
All patients	2,3	2,9	2,6	8,9	3,8	5,9
Emergency	0,5	0,7	1,8	4,4	1,6	3,0

Table 5.3: Average number of arriving patients per specialty per day, for all patients and the emergency patients. Source: excel file.

Bed capacity division

For every specialty the arrival pattern is known along with the LOS of each specialty. Using the Erlang B formula in the M/G/c/c model of the QtsPlus.xls file, the assigned capacities for the year 2018 are evaluated in Table 5.4. The table is divided into a section that considers the LOS of the MHK and a section that considers the LOS of the DRG.

There are different aspect to consider when determining the appropriate capacity. The utilization should never exceed 85% and the amount of refused patients should not be too high.

Tabel 5.5 shows the number of beds and the percentage of refused patients with an utilization of maximum 85%, based on the actual LOS over the year 2017. This can be seen as an absolute minimum required capacity in the current situation. The table shows how

	MCHA	MCHU	MCHU	MIM	MKA	MNEU
Arrival rate	2,3	2,9	2,6	8,9	3,8	5,9
Assigned beds for 2018	15	30	24	71	30	40
LOS MHK	4,5	7,8	7	7,7	4,1	6,2
Utilization	66,0%	73,5%	73,0%	89,8%	51,9%	84,8%
Fraction of time system is full	4,4%	2,6%	3,8%	7,0%	0,0%	7,2%
Rate of lost patients	0,10	0,07	0,10	0,62	0,00	0,43
Percentage refused patients	4,4%	2,6%	3,8%	7,0%	0,0%	7,2%
LOS DRG	4,7	8,3	5,6	6,0	5,0	5,8
Utilization	68,2%	76,9%	60,3%	75,0%	63,0%	81,6%
Fraction of time system is full	5,4%	4,1%	0,6%	0,3%	0,5%	4,6%
Rate of lost patients	0,12	0,12	0,02	0,03	0,02	0,27
Percentage refused patients	5,4%	4,1%	0,6%	0,3%	0,5%	4,6%

Table 5.4: Current capacity as assigned in 2018 assigned evaluated by the LOS of the MHK and LOS of the DRG for one day. Source: excel file.

these numbers influence the fraction of time the system is full and with that the percentage of refused patients. These numbers show why a utilization of 85% is not desired since the percentage of refused patients is excessive.

	MCHA	MCHU	MCHU	MIM	MKA	MNEU
Required beds	7	23	17	79	14	40
Utilization	85,1%	84,5%	85,1%	84,7%	84,7%	84,8%
Fraction of time system is full	42,4%	14,1%	20,5%	2,3%	23,9%	7,2%
Rate of lost customers	0,98	0,41	0,53	0,21	0,91	0,43
Percentage refused patients	42,4%	14,1%	20,5%	2,3%	24,1%	7,2%

Table 5.5: Capacity per specialty with an utilization of 85% based on the actual LOS over 2017. This setup requires 180 beds. Source: excel file

Since a utilization of 85% is a too high percentage, the same calculations are done for a utilization level of 80%. These are shown in Table 5.6. The lower utilization results in an improved percentage of lower numbers of refused patients. But for the smaller specialties, the numbers are still too high. The hospital should provide care if needed, a too high refusal rate endangers this mission.

Utilization level should not be the only focus on planning capacity. Table 5.7 shows the required capacity for a maximum patient refusal rate of 5%. This rate increases the utilization rate of the bigger specialties over the desired target of 80%.

If for every specialty a maximum utilization of 80% and a maximum patient refusal rate of 5% is realized, a capacity of 2018 beds is required. This is precisely the capacity of the MHK in 2017.

All the above calculations are done based on the actual LOS over 2017. To become

LOS of MHK, 80%	MCHA	MCHU	MCHU	MIM	MKA	MNEU
Required beds	10	27	21	86	17	45
Utilization	79,6%	78,7%	78,9%	79,2%	79,8%	79,2%
Fraction of time system is full	23,1%	6,1%	9,0%	0,6%	13,0%	2,6%
Rate of lost customers	0,53	0,18	0,23	0,05	0,49	0,15
Percentage refused patients	23,1%	6,1%	9,0%	0,6%	13,0%	2,6%

Table 5.6: Capacity per specialty with an utilization of 80% based on the actual LOS over 2017. This setup requires 206 beds. Source: excel file

	MCHA	MCHU	MCHU	MIM	MKA	MNEU
Required beds	15	28	23	74	21	42
Individual server utilization	66,0%	77,0%	73,0%	88,1%	71,2%	82,7%
Fraction of time system is full	4,4%	4,7%	3,8%	4,9%	4,0%	5,0%
Rate of lost customers	0,10	0,14	0,10	0,43	0,15	0,30
Percentage refused patients	4,4%	4,7%	3,8%	4,9%	4,0%	5,0%

Table 5.7: Capacity per specialty with a maximum patient refusal rate of 5% based on the actual LOS over 2017. This setup requires 203 beds. Source: excel file

more financially stable, the LOS of most specialties need to be reduced. To provide some guidance, the capacity based on the prescribed length of the DRG is given in Table 5.8. These numbers will result in a maximum utilization of 80% and a maximum refusal rate of 5% if the prescribed lengths are met. The specialties that perform under the prescribed LOS get more capacity assigned, but even with this increase only a total capacity of 198 beds is needed. This capacity can be increased to a higher arrival rate, meaning that more patients can be treated with the available capacity.

	MCHA	MCHU	MCHU	MIM	MKA	MNEU
Arrival rate	2,3	2,9	2,6	8,9	3,8	5,9
LOS DRG	4,7	8,3	5,6	6,0	5,0	5,8
Utilization	65,2%	76,9%	70,0%	79,9%	75,2%	79,1%
Fraction of time system is full	3,5%	4,1%	3,8%	1,3%	5,0%	2,9%
Rate of lost patients	0,08	0,12	0,10	0,11	0,19	0,17
Percentage refused patients	3,5%	4,1%	3,8%	1,3%	5,0%	2,9%
Beds	16	30	20	66	24	42

Table 5.8: The required number of beds based on the prescribed LOS of the DRG, which requires a total of 198 beds. Source: excel file

OR capacity division

Table 5.9 shows the amount of surgeries per specialty per weekday. It is further specified per priority, Priority 3 surgeries require immediate surgery, priority 2 require a surgery within a day and all other surgeries have priority 1, these are the elective surgeries.

