MASTER

Cardiac Catheterization Room Scheduling and Planning

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Master Thesis

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Abstract

An optimal planning of the operating rooms (ORs) in a hospital is crucial, as lots of patients are dependent on the performance of the OR and the OR influences the workload of several other departments in the hospital. The different stakeholders being involved and the various sources of variability make the planning a difficult process. For OR managers, the difficult task to decide about the trade-off between a decrease in elective waiting lists and efficiency on the one hand and the reduction of overtime and the on time service of non-elective patients on the other hand. Our study shows that we significantly improve the current scheduling and planning policy compared to the as-is situation. Most outstanding improvements were obtained by the introduction of flexibility, which brings capacity closer to demand, prevents for undesired fluctuations in the waiting lists and reduces the idle time.

Preface

This report is the result of my graduation project, which has been conducted at the cardiology department of Elisabeth TweeSteden Ziekenhuis in Tilburg, in completion of the master Operations Management and Logistics at the Eindhoven University of Technology.

In September 2016 I started my tertiary education at the Technical University of Eindhoven with the bachelor Industrial Engineering. After completing my bachelor, I continued with the master Operations Management and Logistics in September 2019. After a quiet fuzzy period due to the pandemic and planning changes, I started my master thesis in September 2021. During the execution of this project, I got the opportunity to attend multiple surgeries at the cardiology department and be part of the working environment which was an impressive experience for which I am gratefull.

I would like to thank the people that made this project possible. However, I want to mention some persons in particular. Firstly, I would like to thank my university supervisor Nico Dellaert for his guidance, support and critical feedback. Secondly, I would like to thank my second university supervisor Claudia Ficarotti.

At the ETZ, I would like to thank Loes Clephas (project manager integrated capacity management) for her expertise and knowledge on operations management in a hospital environment. Furthermore, I could not have done this project without the opportunity Nadia (team leader Cardiac Catheterization Rooms) gave to be part of her team for the past couple of months. I appreciate the BIC employees handing me the data requested for and background information freely given. I would like to thank all cardiologists and Intervention Lab Technician who where able to show me around in the first period and where always willing to answer my questions. Last, but not least I would like to thank the planners at the cardiology department. You gave me valuable operation planning information which I never would have obtained from hospital data solely.

Finally, I would like to thank my family, friends and boyfriend for their unconditionally support during my graduation project.

Lonne Bun
Eindhoven, April 2022

Management Summary

In most hospitals, high efficiency of their operating rooms (ORs) and good performances play a crucial role in the service quality delivered to patients and the hospital's goals. The performance of operating theatres is largely influenced by the planning and scheduling policies applied in practice (Zhu et al., 2019). An immense amount of papers have been published related to the topic of OR scheduling in the recent years (Samudra et al., 2016), showing the interest in the topic and its complexity. In literature there are two main patient classes considered; elective and non-elective patients. For elective patients a surgery can be planned in advance, whereas the surgeries of non-elective patients need to be fitted into the schedule on short-notice (Samudra et al., 2016).

This master thesis is performed at the cardiology department at the location TweeSteden of the Elisabeth TweeSteden Hospital (ETZ), Tilburg. The cardiology patient flow is characterised by a high percentage of patients that are non-elective (Vissers & Beech, 2005), making that cardiology patient flows in hospitals are difficult to plan as the arrival of non-elective patients is in most cases impossible to predict and therefore comes with a lot of uncertainty.

Problem Description

The main problem at the cardiology department of ETZ is the perception of an inefficient use of capacity. A lack of time and knowledge prevented a data driven analysis has been performed. Hence, ETZ wants to know how they have performed in the past, if their perceptions are in line with the actual findings and what could be improved regarding their way of working in the future. Therefore, the aim was to design an optimal scheduling and planning policy fit for the organisation, while limiting time between an order requested and a surgery performed (waiting time); limiting the amount of time an operating room was empty (idle time), minimize the time surgeries performed outside standard opening hours (overtime) and maximizing Cardiac Cardiology Rooms (CCR) utilization. Hence, the main research question is formulated as follows:

What is the optimal capacity planning, the capacity allocation and planning policy for elective patients and what (re)scheduling rules are applied to deal with non-elective patients in order to improve CCR efficiency?

At the ETZ cardiology department, there are three type of cardiologists active; interventional, general and device. The interventional and general cardiologists perform procedures related to cardiac cathetherization, while the device cardiologists specialty is to work with external devices such as pacemakers (PM) or implantable cardioverter-defibrillators (ICD). The difference between interventional cardiologists and general cardiologists is that interventional cardiologists are allowed to treat a broader type of medical complications. Consequentially, general cardiologists do not treat non-elective patients. The cardiology department of the ETZ has three operating rooms, so called Cardiac Catheterization Rooms (CCRs), of which CCR1 and CCR2 are used by interventional and general cardiologists and CCR3 is equipped for the surgeries of device cardiologists. The patients treated at the CCRs have a variety of characteristics, amongst others elective/non-elective, urgency level and inflow location. Each of these individual combinations of characteristics asks for a critical different approach, leading to high complexity.

In this study, patients have been split into four priority levels, which vary in terms of urgency.
- Priority Level 1; the non-elective patient should be operated as soon as possible (< 30 min.).
- Priority Level 2; the non-elective patient should be operated on short notice (< 48 hour).
- Priority Level 3; the elective patient should be operated with priority (< 2 weeks).
- Priority Level 4; the elective patient should be operated after a consultation (< 5 weeks).

Methodology

This study consisted of four phases as shown in Figure 1. In the first phase, a qualitative and quantitative analysis was executed to gain insight in the current planning and scheduling policy and current performance. Next, in the design phase insights from the first phase combined with useful planning concepts from literature were used to develop six scenarios for the planning and scheduling policy. In the third phase, a simulation model was developed in order to analyze how different modifications of the planning method affect the planning performance. To make the simulation reflect reality as realistic as possible, the developed model incorporated maximal real time aspects. The data in this study is based on real health care practices taking into considerations the hospital's standing operations and real-life constraints. Finally, in the testing phase the different scenarios have been compared on basis of the results of the simulation model.

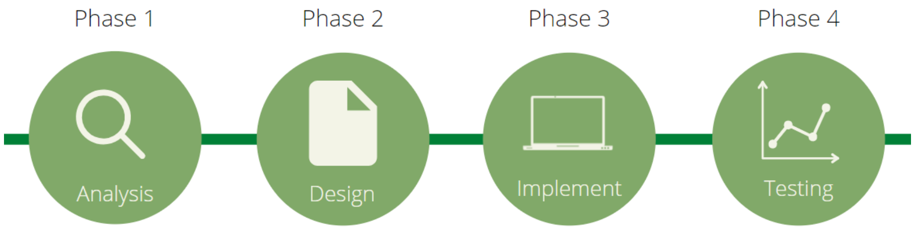

Figure 1: Phases of the Master Thesis study

Results

Interventional Cardiologists

The simulation results showed that the amount of slots for elective patients should increase, while the capacity (dayparts) decreases, making more efficient use of the CCRs. As-is the amount of interventional elective slots per regular week is 22, while in the suggested modification the total amount of slots for elective patients is 25. The amount of dayparts the CCRs are open is one less and in 30% of the time even two (when the flexible daypart is closed). Moreover, reserving per week three slots for priority level 3 patients should cover the demand, contributing to a more accurate match between capacity and demand. Furthermore, it was shown that if two interventional cardiologists are working at the same time, it is more efficient to schedule a fully booked daypart with elective patients for one of the cardiologist, than spreading the elective patients over two CCR dayparts. All in all, comparing the current planning and scheduling policy with the improved one, on average, the utilization of the interventional cardiologists increased with 12.93%, the waiting time of the elective patients dropped with 42.14%, the waiting time of non-elective patients stayed the same at the cost of overtime increasing with 6.96 minutes.