Priority	Specialty	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Week
3	MCHA	0,21	0,08	0,25	0,17	0,21	0,00	0,00	0,92
	MCHG	0,35	0,33	0,21	0,13	0,23	0,04	0,00	1,29
	MCHU	0,17	0,21	0,21	0,19	0,21	0,08	0,00	1,08
2	MCHA	0,35	0,27	0,31	0,27	0,42	0,02	0,04	1,67
	MCHG	0,67	0,79	0,50	0,31	0,58	0,06	0,04	2,94
	MCHU	0,42	0,27	0,42	0,52	0,44	0,00	0,06	2,13
1	MCHA	2,35	2,52	3,02	3,12	2,13	0,12	0,12	13,37
	MCHG	4,40	4,10	4,58	5,69	4,69	0,44	0,15	24,06
	MCHU	2,12	1,81	2,54	2,17	2,12	0,15	0,08	10,98

Table 5.9: Division of surgeries on priority per specialty per day. Priority 3 surgeries require immediate surgery, priority 2 require a surgery within a day and all other surgeries have priority 1, these are the elective surgeries. Source: excel file

Planning for immediate care means that always one OR needs to be available. Since the numbers of these surgeries are not that high, the priorities 2 and 3 are combined in Table 5.10. This is the capacity that one day before the planned day still needs to be available for changes in the schedule. These numbers will be used for determining how much capacity needs to be reserved.

Specialty	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Week
MCHA	0,56	0,35	0,56	0,44	0,63	0,02	0,04	2,60
MCHG	1,02	1,12	0,71	0,44	0,81	0,10	0,04	4,23
MCHU	0,60	0,48	0,63	0,71	0,65	0,08	0,06	3,21
Total	2,17	1,94	1,90	1,60	2,10	0,19	0,13	10,04

Table 5.10: Total 2 and 3 priority surgeries per specialty per weekday. Source: excel file

The average surgery times are given in Table 5.11. The table is specified per Incision-suture time (German: *Schnitt-Naht-Zeit*) and the times including the anaesthesia times (OR time). The times for the priorities 2+3 is a weighted average over the number of surgeries per priority.

Table 5.12 show the Incision-suture time per specialty that needs to be available before the start of the schedule. For MCHA and MCHU this is about half an hour and for MCHG this is about one hour per day.

Time	Specialty	1	2	3	2+3
Incision-suture time	MCHA	0:55	0:34	1:02	0:44
	MCHG	1:03	1:02	1:16	1:06
	MCHU	0:44	0:46	0:53	0:48
OR time	MCHA	1:49	1:50	1:55	1:52
	MCHG	1:54	1:56	1:52	1:55
	MCHU	1:42	1:55	1:51	1:53

Table 5.11: Surgery times per specialty per day, specified per Incision-suture time and time including anaesthesia. Source: excel file

Specialty	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Week
MCHA	0:24	0:15	0:24	0:19	0:28	0:00	0:01	1:54
MCHG	1:08	1:14	0:47	0:29	0:53	0:06	0:02	4:42
MCHU	0:29	0:23	0:31	0:34	0:31	0:03	0:02	2:37
Total	2:01	1:53	1:43	1:23	1:53	0:11	0:07	9:14

Table 5.12: Incision-suture time per specialty that needs to be available after the end of the previous surgery day. For MCHA and MCHU this is about half an hour and for MCHG this is about one hour per day. Source: excel file

Chapter 6

Conclusions & Roadmap

The main conclusion of this thesis states that to improve the performance of the hospital, the MHK should pay close attention to how they plan their capacity. They should pursue a maximum utilization level of 85 % and take the arrival of emergency patients into account. The discussion explains why this thesis concluded that the MHK has no bed or OR capacity problem. Other issues have a way bigger impact and need to be sorted out first. In order to help the hospital to get in the right direction, a roadmap is set out in the last part of this chapter. This roadmap is split up for the patient flow and divided into a short and a long term aspect, which includes suggestions for further research.

6.1 Conclusions

According to Little's law (§3.2.2), if the LOS declines, while the arrival rate stays the same, less capacity is needed. If the LOS declines and the same capacity can be used, more people can be treated during the same period. To realize this, it is important that the amount of patients in the system does not exceed the capacity that can treat the patients during one day. This does not only apply to the bed and operating room capacity, but also to personnel and equipment availability. Otherwise, patients will have to wait, which will increase the LOS and reduce the total amount of patients that can be treated.

The first ways of improving the current situation can be concluded from the research questions that were formulated in Paragraph 1.5. In the following paragraphs, each question will be answered separately.

6.1.1 Optimal patient flow in hospital

At what utilization level is the usage of capacity optimal, while waiting times of patients are kept to a minimum?

Paragraph 3.2.3 showed that hospital utilization rates approaching 100 % are not practical, if quality health services are to be maintained. Figure 3.2 illustrates that maximum utilization results in maximum waiting times. Based on literature [15], [27]–[29], a bed emptiness of at least 15 % are recommended. Discernible risks of failure occur at occupancy rates above 85 % and regular bed crises occur when medical bed occupancy is greater than 90 %. Pressuring hospital utilization above 90 % could produce waiting lists for elective care measured in years, the marginal availability of emergency beds, longer LOS and more expensive care. So from a literature aspect, at least 10% emptiness should be maintained in order to run efficiently.

The utilization should be measured as the sum of the times between admission and discharge over the total available time. The patient is all the time part of the patient flow and therefore the whole time should be taken into account. All the time he or she may require some capacity of the hospital, this could be medical attention, a bed, or some time for the reception.

6.1.2 Determining appropriate bed division

How should the beds be allocated over the different specialties, and how should the specialties be allocated over the wards?

Two aspects were considered when assigning the capacities to the specialties. The utilization rate should not exceed 80% and a maximum of 5% of the patients should be refused due to full capacity. Since the LOS has a big impact on the required capacity, the used values need to be accurate. Since the LOS of the hospital deviates from the prescribed numbers by the DRG, both versions are shown in Table 6.1. The LOS of the MHK should be applied to the current situation, the LOS under the DRG should be used as a guideline for the future, under the assumption that the arrival rate stays the same.

	MCHA	MCHG	MCHU	MIM	MKA	MNEU	MHK
Assigned beds for 2018	15	30	24	71	30	40	210
LOS MHK	15	28	23	86	21	45	218
LOS DRG	16	30	20	66	24	42	198

Table 6.1: Division of the capacities per specialty. The current division is given along with the required capacity based on the current LOS of the hospital and the capacity that is needed if the prescribed LOSs of DRG is followed.

The focus should be on bringing down the LOS of the Internal medicine, in German: Innere Medizin (MIM), since this has the biggest potential. For the other specialties only the MKA has a slight deviation of the current assigned beds. The other specialties only differ a small number, indicating that they are already close to a good solution.

If the specialties are used to work with their assigned capacity and the LOS is at an appropriate level, the hospital could consider switching back to an interdisciplinary bed division to even out variability. But before this can work, the sub specialties need to learn to work with their assigned capacity. It could be possible to first combine the capacity of two specialties to see if better results can be achieved. This can be closely related specialties of the specialties who bring first down their LOS.

This does not mean that the specialties cannot use each other capacities. Sometimes more capacity is needed and if another specialty has some room they should be able to use it. But this should only serve as a temporary solution. The patients should be placed on the assigned ward within a day. Literature showed that there is always one patient that can be sent home early, to make room for a patient that will benefit more from being hospitalized. Especially for the bigger specialties with a lower LOS, such a patient can always be found.

6.1.3 Planning of the new bed division

What is the optimal bed occupancy level, including how much slack should the OR and bed schedule have to take in Emergencies? The optimal bed occupancy level has been answered in the previous questions. The required bed capacity for emergency patients is already included in the capacities per specialty. Per surgery, there should be capacity reserved for surgeries that have to be performed within one surgery day. In the current practice, after 16:00 on the day before the surgery, only the OR manager can apply changes to the schedule.

Specialty	MCHA	MCHG	MCHU
Reserved time	00:30h	01:00h	00:30h

Table 6.2: Incision-suture times per specialty that should be available one day before the start of the planning.

The proposed times are given in Table 6.2. To make them easy to remember and apply, MCHA and MCHU should reserve half an hour of Incision-suture time, for MCHG this is one hour. This way the schedule will be able to better respond to changes due to arrival of emergencies.

6.1.4 Sustainable solution

What is a simple yet effective way to ensure that the results can be maintained and actually will be used?

To maintain the solution in the future, an excel file was created from which most KPIs can be evaluated. However, most values can also be obtained from the controlling department. Based on the LOS and the arrival rate, the QtsPlus.xls file can be used to determine appropriate bed capacities in the future.

Before the improvements can be applied, the reason behind these improvements must be explained. There will be an additional presentation for all the personnel of the MHK. To assure that the proposed improvements will be carried out, there will be some need for controlling. To assure the planned times are met, the OR coordinator has to ensure that the OR schedule keeps it reserved time free. The OR coordinator is responsible to keep the reserved times for emergency patients free in the schedule. If too much surgery time is planned, he will have to enforce his power and determine which surgeries can be planned. In addition the coordinator has to check if historical data are used for the durations.

Management should use the established KPIs to discuss the performance of the previous periods. There may be some need for additional KPIs, since the current indicators were only designed for the surgical patient flow.

6.2 Discussion

The initial goal of this research was to determine if the MHK has a bed- or OR capacity-problem. Although there is some room for improvement, it is safe to say that there are other issues that have a bigger impact on the performance of the patient flow through the hospital. As long as these issues are not solved, changing the planning will not bring the desired results. Changing the planning will only work if the actual situation is close to the planned situation. Why would you otherwise make a plan, if the reality always turns out to be different.

There are three things that impact the accuracy of a planning. In the first place, the surgery schedule has to start at the prescribed times. Delays will cause waiting times for the patients who are on time, which is a waste of time and have to be made up for later on. This is particularly true for the first surgery of the day. If the first appointment is delayed, all the appointments that follow will be impacted. Secondly, the planned times must be reliable in order to resemble the true outcome of the procedure. Not only the mean time, but also the standard deviation need to be known, in order to make a good planning. Thirdly, the planning should be able to anticipate for certain changes. Due to the natural variability of the arrival of emergency patients, it is unclear when patients require help. This is harder to plan and will result in some empty beds if no emergencies occur, but not anticipating for these patients will bring way bigger problems. These empty beds are included in the occupancy rate and are one of the reasons that a high occupancy rate will lead to big problems. From historical data it is possible to estimate the daily and weekly arrival pattern. The exact surgery time might be unknown, but it is almost certain that a number of patients will require a bed.

The model of Vanberkel et all. [1] was used to analyze a (simplified) version of the schedule. It showed that at a specialty level, no improvements regarding the bed capacity could be realized. Now only all surgeries of one specialty are considered, the model could be extended by allowing the scheduling of sub-specialties. Planning based on different LOSs could result in a reduction in needed beds. Another improvement could be realized if the model allowed for multiple surgeries to operate an OR per day. This will require the option to schedule different time slots. The model will become more complex, but will also provide more possible options to schedule the surgeries. This could lead to a further improvement. But since no initial results were shown from the model, it has to be seen how big these improvements can be. Improving the model of Vanberkel will only work if the above mentioned problems need to be solved. When planning does not resemble the reality, detailed scheduling brings no improved results. Adding complexity will probably only add more delays.