General and Device Cardiologists

For the general cardiologist closing one of the dayparts in 43.03% of the regular weeks, increased the utilization with 20%. Without the closing of the flexible daypart, the demand is simply too low to fill the schedule in a profitable way. The ratio of 60% elective and 40% non-elective patients currently applied for device patients, is near optimal. With the introduction of flexible slots the on time service of the elective patients was improved. However, the relatively long surgery lengths and the highly fluctuating arrival of the non-elective patients ensure that the idle time could not be decreased.

Overall Results

Overall, the simulation results showed that more flexibility in the schedule increased the utilization, reduced idle time and prevents for undesired fluctuations in the waiting lists. In only 12.90% of the time elective patients of interventional cardiologists scheduled on a flexible slot were needed to be cancelled, which was only 8.99% for the patients of device cardiologists. It was found that loosening the allocation policy with 30 minutes resulted in improved on time service. The downside of the suggested modifications is a slightly negative effect on the on time service of non-elective patients, the overtime and expects staff to have a flexible mindset.

It was expected that modifications in patient sequencing, holiday weeks and surgery length could lead to further improvements. However, no significant improvements could be found for these scenarios. Despite that during holiday weeks less CCRs are open, it is important to keep the time available for non-elective patients constant at all times.

Recommendations

Our research shows that there is potential for improvement, provided that management is willing to reconsider the current planning and scheduling policy. In line with the findings the research of Vissers and Beech (2005), the main learning points for the cardiology organisation is to rise above the level of ad hoc solutions for the short term and to investigate lasting solutions for the future. To formulate scenarios for future research, it will be important to involve cardiologists in the process because of their medical expertise. Management should be aware that always serving non-elective patients on time is not realistic due to the fluctuating characteristic of this patient group. Hence, they should decide what type of risk they are willing to take in order to improve efficiency. It is recommended to start with the redistribution of capacity, the introduction of priority levels and;

- *Data Registration*
  Observations brought to notice the inconsistency of the way of working throughout the various departments related to the CCR. For some topics, it seems to be unclear whom is responsible for and how certain things should be registered correctly. Therefore, it is recommended for management (in collaboration with data staff), to define who is responsible for which administrative task and how the responsible staff should register these tasks correctly. For mandatory data, it should be insured that a pop-up appears. If implemented, this should be communicated thoroughly to all departments involved, leading to an unambiguous way of working.
- *Surgery Length*
  For as long as known, the scheduled surgery lengths have remained unchanged. It is recommend for management to sit down with ILT staff and cardiologists and have a close look at these scheduled times. Moreover, it would be more beneficial if the request for additional time would be a build in feature in the surgery request form in the software system and that the system automatically processes this. Furthermore, there are procedures which cannot be booked as they are no part of the procedure category. Subsequently, these have to be ordered as if they were a different procedure, resulting in poor data quality. Hence, these procedures need to be incorporated into the system.
- *Planning Policy*
  Interfering with the planning, mostly with good intentions or out of need, happens on a daily basis. This should be tried to avoid, as it causes unnecessary additional work. If decided upon a new planning and scheduling policy, it is highly recommended to communicate this policy with all staff members involved, leaving no room for personal interpretation.
- *Dashboard*
  For this research, the data first needed to be downloaded, saved as input files and assumptions about the linking of data needed to be made. It would be faster and more accurate to link the data in the software system. Even better, would be the introduction of a real-time dashboard, which helps to monitor the healthcare KPI's in a dynamic and interactive way. A dashboard aims to give a holistic view of analytics data with global insights to enhance the decision-making process. It would enable the hospital to increase its overall performance, also has a positive effect on patient satisfaction and costs.

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List of Abbreviations

BIM	-	Break in Moments
CAG	-	Cardiac Catheterization
CCR	-	Cardiac Catheterization Room
CCU	-	Cardiac Care Unit
CIO	-	Cardioloog in Opleiding (Cardiologist in Training)
DBC	-	Diagnose Behandel Combinatie
DTC	-	Day Treatment Cardiology
ECG	-	Electrocardiogram
ETZ	-	Elizabeth TweeSteden Ziekenhuis
FCFS	-	First Come First Served
FFR	-	Fractional Flow Reserve
FHA	-	First Heart Aid
HC	-	High Care
ICD	-	Implantable Cardioverter-Defibrillator
ILT	-	Intervention Lab Technician
LCF	-	Longest Case First
LOS	-	Length of Stay
MDO	-	Multidisciplinair Overleg (Multidisciplinary Consultation)
OR	-	Operating Room
PM	-	Pacemaker
SCF	-	Shortest Case First
S-ICD	-	Subcutane Implementeerbare Cardioverter Defibrillator

1 Introduction

Delivering high quality care with limited resources is the status-quo over the last couple of years which the health care system has been confronted with. For most hospitals operating rooms (ORs) count both as the greatest source of revenue and as the largest cost center (Denton et al., 2007). The planning and scheduling of operating rooms (ORs) is a highly complex process due to among other variables the involvement of multiple stakeholders. All kinds of variability related to an operation influence the OR schedule. Hence, in surgery planning and scheduling, uncertainty is the most challenging factor. Consequently, the functioning of the ORs influences several other departments in the hospital due to its inherent cohesion. 60 to 70% of all hospital admissions are triggered by a surgical intervention and account for more than 40% of the total expenses of a hospital (Guerriero & Guido, 2011). So, an efficient OR planning will impact to the rest of the hospital's operating due to its pivot function.

A difficulty in operating room planning and scheduling is the trade-off between cost and efficiency on the one hand and patient satisfaction and medical quality on the other hand. Furthermore, OR planning capacity ability needs to be shared by two competing patient types: elective patients that need to be planned ahead of time; and emergency patients that must be treated as soon as possible. Subsequently, hospital (department) managers are eager to implementing more efficient ways of dealing with the OR planning and scheduling (Fei, 2009).

The perception of inefficiency and need for a more optimal way of working led to the researcher being granted the opportunity to study the existing Cardiac Catheterization Room (CCR) planning and scheduling practices at the Elizabeth TweeSteden Ziekenhuis (ETZ). The aim of the study is to investigate the potential for CCR scheduling and planning policy improvement.

1.1 Company Description

Elisabeth-TweeSteden Ziekenhuis (ETZ) is a regional, top clinical teaching hospital in Noord-Brabant. ETZ healthcare is spread among four locations; ETZ Elisabeth (Tilburg), ETZ TweeSteden (Tilburg), ETZ Waalwijk and ETZ Oisterwijk. Every location facilitates 'regular' healthcare, but they also all have their own specialty. Cardiology is one of the specialties of the location ETZ TweesSteden, where the research will be carried out.