Concluding that (only) changing the planning will not solve the problems of the MHK, real improvements can only be made if the following things are taken into consideration. The focus should be all about bringing down the LOS, at least to the level of the DRG. The MIM specialty on their own had exceeded the prescribed LOS by 1.7 days for 3264 patients, these are 5681 unpaid days for only the MIM. To lower the LOS, the utilization of the capacities should be under 85 % and definitely not exceed 90 %. Little's Law shows that this rate can be achieved with either more capacity or less patients at the same time. Since capacity is hard to change, less patients should be in the hospital at the same time. If this is not the case, the (uncovered) waiting times will grow exponentially and therefore the LOS. Another way to reduce the LOS is the elimination of all other waiting times (see Figure 2.10).

Other aspects where the MHK should focus on are set out in a road map in the following section. Next to some direct suggestions, there are also points of interest that fell outside the scope of this research. There are also suggestions about how this research could be improved and aspects for further research.

6.3 Roadmap

Change is hard to achieve and a science on its own, but without change the same old actions bring the same old results. In the following paragraphs, changes are proposed that should improve the processes within the hospital. Since the whole patient flow needs to be taken into account, changes should be carried out in the whole hospital. First, some general subjects will be given that involve the whole hospital. Next, every part of the surgical patient flow will be followed by some possible improvements.

6.3.1 Hospital in general

There are some general aspects that need to be carried out through the whole hospital and should be improved overall. If this is are only done partially, it will not have the maximum effect.

Focus on occupancy rate

Like mentioned in the discussion, one of the key aspects is to focus on the occupancy rates. Too many patients in the hospital will increase the waiting time for patients and staff. This will increase the LOS, which reduces the income per day and increase the working hours of the personnel.

Every day, the controlling department in Kleve sends an overview of the bed occupancy to the managers of the hospital. The number of available beds and the number of patients per hospital per ward are specified. The managers know the target occupancy and should inquire the doctors if the numbers are too high. The doctors can use the LOS analyzing tool options of *iMedone* to check which patient should have been discharged. If all of them are within their length of stay, there are too many patients of that specialty admitted. This can for example happen if more emergencies arrived than expected. This is not a direct problem, but it should be known in the hospital and actions should follow. An easy solution is to cancel some of the elective patients beforehand.

Financial analysis

The financial aspect is of high importance, but was kept out of scope for this report. It was assumed that reducing the LOS will bring the LOS closer to the prescribed length by the DRG, which will reduce the amount of not covered days by the health insurance agencies and therefore improve the financial situation of the hospital. To operate even more profitable, one needs to know where the costs and revenue of the hospital take place.

The biggest impact will be made if the treatments which generate the most profits are expanded and those who make a loss will be reduced. The controlling department should discuss the numbers with the whole team, not only with the chief doctor. Everyone needs to know what factors have a big impact and if a treatment only costs money. The personnel should ask themselves why it is that they are not performing according to the DRG and make sure the patient is cured as soon as possible. If a treatment always results in a loss, the prescribed DRG criteria cannot be met. Most of the time, these are treatments that occur less than ten times per year and the personnel lacks the required routine to carry out this treatment. It is questionable if this hospital is the best place for the patients to be cured since other hospitals have way more experience and perform the treatment in a shorter time. If this is the case, it might be better if the patient is transferred to another hospital if possible. This will leave more time for treatments in which the hospital is specialized, providing the best care for the patients and generating more revenue.

Benchmark

In general, the hospital should use its data not only to declare its procedures with the health insurance agencies, but also to analyse and improve its performance. By using a benchmark report, insights can be gained about where the hospital stands. Only comparing to yourself may not lead to big changes if the performance is too bad or too good. Using the data of other hospitals, surgery times can be compared to the benchmark. This can lead to the conclusion that some surgeries are best performed at another hospital since they cost too much time in the own hospital. This will be the best for the patient since the other hospital is probably better at performing this surgery. Referring the patients to another hospital leaves time open for surgeries on which the hospital performs better than the benchmark.

All important results of the benchmark organization can be found in the following files, which can be obtained from the Controlling department of the KKLK;

- 84_opbenchmarking_algemein
- 84_opbenchmarking_drg
- 84_opbenchmarking_klg
- 84_opbenchmarking_ops

Specialize

From the financial- and benchmark-section it can be questioned if it is wise to perform a big variety of treatments in this small hospital.

If the hospital focuses on a subset of treatments, it will become better at these procedures. This will probably result in shorter surgery times. These times will be better predictable with a smaller standard deviation. This makes it easier to cluster the treatments on a surgery day.

Moreover, having fewer amount of different treatments will make the work easier for the nursing personnel. It will also decrease the wide spread in LOS of the different treatments, which should also make planning easier.

Not accepting all patients can decline the number of arriving patients. But when specializing on a certain group, this will attract patients from a broader area. In Germany patients have the right to choose their hospital and when specializing brings a better treatment, patients may want to travel a bit further.

Other hospitals that do not specialize their treatments will have higher surgery times and length of stays. In addition, they will also have higher costs. In the long term, they cannot help their patients in a profitable way and should refer their patients to the specialized hospital. In turn, they can focus on there own specialties which will result in better care for patients in general.

The specialization is not only about generating money, but also about what is best for the patients. The German legislation is designed to reward efficient care. The goal is to perform good medicine and the incentive is, like almost always, money.

Communication

The arrival of an emergency patient causes disruptions in the current planning. Wards need to know that a bed will be needed and, in case of an emergency surgery that the OR is occupied and that the next patient will be treated later. They will also have an idea if the patient will get surgery on that day at all.

A daily stand up, like seen in the scrum development process, lets people discuss there last and upcoming day together with the problems they encountered. This meeting should take maximum ten minutes.

If the chief doctor is absent, not all PHI patients want to be treated on that day. In addition, one experienced doter is vacant, so less work can be done in general. The planning for especially the outpatient clinic should be adjusted based on the presence of staff. Patients can be told that long waiting times are expected in the hope some will leave. These patients will come if the chief doctor will be back, so less follow up consults should be planned on such days, if this is known in advance. This can be done when doctors go on holiday, since then a lot of patients will be discharged, which will result in a big flow of beds towards the CBS. One central overview of the availability of doctors should be available throughout the whole hospital. This can be seen as a first step towards tactical planning (see Figure 2.1), since not only the bed capacity will be influenced. This would be a nice topic for further research.