ETZ features 782 beds, which are good for taking care of 37.000 hospital admissions and 48.000 first aid treatments. 356 medical staff members, 1570 nurses, 44 physician assistents, 46 nurse specialist and 108 docters in training. Together with all other staff ETZ has 5.184 employees. They all contribute to the €574.000.000 annual revenue of ETZ.

In 2025, ETZ is planning to extend the Elisabeth location and phase out the healthcare facilities of TweeSteden. All emergency healthcare of Tilburg will be handled in Elisabeth. Furthermore, all departments where patients stay overnight will be moved there. Only low-complex treatments remain at TweeSteden (ETZ, 2021).

1.2 Outline Thesis

The structure of the remainder of this thesis is as follows; the study starts with a literature review, providing useful concepts related to OR scheduling and planning. Chapter 2 also underlines the research gap on which the study will focus. Chapter 3 outlines the problem description. It discusses the current way of working, followed by the problem statement, research questions and scope. In Chapter 4 the method, including the data availability and intended deliverables are discussed. An extensive analysis of the current performance is presented in Chapter 5, which is followed by the simulation model (Chapter 6) and the scenarios to be tested in the simulation (Chapter 7). The results of the simulation are discussed in Chapter 8 and the overall conclusion of the study is formulated in Chapter 9. The thesis ends with the limitations and recommendations for future research (Chapter 10).

2 Literature Review

Prior to this Master Thesis, a literature study has been performed on the topic of operating rooms' (ORs) planning and scheduling. Before the problem of this study is described, literature will provide background information on the topic of OR planning and scheduling. This literature review is a summary of the relevant aspects of the literature study performed. First, some general topics related to OR planning and scheduling are discussed; the decision levels, patient classification and uncertainty. Second, some relevant scheduling policies are highlighted. This chapter ends with a summary highlighting literature gaps.

2.1 Operating Room (OR)

Planning and scheduling are two concepts commonly used together. Sometimes, there is a misunderstanding about what planning and scheduling actually is; their similarities and differences. 'Formulating a course of action to achieve some desired objective or objectives' is the definition of planning according to Smith et al. (2000). It deals with finding plans to achieve a goal/set of goals (Barták, 1999). Dealing with exact allocating of resources to perform these actions is called scheduling (Barták, 1999). Nowadays, the border between planning and scheduling became a bit fuzzy. Therefore, in this research both concepts are assumed to carry the same definition, so are used interchangeably.

2.1.1 Decision Levels

In multiple studies (e.g. Guerriero and Guido (2011), Vissers and Beech (2005) and Zhu et al. (2019)) a distinction between the three commonly used hierarchical decision levels as presented in Figure 2 is made. The outcome of activities or decisions on one level serve as input for the level following, making them consecutive.

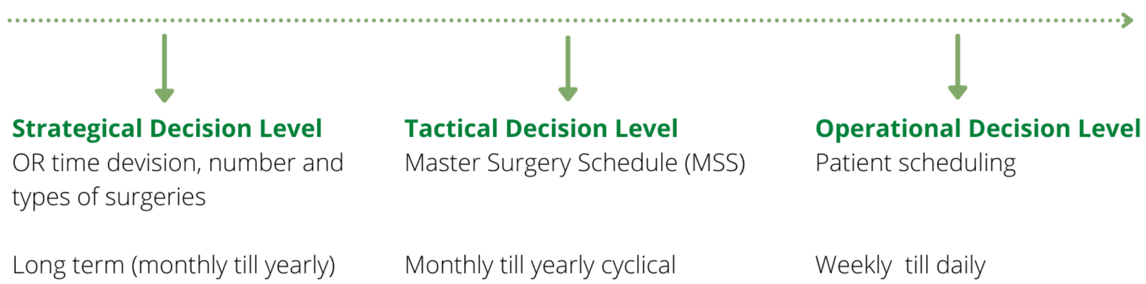

Figure 2: Hierarchical decision levels in a hospital setting

Strategical

On the strategic level the long-term functioning terms are defined. The objective is to maximize profit or minimize cost (Abdelrasol et al., 2013). The operating room time is distributed among the different surgical departments and it defines the number and types of surgeries to be performed. The planning horizon is mostly several months to one year or longer. In order to make adequate decisions, historical data and forecasts are typically supporting tools in decision making.

Tactical

Once the red thread is marked, on the tactical level the development of a so called 'Master Surgery Schedule (MSS)' or also referred to in literature as 'Master Surgery Scheduling Problem' (MSSP) is accomplished. Abdelrasol et al. (2013) states that the purpose is to maximize utilization or leveling utilization. Usually, a MSS is cyclically over a given time period (commonly monthly or quarterly to one year). The MSS defines the opening hours of the ORs, the number and type of available ORs and to which surgeon the available OR time is assigned (Blake et al., 2002). The assignment of the available time is most of the time established by assigning time blocks to surgeons/surgeon groups, patient groups or operation types.

The construction of a MSS requires a lot of research and time, many aspects need to be considered. A term commonly used in MSS is slack; a certain frequency of overtime is scheduled (Hans & Vanberkel, 2012). Slack is introduced to avoid the probability over overtime (Guerriero & Guido, 2011) or to make it easier to threat emergency patients (Wullink et al. (2007), Kamran et al. (2019)), but it also reduces utilization (Hans & Vanberkel, 2012). In order for this policy to be successful, it requires all stakeholders on the OR to strictly adhere to the policy, concluded the research of Wullink et al. (2007). Their discrete-event simulation study showed that the distribution of free OR capacity, should be evenly spread over all elective ORs. In their study this strategy resulted in cost-effectiveness, hospital staff satisfaction and patient care quality.

Operational
The scheduling of patients is addressed at this stage; a detailed planning of surgeries including assignment to an OR, start and end time of the surgery (sequence) and reservation of special equipment (Guerriero & Guido, 2011). Modifying the schedule due to unexpected events (e.g. arrival of non-elective patients, no-shows, cancellation of a surgery, longer or shorter surgery duration) are also dealt with at operational level. It encompasses both patient and hospital (staff) last-minute changes. Prohibiting a reschedule of a patients surgery once the patient has been anaesthetised is a commonly made assumption (Spratt & Kozan, 2021). For the Master Thesis case study, once a catheter is applied or an incision in the chest is made, rescheduling is not possible anymore and a procedure will continue. The number and type of performed procedures is not adjusted at this level. The purpose of this stage is to minimize cancelled cases or maximize utilization, minimize OR overtime and minimize the patients waiting time (Abdelrasol et al., 2013).

2.1.2 Patient Classification

In literature patients are classified according to several aspects. In this study, length of stay and the urgency of their surgery are the input variables used.

Elective Patients
Patients who will undergo a surgery in the foreseeable future, hence can be planned in advance, are classified as elective patients (Rahimi & Gandomi, 2021). Since elective patients do not have to be treated immediately, they may be put on a waiting list (Zhu et al., 2019).