Involving all personnel in decision making will generate more support and acceptance for these decisions. To understand these decisions, management should be open about the figures like the number of cases and the financial aspects. The hospital views its personnel as the most important part of the hospital, so it should also act in line with that view.

Collaboration

At this point the specialties all perform individually within the hospital and the hospitals individually within the KKLK. There is of course some communication between the specialties and hospitals, but everyone has his own patients. The doctors treat the departments as their own and not as one big hospital. But the departments get evaluated based upon the department. Not as a hospital as a whole.

This could be improved if the admissions of new patients would be centrally monitored. A central department will have a better overview on where place is for patients. The hospital can transfer the patient, even if he will be a little bit further from his home. Doing so the hospital takes its responsibility to provide the best care for all its patients.

Intensive Care Unit

The intensive care unit (ICU) is a costly part of the hospital. Expensive equipment is needed and the department also requires a high amount of personnel per patient. Since the ICU is also used by the non surgical specialties and the usage it is hard to distinguish per specialty, the ICU was left out of scope of this research.

Some surgeries require an empty bed at the ICU in case a complication occurs during an examination. The MKA for example needs an empty bed if they are performing heart checks. Often the patients are healthy and do not require further action. But sometimes the doctor needs to place a *stent*, where after the patient will need to stay a night at the ICU for observation. If no bed is empty, the same procedure has to be performed to help the patient the next day.

Some patients require artificial respiration, but are in no *direct* danger. These patients can be transferred to the Pulmonology department of KKLK parter Wilhem Anton Hosptial in Goch. They are specialized in these procedures and it makes the bed available for other specialties. The data showed that these patients have a longer LOS in the MHK compared to other hospitals.

The different specialties should forecast when they expect to need ICU capacity. This should be in collaboration with the other specialties of the hospital. Better planning can be realized if the available capacity is known in advance. The ICU personnel should be able to judge which specialty is in most need of capacity. At the beginning of the day all expected patients should be reported such that the ICU personnel can prioritize them and see if patients need to be brought back to the wards or transferred to another hospital.

Currently the MHK operates seven beds at the ICU, where there is place for ten, but not the equipment. If there is still a lack of ICU capacity after all the possible patients are transferred to other hospitals, the board should consider purchasing at least one additional set of equipment since there is enough room for the beds. If this is a financial issue, the board should negotiate a payment period since the additional equipment will also generate additional revenue.

iMedOne

iMedOne is the planning tool used in the hospital. It is an essential tool throughout the hospital. But not all employees use the full potential of the system since most of the options are unknown to them.

If delays occur, these can be reported in *iMedOne*. But the current version only allows to enter one cause of delay. Most of the time there are multiple causes, which cannot be reflected in the system. These cases get marked as 'general delay', which makes it hard to find the real cause from the data. The employees would like the possibility to add multiple reasons of the delay per surgery.

New employees need to be tough how the system works, before they start working. All the other personnel need to be brought up to date with the possibilities of the latest version. One important thing to learn is how a bed can be reserved, such that real patients are no longer used as physical placeholders.

All functionalities of the system can be explained by a representative of the *Deutsche Telekom*, the provider of *iMedOne*. At least once per month a representative is present in one of the clinics of the KKLK to answer questions. He should elaborate the additional options the system has to offer and how they can be used. Further research could investigate if the additional costs of the software expansions will be offset by the saved costs in time and material. Personnel should be asked what they are missing in the system and what steps are devious.

The default planning option shows a calendar with intervals of 30 minutes. Some consults take only 10 minutes, so three of such checks are planned in one session. Often sessions get overbooked by two or three checks of half an hour. The calendar has also able to show the calendar per 20, 15, 10, or 5 minute intervals. This way, a better feasible overview can be created. But the employees were unaware of this option.

Closer contact specialties and management

There should be a closer collaboration between the management and the executive personnel. At least once per month the numbers of the previous period should be evaluated with the entire team, such that management is acquainted with the problems in that department. The executive personnel will get a better view on how they are performing and together they can adjust the way of working or the targets such that the situation can be handled.

Managing personnel should also visit the working spaces, such that they are in contact with the rest of the personnel. The managers will encounter problems much sooner and the rest of the personnel can ask their questions more frequently. This also leaves room for compliments instead of only visiting if there is negative news.

Applying the lean principle

Reducing waiting times is one of the ways the lean principle reduces waste. The MHK should also investigate other aspects to improve their processes. This can be a good subject for further research. In the end, the hospital should apply constant renewal and improvements of their processes. This is not a plan but a way of operating, it always continuous and is not finished at some point in time.

One example for further research is the 5S methodology, which states that every tool or necessities should have its own place. These could be implemented in the OR. Everything has its own place such that everyone knows where to find it. If the equipment is missing or is in use, this is also directly clear. Equipment that is not needed in this room should not be there at all. An easy way to do this is by marking the area on the ground or wall with different colours of tape.

The area in front of the first aid room (German: Schockraum) should always be clear. Since this is a huge space in front of the elevators, it often happens that containers are put in front of the door. In case of emergency, all these containers have to be moved away when every second counts. By applying the tape to the floor, it is directly clear for everyone that this area should be kept empty.

Hospital should be in control

In the current situation, the patients have a huge influence on when they will receive their treatment. This is fine if this also results in the best situation for the hospital, and the other patients. The hospital has to treat more than one patient and needs to have a schedule that provides the best overall planning, also for the other stakeholders like personnel and management.

Therefore, the hospital should be in charge when assigning the treatment spots, not the patient. He can have a preference, but in the end the hospital decides. This is one additional way in having influence on the variability.

Medical controlling

The medical controlling departments is responsible for documenting the procedures such that they can be processed to the health insurance agencies. But these patients files are often not complete. Before starting their actual job, the medical controller has to complete the file by searching and printing the missing files. There is already an employee collecting all the patient files, if there was a desk with a computer and printer, someone could make sure that the files are delivered complete to the medical controlling.