Elective surgeries can be either inpatient or outpatient according to Marques et al. (2014). A patient who stays overnight in the hospital in literature is referred to as 'inpatient', whereas the term 'outpatient' is for patients who enter and leave the hospital the same day (Zhu et al. (2019), Rahimi and Gandomi (2021), Denton et al. (2007), Cardoen, Demeulemeester, and Beliën (2010)). Inpatients often are hospitalized one or more days before surgery, due to medical checks that need to be conducted or to monitor the patients' health condition. After inpatients had surgery, they need to stay in the hospital a day or a couple of days for after care. Elective patients that fill up remaining OR time are named add-elective patients by Guerriero and Guido (2011). Add-on cases include the add-electives as well as emergency patients.

Non-elective Patients
Spratt and Kozan (2021) defined non-elective patients as those requiring either emergency or urgent surgery. This patients group arrival is unexpected and should be treated as soon as possible (Zhu et al., 2019). Delay of an emergency patients' surgery increases a patient's risk of postoperative complications and morbidity (Hans & Vanberkel, 2012). The fact that this type of patients should be placed in an OR as soon as possible introduces more uncertainty and could drastically affect the ORs schedule.

Besides urgent patients, the concept of semi-urgent patients is often used in literature as well. In the research of Zonderland et al. (2010) semi-urgent patients are classified as patients who need surgery soon, but not necessarily today. Uncertainty of arrival and priority over surgery of elective patients also holds for this patient class.

2.1.3 Uncertainty

Uncertainty related to OR scheduling is a topic with increasing attention. As Zhu et al. (2019) stated: "Uncertainty is inherent to surgical services and cannot be ignored." Patients' arrival, surgery duration, emergency arrival, operation cancellation, staff absence, OR breakdown and unforeseen events are examples of several aspects relevant to take into account in order to optimize OR scheduling. In the upcoming subsections two uncertainty forms are highlighted; surgery duration and emergency patients.

Surgery Duration

According to the research of Spratt and Kozan (2021) surgery duration uncertainty is the most studied uncertainty form in recent years. The deviation between the actual and the planned duration of a surgery is named duration uncertainty. The cause of this duration length deviation can have several origins; the patient, the surgeon, operation type and many more (healthcare) related factors.

Emergency Patients

The random arrival of emergency patients during OR opening hours, but also outside these, might alter the schedule of the elective patients. Due to urge, the surgeries of non-elective patients should give way if needed, leading to rescheduling. A common technique to cope with this uncertainty is reserving OR capacity to maximize the responsiveness of an OR in case of emergency arrivals (Wullink et al., 2007).

2.2 Scheduling Policies

In OR scheduling and planning literature there are three well known scheduling strategies in order to dedicate OR time to surgical groups (Rahimi & Gandomi, 2021); open scheduling, block scheduling and modified block scheduling. The number of ORs highly impacts the success rate of policies. In this section, the three policies will be discussed, followed by some sequencing policies and a few applied policies relevant for the thesis.

2.2.1 Open Scheduling

In an open scheduling policy surgeons can treat patients of any speciality at any time since this strategy does not make use of time blocks (Spratt & Kozan, 2021). Consequentially, the preference of surgeons plays a crucial role in this strategy. The principle of first-come-first-serve (FCFS) is often applied under a open scheduling strategy (Rahimi & Gandomi, 2021). Low utilization and lots of delay are common results of an open scheduling system.

2.2.2 Block Scheduling

Block scheduling is the most widely used scheduling policies among (private) hospitals (Fei, 2009). Under a block strategy, surgeons are assigned time in a specific OR in a periodic schedule and the corresponding resources are blocked in advance (Zhu et al., 2019). Typically this block schedule is of cyclical nature (weekly or monthly), constructed by solving MSS problems (Rahimi & Gandomi, 2021). The most important drawback, also mentioned in the research of Zhu et al. (2019) is the inflexibility of the strategy.

2.2.3 Modified Block Scheduling

As a consequence of both earlier mentioned scheduling strategies having several drawbacks more and more interest went to exploring alternative options and so a third strategy arises; modified block scheduling. Modified block scheduling simply is a mixture of open and block scheduling

(Zhu et al., 2019). According to Kamran et al. (2018) modified block scheduling seems to be more efficient than open or block scheduling policies.

There are multiple interpretations of a modified block scheduling system. A policy touched in the research of Zhu et al. (2019) is to makes sure when underutilization of an OR block deems to happen, the block will be opened for other surgeons/surgeon groups. Another option is the use of flexible slots, which Bovim et al. (2020) implemented. Two types or slots were scheduled; slots only for elective patients and flexible slots, the last one being primarily intended to serve non-elective patients.

2.2.4 Sequencing Policies

In the paper of Harper (2002), three sequencing methods for OR planning are discerned;

- First-Come-First-Served (FCFS): The surgeries are sequenced in order of their arrival.
- Shortest-Case-First (SCF): The surgeries are sequenced in increasing order of the scheduled OR time (Marcon & Dexter, 2006).
- Longest-Case-First (LCF): The surgeries are sequenced in decreasing order of the scheduled OR time (Marcon & Dexter, 2006).

In his research Harper (2002) points out in case of a LCF strategy, the chance of closing a session early is smaller and thus increasing throughput and utilization. This comes from the fact that generally speaking longer operations have the most variability in surgery duration. The extra time saved could be used to operate one more patient. Another advantage stated by (Marcon & Dexter, 2006) is the reduction of overutilized OR time by ending the working day with short cases. If the longer operations at the start of the day tend to take longer than expected, the shorter case(s) are respectively easier to reschedule (preferably to an idle OR).
However, in the research of (Denton et al., 2007) it turned out that planning complex and longer surgeries first on the OR planning might have a negative impact on OR performance measures. This finding is in line with the one from (Marcon & Dexter, 2006). They advised against the use of LCF and equivalent sequencing models; more nurses were required during the workday and more over-utilized OR time.

In the handbook of Chan and Green (2013) it is pointed out that another option should be looked at; not the length of planned surgery time should determine the sequence, but rather the variability in operating time. Best results could be obtained in the research of Klassen and Rohleder (1996) if patients with the largest standard deviations in operation time are scheduled at the end of the appointment session.

2.3 Summary

Strategical

On the strategical level, OR planning and scheduling could be split in a two-step approach, which is in line with the policy in the research of de Keijzer (2014). First, OR time is allocated to either elective or non-elective patients. Non-elective patients enter the hospital via a variety of locations (e.g. ambulance, FHA, external hospital). It is relevant to know the patient mix (ratio elective/non-elective patients) in order to deal with the trade-off of capacity planning between elective and non-elective patients (Van Riet & Demeulemeester, 2015).
Second, a scheduling policy deals with the sequencing of the patients over the available OR time. How to determine what level of demand and which patient mix is required before a policy should be pursued remains unanswered (Van Riet & Demeulemeester, 2015). There is a gap between how to divide capacity and which elements are important to make these decisions. Ideally, this two-step approach of allocation OR time to patient types and the scheduling policy is a back and forward approach leading to an optimal use of the OR.