Most medical personnel does not know the requirements of the health insurance agencies before a treatments qualifies for a certain DRG. The medical controllers would like to help at the wards to determine the correct DRG and explain what steps need to be taken. A correct DRG will also bring the correct LOS for that patient. By determining the correct DRG up front, a lot of problems at the end can be avoided. But the controllers lack manpower to perform these visits.

After the files are send to the health insurance agencies, the files are put into the archive. But it often happens that the file will be requested for checks. The health insurance agencies often have questions which requires the original file. It would be a lot easier and time saving if the files were scanned when entering the archive. Of course not using paper at all convert to an all digital way of working will eliminate these problems.

In order to analyse the LOS, the medical controller use simulation tools that require a lot computing power. However, the department uses old computers, which results in a lot of waiting time. If one would install an SSD-harddrive, they could work much faster.

6.3.2 Admission

The morning is the busiest period of the day. Nurses have to welcome new patients, bring breakfast and medicines to the patients, bring the first patients to the OR, help doctors with their daily patient visits and prepare the discharges. Currently there is not enough personnel to perform all these actions on time. If the same amount of work needs to be done, more personnel is needed to secure a smooth start of the day. This can be realized by having more dedicated personnel at the reception and of course more personnel on the wards. Additional help for only two hours would already make a big difference.

Admissions one day in advance

Since the morning is the busiest period of the day, only activities that need to be done in that period should be done. When moving these activities to another point in time, patients could be admitted one day *earlier* compared to now. This will lead to a higher bed occupancy, but it will remove a part of the work in the morning, dividing the workload out over the day. If this is done at the end of the day, the additional costs will not be that high, especially if the admissions occur after supper. This will increase the calculated length of stay, but this is not the core problem. The main goal is to reduce the costs that are related to the length of the stay. But if these additional costs of an evening are not that high, this is not really a problem.

Next to reducing the load in the morning admitting the patient one day in advance has also other benefits. First, patients are already in the hospital, which means that they can be brought on time to the OR. The personal now has also the time to bring them on time. The second benefit is the related to the LOS considered by the health insurance agencies. If the LOS is below a prescribed amount of days by the DRG, the hospital gets money deducted. Admitting (some) patients earlier, reduces the risk of these deductions. Thirdly, the patients do not require breakfast in the morning, so no additional costs need to be made, but this also means that he will be sober on the day of the surgery. This reduces the risk of having to cancel a surgery and brings the actual surgeries closer to the planned schedule. Last, having the patient already in the hospital eliminates the risk of having the patient show up too late or show up at all. It is also clear that the patient will not be treated in another hospital (these are all problems that occur, see Figure 2.10).

It has to be investigated if these practice can be considered. The higher occupancy rate at night could increase the number of nurses needed. But since *nothing happened to these patients yet* and they normally would be at home, the need for a nurse should be minimal. One could ask the patients what option they prefer, or only apply this to the first scheduled surgery of the next day since those are the ones with the biggest delays.

Central elective admission department

The current practice is to admit a patient directly to his ward. This requires a nurse to welcome him and an available bed. Since most admissions occur before the patients are discharged, there is often no bed available. If the patient however could be brought to a central admission department, the nurses on the wards can continue with their work. Before surgery, the patient does not require a bed. He can still sit in a chair or walk around. If the surgery is about to start, the patient will receive his bed and will be brought to the OR. His personal belongings will be brought to his ward, which should have a place for him after he is leaving the recovery. If the ward is still occupied, the patient can stay a bit longer in the recovery. This reduces the work for the nurses in the morning and also reduces the need for a bed in the morning.

This also provides a better overview of the available bed. Most new beds just have to be brought to the central admission department. A central bed coordinator can keep an overview on where beds are needed and decides who will receive a bed. He needs the authority to do so.

Seamless admission

The preliminary investigation should be performed by experienced employees. They can better determine what the problems of the patient are and how these should be treated. By noting what has to be done, the less experiment personnel know exactly what to do. If less experienced personnel perform the first contact, they have to check and interrupt the experienced personnel. So in the end, the experienced ones are still performing the admissions.

6.3.3 Operating room

Although the OR is seen as the engine of the hospital, it is not wise to plan the OR full without knowing *what* the engine is driving. If there is not enough capacity to supply the OR, or bed capacity to process the patient flow, the OR will not operate at the planned level.

The OR is considered the most expensive resource of the hospital, so letting it run empty costs money. So the planning should minimize the emptiness of the OR via reliable planning.

Operating room times

To improve the OR usage one should take a look at Table 2.5 and Figure 2.10 to see the biggest delays in the current process. These delays are a waste of time and it has been seen that the biggest delay concern the first surgery per OR (see Figure 2.10). Improving this would benefit the overall solution already since delays of the first surgery influence the whole day.

In order to improve the documentation of the current delays, it would be helpful if multiple reasons for the delay can be indicated in the system. If multiple delays occur, they are now booked as *organizational delay*, which provides no insights into the real cause of the delays. In order to evaluate the delays, the staff needs to be counseled.

Use historical data to estimate surgery durations

The biggest delay in the OR are caused by surgeries that take longer than planned. Literatures showed that this problem can be minimized when historical data is used. iMedOne can provide these times under the option "*OP-Profilzeiten und aktuellen OP-Zeiten*". But the surgeries need to be characterized right by the IT department (German: EDV). This option was already available before the start of this thesis, but never assumed to be needed.

When asking why no historical data was used, the surgeons said that not every patient is the same. This is without a doubt true, but these will be reflected in the historical data. The average is still a better estimator than the individual estimations. It could be possible that some surgeons have different times than their colleagues. But also this can be seen from historical data. Lastly, obese patients require in general more time, but this can also be extracted from the historical data.

Earlier use of the recovery

After surgery, patients are placed on the post anaesthesia care unit (PACU) or recovery (German: Aufwachraum). But before the first surgery has finished, the recovery is empty. Especially if the first operations are long, there is some room for other patients.