Once the OR time is allocated to the elective and non-elective patients, the next step is to apply a scheduling policy. The three common policies are; dedicated, flexible and hybrid (Van Riet

& Demeulemeester, 2015). The hybrid/mixed policy is one of the more novel policies which received more attention recently. In contrast to the hybrid policy, the flexible policy is a more commonly applied policy. However, this policy has multiple variations, which are not researched that thoroughly. The literature on the impact of inserting breaks as well as the required slack in the schedule of a flexible policy is scarce concluded Van Riet and Demeulemeester (2015); leaves opportunities for future research. Moreover, several policies/initiatives have been handled in research, but its impact on the full spectrum of performance measures remains unclear.

Operational
In order for a scheduling strategy to be implemented successfully in a real-life hospital working environment, the system should be able to adapt to the inherently dynamic planning situation. In the ideal situation, the program used generates solutions within seconds. Outdated software systems in most hospitals however make it fairly unlikely to successfully develop an automatic scheduling system.

Abdelrasol et al. (2013) conclude in their research that a literature gap is present on the subject of on-line scheduling; the possible rescheduling of elective surgeries due to arrival of emergency patients. Generally, it is assumed that emergency patients can undergo surgery immediately. This is in line with the flexible policy variant most hospitals (85%) apply according to the survey conducted in the research of Cardoen, Demeulemeester, and Van der Hoeven (2010); an emergency patient is scheduled on the first OR that is available. To meet this request, elective surgeries might have to be rescheduled. However, a very limited amount of literature pays attention to this on-line rescheduling problem, while off-line approaches are often devised. Concrete rules on how to deal with daily operations such as last-minute scheduling changes and operation cancellations, are hard to find in literature.

Human factors
Besides the strategical and operational scheduling and planning struggles mentioned, the real-life implementation of policies also has a human factor which is crucial and critical. Subsequently it should be considered. Only limited amount of attention is paid to medical staff and patients feelings towards OR scheduling and planning approaches. Adan et al. (2011) even stated that increasing patient satisfaction can only be reached at the expense of a decrease in hospital efficiency; it is a trade-off between patients' satisfaction and hospital inefficiency. Another key trade-off in appointment scheduling according to Hulshof et al. (2012) is the balance between patient waiting time and resource waiting time, where the is assumption in most cases is made that resource waiting time is more costly.

Literature Gap
Based on the literature study performed and the research gaps highlighted in the studies discussed, the relation between OR time allocation to elective and non-elective patients and what scheduling policies to apply leaves room for improvement. The gap in findings with regard on concrete rules on how to deal with rescheduling and cancellation on operational level will be the topics tackled in this study.

For this Master Thesis to be successful it will be important to focus on data and apply strategies suggested in literature, but not to lose sight of the human factor involved in this process. Guerriero and Guido (2011) mention in their study that besides capacity constraints other issues should be taken into account in order to achieve optimal OR scheduling. The optimal solution in most literature is obtained purely based on data. A review of literature points to less than 7% of study results being incorporated mainly due to practice oriented research questions answered in a theory oriented manner (Samudra et al., 2016). Hence, the preferences of the medical staff, crucial for practical acceptance, is often neglected/left out.

3 Problem Description

This chapter starts by explaining the current way of working at the CCRs. After that, in Section 3.2 the problem statement is formulated, followed by its resulting research questions which are covered in Section 3.3. The chapter ends with the research scope (Section 3.4).

3.1 Current Way of Working

In 2020, 2,800 surgeries have been performed in the three CCRs. Regular CCR opening hours are from 8:30-12:00 and 13:00-17:00, so seven and a half hours of surgeries can be performed. 13 cardiologists are certified and regularly perform surgery in a CCR. The intervention lab technician (ILT) team, supporting the cardiologists during surgery, consists of 14 people; three of them work full-time (36 hour), seven work 32 hours and four work 24 hours a week. All ILTs can support during any type of surgery. Two ILTs work from 8:00-16:30, while the remaining work from 08:30-17:00.

Cardiac Catheterization Rooms (CCRs)

The cardiology department of ETZ owns three operation rooms, the so called 'Cardiac Catheterization Rooms'. Both CCR1 and CCR2 are equipped in order to perform the same procedures, whereas CCR3 is equipped to perform a different type of surgeries. As can be seen in Figure 3 CCR1 and CCR2 share their stockroom (located in the middle and accessible via both CCRs, orange box), whereas CCR3 has its own (red box).

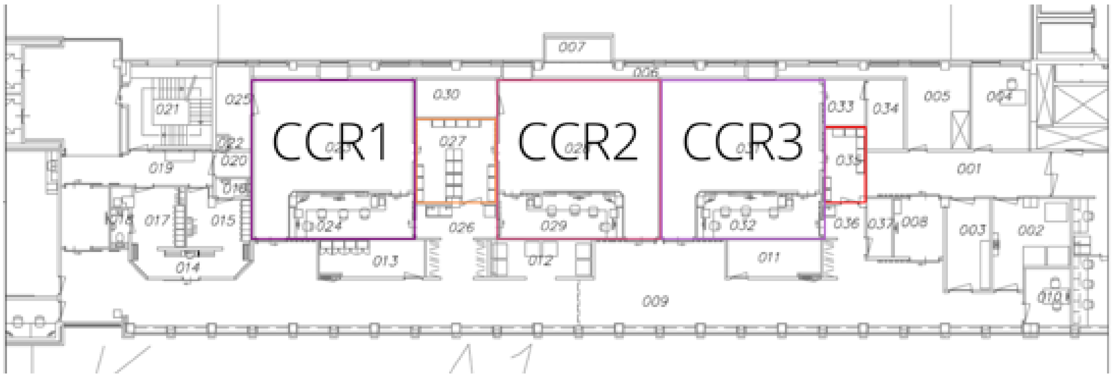

Figure 3: Map of CCR environment

CCR1 and CCR2 are equipped to perform procedures by which the patient is only entered via skin surface. Mostly this is done via a catheter in the artery of the right wrist. If this is not possible, the left wrist or the groin are also entrances into the patients' body in order to perform the surgery. Procedures by which an incision is made in the patients' chest are done in CCR3. In Appendix D per procedure is listed if they are performed on CCR1/CCR2 or on CCR3. In basis, the three rooms consist of the same medical equipment. The layout of the equipment in CCR3 and its stockroom are adapted to the performance of these specific operations, the same holds for CCR1 and CCR2. Consequently, the decision is made to only schedule surgeries in a CCR it belongs to. In case of highly exceptional situations, operations could be performed in a CCR where the surgery is normally not performed. This happens for example if one of the rooms should get a software update, or equipment is broken.

Patient Types

Looking at all patients treated at the CCRs, four main patients flows can be indicated; daycare patients, inpatients, urgent patients and emergency patients (see Figure 1 for a quick overview). These come with their own characteristics. In order for a patient to be identified as daycare patient s/he is not staying in the hospital overnight and discharged on the same day as arrival. Daycare patients are located at the 'day treatment cardiology' (DTC) ward. Staying in the hospital for one night at the cardiology department and receiving a non-emergency surgery at one of the CCRs makes you an inpatient. Inpatients are first located on the DTC and only after DTC closing time are transferred to the cardiology department to stay the night. Staying at the hospital for one or multiple nights with the need to be treated in the close future are urgent patients. The aim is to treat these within 48 hour. Last, as the name already reveals, emergency patients are the ones who come in with an urgent need for surgery. These patients need to be treated as soon as possible, since every minute counts. After their surgery, emergency patients always stay overnight in order to monitor their recovery. Whereas planning the surgeries of daycare patients and inpatients can be done beforehand (elective), urgent and emergency patients' (non-elective) arrivals cannot be predicted and need to be scheduled last-minute. In Appendix D it is documented whether a patient can leave the same day (daycare patient) or needs to stay the night (inpatient) depending on the procedure.

Characteristics	Daycare patient	Inpatient	Urgent patient	Emergency patient
Maximum waiting time	Five weeks	Five weeks	48 hours	As soon as possible
Length of stay (LOS)	Leave same day	One night	Multiple days	Multiple days
Department	DTC	DTC and cardiology	Cardiology	Cardiology
Elective/Non-elective	Elective	Elective	Non-elective	Non-elective
Clinical patient	No	Yes	Yes	Yes

Table 1: Overview of the four different patient types and their characteristics

Patients that get a surgery at the CCRs come from different places in the hospital. Figure 4 maps the patients inflow and outflow to the CCRs. Notice that we only consider direct inflow and direct outflow of the CCR in this overview. Inflows with a star represent clinical patient flows; these patients already occupy a bed in the hospital. For the outflow options, bed capacity is given.

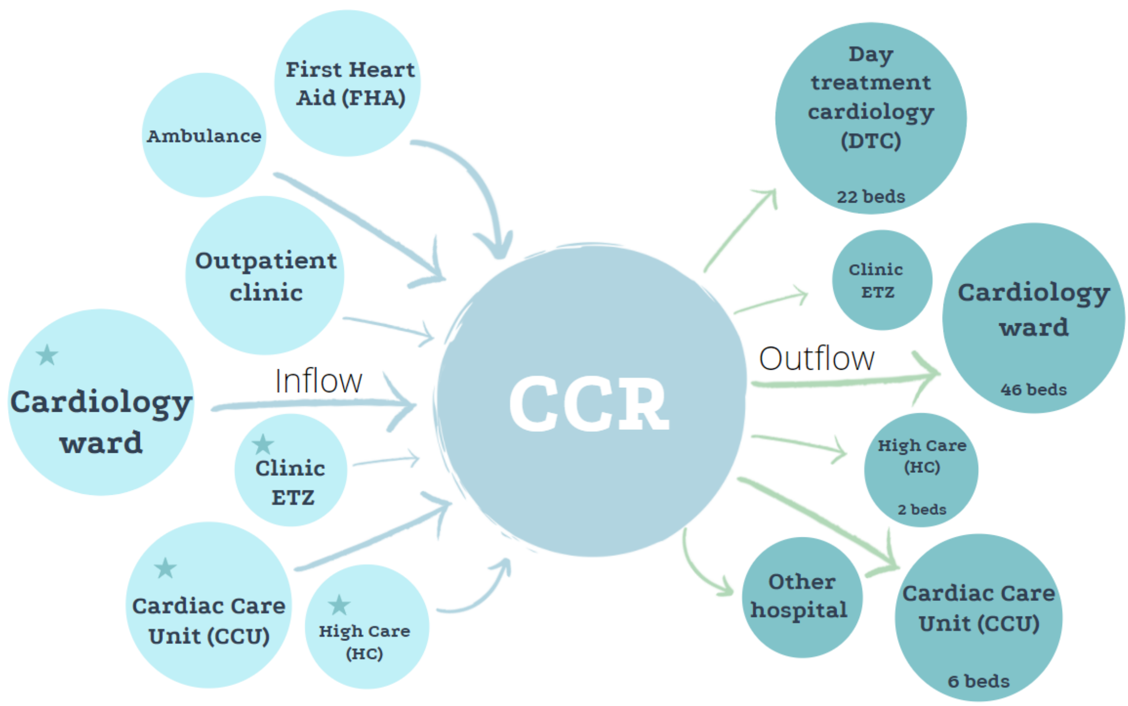

Figure 4: Direct patient inflow and outflow to CCR

Inflow

For the inflow of patients, seven possible paths have been identified, which are discussed shortly;

- *First Heart Aid (FHA)*
  The function of the FHA is to check patients with fierce heart problems and send them to the correct department withing three hours. Patients enter the FHA either via an ambulance or their own transport. From the FHA a patient can either go directly to a CCR, could first be placed on a clinical department for further research or could be send home. The patient stream at the FHA is one-way, patients never come back to the FHA.
- *Ambulance*
  In case a patient is transported by an ambulance, contact takes place between an intervention cardiologist and the ambulance staff. Depending on the decision of the cardiologist and availability of a CCR, a patient can be either brought from the ambulance straight to a CCR or first be temporarily located on the FHA. The ambulance can also serve as transport for patients of a different hospital. These patients might go directly to a CCR or will be hospitalized while surgery is pending.
- *Outpatient Clinic*
  In the outpatient clinic, cardiologist have appointments with patients to see if and what trajectory is needed. If a patient needs a procedure on a CCR, the cardiologist will order this procedure and the patients' surgery will be either scheduled by the planner or put on the waiting list. In case a surgery is ordered after a consultation at the outpatient clinic, the aim of ETZ is to perform the CCR surgery within the upcoming five weeks. Note, patients visiting the outpatient clinic are referred to as outpatients.
- *Clinical Inflow*
  The remaining four patient inflows are marked with a star in Figure 4. The patients from these inflows are already labeled as clinical patients; they already occupy a bed. These patients are always forwarded, mostly by the FHA or outpatient clinic. The most common place for clinical patients to be located is the cardiology department. If there is no free bed, a cardiology patient could be placed on a different ward somewhere in the hospital, referred to as 'ETZ clinic'. If a patients status is critical, a patient can be put on the Cardiac Care Unit (CCU) or in worst case on the High Care (HC).

Outflow

Daycare patients only need to stay in the hospital for a couple of hours after their surgery. These patients are located in the Day Treatment Cardiology (DTC), which is open on Monday, Wednesday and Friday from 08:00-16:00 and on Tuesday and Thursday from 08:00-20:00. Even though beds are mostly only occupied for part of the day, they are not assigned to multiple patients due to a limitation in planning capability. In case there are still patients at the DTC department at closing time, due to whatever circumstances, these patients are transferred to the six available beds for DTC patients at the cardiology department. These patients can either go home later that evening or need to stay for the night. In case of the last, a daycare patients has become an inpatient (clinical).

The cardiology department takes care of the patients who need to stay one night or more in the hospital (non-elective patients). If there is a lack of available staffed beds, patients can be put on a clinical bed somewhere else in the hospital (clinic ETZ). The HC and CCU are located together. Between the CCU and cardiology ward patients are exchanged constantly throughout the day. The patients in most critical conditions are placed on the CCU, while more stable patients at treated at the cardiology ward. The availability of beds at the CCU plays a crucial role in the decision what patients are seen as most critical and need to be at the CCU instead of the cardiology department. In the exceptional case that there are no available beds for patients that need high intensive care, a patient is moved to another hospital.