The start of the day is the busiest moment of the day. Nurses have a lot to do and therefore do not always have time to bring the patient to the OR. This is the third longest delay in the surgery process. The recovery could be used as a buffer, such that the nurses can bring the patients in advance and not have to wait before the OR is ready to receive the patient. This will reduce the time of the nurse and the OR can have direct access to the patient once they are ready. This should reduce the waiting times and make it easier to start the surgery on time.

The recovery should be in close collaboration, and preferably close in distance, to the elective patients admission.

First surgery of the day

The delays of the first surgery of the day are mainly caused by the waiting times for personnel, and for the surgeon in particular. The admission section has already proposed some ideas how the hospital can make sure that the patient is on time at the OR and able to receive his surgery. This should reduce the waiting times for the personnel, so there should be no reason for them to be in another place. The operating room coordinator should have to authority to reprove the personnel that shows up too late. If this happens too often, the department should discuss why this is still happening and remove these barriers.

Which surgery to plan first

The current practice is to plan the longest surgery of the day first. This way the chance that this surgery has to be finished in overtime is minimized. These surgeries are often complex procedures which can require more preparation time and have a high variability in the length of the surgery. The high variability will occur on every moment of the day so it does not matter when these surgeries are planned. But the preparation can be done before the start of the OR, such that there are minimum delays before the surgery.

The downside of planning the longest surgery first, is that it increases the chance that smaller surgeries at the end of the day have to be moved to the next day. The smaller surgeries have often a lower LOS, so one extra day is most likely already above the prescribed number of days. But there is a bigger chance that the smaller surgeries fit in the schedule of the next day. Only rescheduling the one big surgery will not only impact the LOS of that surgery, but it will also have a big influence on the schedule of the next day. Like suggested in the begin of this chapter, the specialties should reserve some unplanned time to handle changes in the planning.

The advice of this thesis is to keep the longest surgery at the beginning of the day, since it will have some additional benefits if an elective patient admission will be installed (see Section 6.3.2). When taking the elective patient admission in operation, a patient will only need a bed after surgery. Since these take longer on average, a bed will be needed later on the day. So there is more time to get a bed ready. The other elective patients can come later to the admission, which reduces the peak of arriving patients by smoothening them out over the day.

Interim cleaning

New legislation obligates interim cleaning between surgeries. This takes on average 10 to 15 minutes, which have to be taken into account. During the process of this thesis, no data was available for these times. But it should be clear that due to the cleaning service, less surgery time is available. This means that also less surgeries should be planned.

To minimize the waiting time due to the cleaning process, the cleaning service should be available at all time to clean the OR. One minute of OR time cost 30 euro, so the costs of an additional service person can be quickly paid back. This extra person may only be needed during a busy schedule, but this something that can be concluded from historical data. The person could also perform other tasks in the OR.

To get this historical data, it should be possible to declare the (additional) delays due to cleaning in iMedOne. This is something that the IT department of the MHK can do by themselves. Once this is put into place, the OR personnel should be instructed when they can mark these delays.

Creation of the OR plan

In the current situation, changes to the OR plan can be passed until 16:00 on the previous day. This leaves almost no room to anticipate on the required capacity. Elective surgeries are planned in advance and should be verified some days before the actual surgery. There should always be some room to take on emergencies, so some capacity should be reserved. If too many elective surgeries are planned, a solution should be searched in advance.

6.3.4 Wards

Reducing the amount of patients in the hospital should reduce the workload for the wards. All the personnel on the wards should be aware of the LOS of every patient. All patients are listed on a whiteboard in the nurses office. For every patient, the expected discharge day should be added. If this date approaches, nurses and doctors should ask themselves why this patient is not already discharged and what needs to happen before he can go. The expected discharged days can be generated in iMedOne. To get a reliable discharge day, the patients should have a correct DRG.

The whiteboard should also be used to write down problems that were encountered by the personnel. Once a week all the staff can discuss these problems and look for a solution. This approach is also one of the principles used in the lean philosophy.

6.3.5 Discharge

Variability in bed demand is best reduced by smoothening out weekly admissions. In order to generate a smoother patient flow and reducing overall waiting time, it is better to give priority to patients with a shorter LOS. However this cannot always be medically justified (§3.3.2).

Early discharges have more pronounced effects on increasing capacity than the addition of extra beds. The way of early discharge option significantly improves system accessibility and does not jeopardize care equity among patients (§3.3.2).

A new arriving patient will benefit more of the hospital care than the patient with the shortest remaining expected LOS, who is assumed to be best able to tolerate early discharge (§3.3.2). If a new patient arrives, the patients expected to be discharged the first should already be discharged instead of refusing the new arriving patient.

The expected discharge day should always kept in mind, like suggested in the previous section. The whole process should be focused on getting the patient discharged as soon as possible.

6.3.6 Long term roadmap

During the process of this thesis, a lot of conversations where conducted where problems were addressed. This thesis is about the optimization of the patient flow, in particular about the bed and or division. Since it was the first industrial engineering research in the hospital, also other rooms for improvements where found along the way.

Further research

There are also some aspects that would be great topics for students to further research. The KKLK could reach out to the Rhine-Waal University of Applied Sciences in Kleve to discuss possibilities for further research. The Hochschule Rhein-Waal has various studies which could benefit from collaborating with a close by the hospital, some of these are: Industrial Engineering, International Business, Economics and Finance and Social Sciences and Health Sciences and Management. Other Industrial Engineering studies can be found at the Fachhochschule Aachen or at the University of Cologne, where Dr. Andreas Fügener teaches. He works on precisely this topic and collaborated with Prof. Dr. Ir. Hans and Dr. Vanberkel on the Master Surgery Scheduling problem.

The following points were not of direct influence on solving the core problem, but are worth mentioning.

Personnel planning

This research is about the capacity of the beds and the OR. Another important factor are the employees that treat the patients. investigate personnel planning, when are how many people needed and can personnel be hired on a flexible contract.