Cardiologists
Three general cardiologists, five interventional cardiologists and four device cardiologists work at ETZ. An overview of which procedures every type of cardiologist is allowed to perform is listed in Appendix F.8. Generally speaking, interventional cardiologist can perform all procedures performed at CCR1 and CCR2. Device cardiologists are specialized in the procedures done in CCR3. General cardiologists' operations are limited to the performance of only one surgery type, Cardiac Catheterization (CAG). In practice this means, that if during a CAG procedure the cardiologists doubts if any further procedures should be performed, an interventional cardiologist should be consulted and several situations may occur;
(1) An interventional cardiologist is available and performs a quick consultation.
(2) An interventional cardiologist is available soon and the patient needs to wait in the CCR.
(3) No interventional cardiologist is available and the images and movies made of the CAG procedure need to be checked later by an interventional cardiologist. This could result in patients needing to come back another time to have an interventional cardiologist perform further tests.
If an interventional cardiologist did step in on the procedure, this can result in;

- No further procedures are needed.
- Another procedure is needed and performed immediately by the intervention cardiologist.
- Further procedures are needed, but the intervention cardiologist has no time for this right now. The patient then needs to come back later.

In Appendix B a decision tree is shown regarding the situations that can occur if a general cardiologist performs a procedure.

Planners
Between 08:30-17:00 on weekdays, at least one and most of the time two, planners are present at the CCR department. They are responsible for the planning and scheduling of the operations at the CCRs. The planners have an overview in their information system with all surgery requests for the CCR. If a cardiologist orders a surgery, s/he states in the system what procedure this will be. The system automatically plans the duration time belonging to the procedure booked (see Appendix D). If needed, the planners can manually change the assigned duration time. When a surgery is ordered for a non-elective patients (urgent or emergency), who is already located in the hospital, the planners are always notified by a call about the surgery request since these should be scheduled as soon as possible. The aim for the planners is to fulfill the elective time slots up to two weeks in the future and preferably even three weeks. This two week ahead planning is desired by the team leader.

Furthermore, the planners schedule the MDO (Multidisciplinair overleg) sessions between cardiologists of ETZ and the Catherina Hospital (Eindhoven). In an MDO the cardiologists discuss the treatment trajectory of patients with complex health issues. Outcomes of an MDO can be; perform surgery in ETZ, perform surgery in the Catherina Hospital or perform no surgery at all. If a new surgery is needed for the patient at ETZ, this surgery needs to be performed at short notice. For elective patients preferably within two weeks. The planners then check what the outcome was of such a MDO and plan the next steps of the patients trajectory and send letters and medical images.

Planning and Scheduling
The standard planning and scheduling policy is shown in Figure 5. The standard openings of the CCRs according to the basic schedule is presented in Appendix C. This is the most optimistic scenario since e.g. holidays, sick leave and cardiologists attending congresses are not taken into account. In reality, the standard CCR opening is never followed. Therefore, in Figure 5 the most frequently used openings of the CCRs are presented.

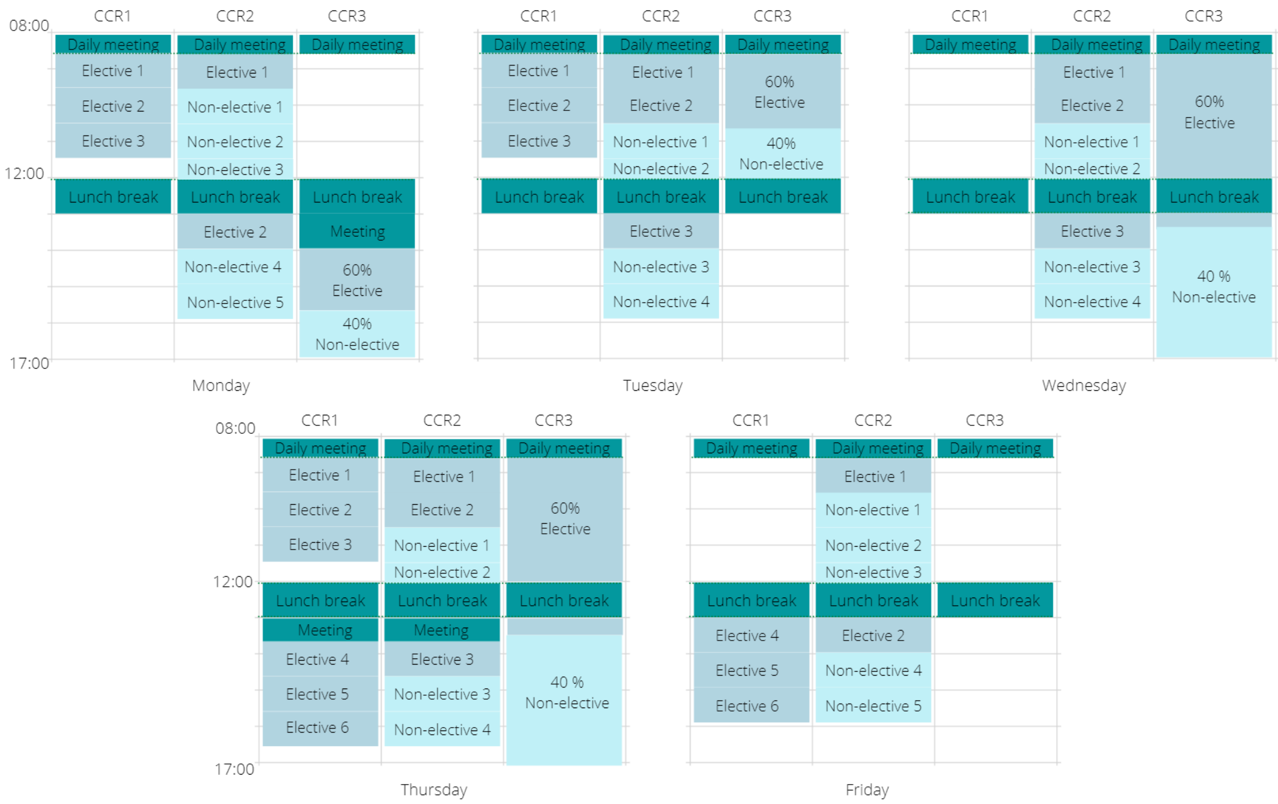

Figure 5: Standard planning of elective and non-elective patients per week day

Next, some general information about the CCRs relevant for the planning and scheduling is listed. Followed by a more detailed explanation of the current planning and scheduling policy.