Scheduling of sub-specialties

The model of Vanberkel et al. was only used to swap the three surgical specialties and the empty spots in the schedule. It could be interesting to divide the specialties into sub-specialties and determine if scheduling certain surgeries only on certain days. Since the three specialties all perform surgeries with different length of stay, the effect of rescheduling the slots can be minimized.

It has to be determined what appropriate sub-specialties are since such a surgery should be available to schedule in the assigned spot. Using only the DRG will probably make the problem to complex, but there should be an in-between solution.

Other ways to reduce the LOS

This researched focused on the planning and division of capacity to reduce the LOS, but there could be also other ways to achieve this. For example, the usage of another disinfectant (with double concentration) reduced the waiting time due to cleaning from 1 hour to 15 minutes.

Allocation new investment

Personnel can be motivated to focus on reducing the LOS when the hospital rewards their efforts. One way to do this could be by dividing the budget for new investments by the amount of how that department was able to reduce the LOS and performs on the KPIs. If the personnel makes an effort, they get rewarded with new equipment. This way, the department will be able to help their patients even further, improving the LOS even further. Other departments, who do not improve the LOS, can be told that they will also receive these funds if they show the effort that is needed to justify the investments.

Elevator

Since the CBS is located in the basement of the hospital, (almost) all beds need to be transported by an elevator. There are multiple elevators, which are used by everyone in the hospital. Nurses sometimes have to wait up to 10 minutes to get an elevator. There is a small elevator for *normal* usage, but almost always the bigger elevators are used. Especially after 10 AM the elevators are also used for breakfast distribution, the cleaning process, transport of the patient to the OR and admissions. This is a big reason why there is disruption in bed flow to and from the CBS.

Before 10.00 am there would be some room in the *elevator schedule* but during that period the nurses are extremely busy.

The reception used to send patients in the direction of the elevators. Straight up, the bigger elevators are located. The visitor elevator is a bit hidden on the side. On suggestion of the researchers, signs are posted next to the elevator, making them more recognizable as can be seen in Figure 6.1.

It could be interesting to investigate who is using the elevator at what times. The hospital could also promote the usage of the stairs since taking the stairs is also more healthy.

Laundry

The Laundry is done by the 4K service department of the KKLK and its equipment partial rented. The own pillows can be cleaned in the hospital, but the rented ones need to go back to the laundry service. Blankets always go back to the laundry service. Sometimes a bed cannot be finished because there are no more pillows, so only when a new bed with an own pillow arrives, the previous bed is ready. Because this is known and patients sometimes want an additional pillow, wards keep pillows in the ward, which does not contribute to the

Figure 6.1: Picture of the main elevators in the middle and the visitors elevator on the left, indicated by a sign.

pillow shortage. Additional, extra *Tauschbetten* require extra laundry. No one knows why pillows are rented and no new ones are bought.

Patients that have a long stay, require a special mattress, this need also extra cleaning. This also results in missing mattresses and therefore unfinished beds.

It would be worth to investigate if the costs for renting are indeed lower than keeping own stock. It also has to be seen if this ways up against the dependencies for waiting on the equipment. Compared to the OR, the costs for materials in the CBS are very low. It should never occur that a bed cannot be brought to the OR due to missing equipment in the CBS. Further research could investigate how much stock the CBS should keep in order to reduce the risk of running out of stock.

New employees

The MHK is understaffed and requires new employees. In the current process, there is a lack of a good introduction of new employees. There should be a procedure of steps that have to be taken care of before the new employee arrives. Required equipment, like work shoes or personal X-ray protection, should be available on the first day of work. These things need to be cleared after signing the contract. The hospital needs to ask its employees what these things are and when they need to be available. These questions can already be settled during the job interview (like shoe size).

For the first period, there should be a plan to let the employee get to know the hospital. This should not only focus on the designated department, but on the whole hospital. In the past, new nurses worked their first day in the CBS to get familiar with the processes and encounter the need to bring the beds all the way down to the station. All personnel should get a personal introduction to the different software systems. Creating a how to is good if the employee has forgotten certain steps. But he needs to see it work in order to learn it. In addition, he will be able to ask questions.

External specialties

The OR is also used by the two external specialties, MHH and Augen. The MHK should only allow these specialties access if it benefits the hospital. In the first place, this has to be a financial benefit. All the costs should be covered, including the depreciation of the medical equipment. But the hospital should also make a profit since otherwise the rooms could be left empty. Filling the rooms will result in a loss of opportunity, no other surgeries can be performed in that room so this has to be taken into account during the planning. But this means that the OR is also not available for emergency surgeries. Finally, renting the OR to external specialties do not only occupy the OR, but also requires personnel. They cannot treat their own patients, which increases the waiting time of these patients. More patients will make the situation more complex.

Hearse

The hospital is able to help a lot of patients, but unfortunately sometimes a patient passes away. In this case a hearse (German: Leichenwagen) will come pick up the mortal remains. It was noticed that the hearse parks in front of the main entrance of the hospital. If this is done out of respect than this should absolutely stay the same. But the spot is also in front of the terrace where patients can sit outside. This can be confronting for other patients, so it could be a possibility to use the ambulance entry to the hospital. This is an ethical question and this part just serves to bring it under the attention. The hospital should decide themselves how to handle in this kind of circumstances.

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Appendix A

Literature search process

The search for literature started with listing the most promising key words for this thesis. The list contained the following terms:

- Bed planning
- Mixed integer programming
- stochastic LOS
- Length of Stay
- German
- DRG
- hospital
- excel
- spreadsheet

During the search process, combinations of these terms where used along with some variations in the spelling. Plural words where written as the singular noun with an asterisk (*) behind it.

In order to obtain recent results and up-to-date literature, it usual that literature should not exceed an age of 10 years. But the core principles of how hospitals should be planned date back further. Since these principles are not used by know, they can still be beneficial to the hospitals. Therefore also older literature was accepted. However, most found literature was from the last 10 years.

After finding promising articles, the snowballing approach [17] was applied by using the citations of the papers and searched for papers that cited the original paper, (so-called forward and backwards snow bowling).