- Opening hours in the morning are from 8:30-12:00, in the afternoon surgeries can take place between 13:00-17:00. Both ILT staff and cardiologists have half an hour lunch break. Since cardiologists often have a shift in the afternoon on a different department than their morning shift, time is reserved for traveling. Consequentially, for one full hour there are no surgeries scheduled.
- Every Monday from 12:00 till 14:00 the device cardiologists have a meeting and on Thursday from 12:30 till 13:30 the interventional cardiologist have one. Therefore, the program sometimes starts later than 13:00.
- During school holiday periods, maximum two out of three CCRs are open because of the increased amount of vacation days during this period for both CCR medical staff and cardiologists. On public holidays, the CCRs are closed.
- With the current policy no slack/breaks are scheduled between surgeries. The assumption is made that scheduled surgery time include a possible quick coffee break.
- Emergency patients are scheduled on the first CCR that is available, this is in line with the outcome of the survey in the research of Cardoen, Demeulemeester, and Van der Hoeven (2010). Most hospitals (85%) apply this form of a flexible policy.
- Only emergency operations are performed if there is no regular program, staff is not present in the hospital, but are available on a call base.

On CCR1 always three elective patients are planned in the morning as well as in the afternoon, if open. No non-elective patients are handled on CCR1, so according to the scheduling policy always six elective patients are treated on CCR1. On Tue-Wed-Thu, two elective patients are planned in the morning and one after lunch on CCR2. The remaining OR time is left open for non-elective patients. According to the planners, on CCR2 six or seven patients can be handled during a complete day. On Monday and Friday instead of three, only two elective patients are planned on CCR2. The reason for this according to professionals' opinions is that urgent patients arriving during the weekend would be responsible for an increase in non-elective urgent patients on Monday. Furthermore, extra urgent patients would be scheduled on Friday, to make sure these patients do not need to wait until Monday for surgery.

In contrast to CCR1 and CCR2, on CCR3 not a fixed number of patients is planned. The fairly high variability in standard surgery duration (see Appendix D) makes they have a different standard rule on scheduling patients on CCR3. Spread over a week around 60% of the time is assigned to elective patients, leaving 40% for non-elective patients. When a patient has a PM (Pacemaker), ICD (Implementeerbare Cardioverter Defibrillator) or S-ICD (Subcutane Implementeerbare Cardioverter Defibrillator), one, two or three wires are attached to it. The more wires need to be applied, replaced or removed, the longer the surgery takes. A rule of thumb maintained for the planning of operations at CCR3 is to never schedule more than five 'wires' a day.

In case of disruptions of the schedule, the planners are the ones who reschedule and manage the planning system. But, they are not the ones who make the decisions. The planners follow the orders of the cardiologists, whom are the ones that decide. There are no concrete cancellation rules. If a cardiologist on the day itsself expect surgery to take too long or they find the schedule too busy (in the upcoming days), they notify the planners and give them the order to cancel surgeries and reschedule them. Most of the time the cardiologist even specify specifically which clinical patients should be rescheduled since they performed a quick medical check. Note, the cancellation of elective patients' surgery is something which rarely happens and therefore can be neglected for this research. Patients have been waiting for surgery mostly for a long time, so will not cancel easily. Furthermore, if the program deems to be too full, elective patients will not be the ones who will be rescheduled.

Staff Perceptions
Observations and interactive inquiry with ETZ staff brought forward the divergent views on the current way of doing things in the cardiology department. [redacted]

Second, the scheduled time and the actual duration time of an operation might differ due to the lack of insight in the consequences of complications indicated when the surgery is booked. As stated earlier, the system assigns a standard time to surgery types dependent on the variant a planner chooses. ILT employees brought to mind that the estimation of the surgery duration by the planners is lacking. ILT employees would have a better judgment of expected procedure length due to their medical background. An ILT member observed that in a different hospital where he/she also works, planning of non-elective surgeries is not done by a planner, but by an ILT employee who is in charge of the planning; a so called 'directing nurse'. This directing nurse possesses a list of all clinical patients which s/he gradually schedules during the day.

A third point of interest that came to mind during a conversation with a cardiologist, is his/her perceived low throughput speed. It takes a long time (in comparison to other hospitals) before patients are prepared for surgery. The time between the call that a CCR room is ready and the actual transfer of the patient can take quite some time. Furthermore, preparation inside the CCR namely cleaning and preparing equipment for a new patient is perceived to lack efficiency.

Fourth, DTC nurses are annoyed by the fact that during some day parts one or multiple CCRs are closed. As a consequence of this, workload is fairly low at these moments. Sometimes, one nurse should stay on the ward for only one or two patients.

Lastly, the complete closing of CCR3 on Friday is an annoying factor for DTC nurses as well as other medical staff. Often staff complain about this. The reason for not performing any type of surgery on CCR3 on Friday is because these patients need a check of a device cardiologist the day after. The absence of a device cardiologist in the weekend would mean a patient needs to stay the whole weekend and can be checked at its earliest on Monday. Therefore, management made the decision not to allow PM or ICD surgeries on Friday. In exceptional cases when a device cardiologist works during the weekend, s/he takes the initiative to schedule a PM or ICD patient on Friday.

3.2 Problem Statement

To objective of the Master Thesis is to maximize the efficiency of the Cardiac Catheterization Rooms (CCR) during the standard opening hours. The hospital's current strategy, according to several hospital staff members leads to an inefficient use of the scarce CCR time. There exists a potential mismatch between surgery demand and patient supply, which will be analyzed and suggestions for improvement will be given in this study. Other than a lack of perceived efficiency, professional dissatisfaction among hospital staff with respect to their current way of working.

In the event of schedule disruptions, hospital planner staff members use general intuition/experience to reschedule surgeries. Whilst rescheduling, the planners stay in close contact with the cardiologists. At present, the elective patients are scheduled at the start of the morning daypart and the start of the afternoon daypart. The remaining time is available for non-elective patients (as illustrated in Figure 5). In case of an emergency patients' arrival, the execution of the surgery schedule is monitored by the planners in cooperation with the cardiologists and if needed adjusted. Rescheduling on a daily basis due to emergency patients or other disruptions of the schedule are often perceived as unfair by staff. The original planning is almost never executed. The rescheduling of patients mostly leads to a different work schedule and even could lead to last-minute overtime. Moreover, intervention lab technician (ILT) staff and cardiologist tend to interfere with the rescheduling of patients. The current working policy leaves room for this interference, as the planners claim no decision making power. The constant change, interference that comes with these changes and uncertainty leads to irritations.

The current way of working results in some more interesting findings, which leaves room for research and improvement;

[redacted]

(2) In an ideal situation the rescheduling of the planning happens in close cooperation between the planners, cardiologists and medical staff. However, it sometimes happens that cardiologists decide, without discussing it with the planners, to add a clinical patient to their schedule, if they notify they will finish their program earlier than expected.

[redacted]

3.3 Research Questions

As described, perceptions prevail that the current way of working is deemed far from optimal. Generically, decisions are made based on gut feeling. ETZ wants to know if their current scheduling and planning policy is in line with what data shows. If not, what should be the new (data supported) policy and what should be the decision rules related to rescheduling?

So, the objectives for this research are; (1) maximize the utilization of the CCRs, (2) minimize the waiting time for elective and non-elective patients, (3) minimize the idle time, (4) minimize the overtime. Consequently the following research question has been formulated:

Research Question

What is the optimal capacity planning, the capacity allocation and planning policy for elective patients and what (re)scheduling rules are applied to deal with non-elective patients in order to improve CCR efficiency?

In order to be able to answer the main research question, six sub questions are formulated. Before any improvements can be made, it is first needed to understand and outline the current way of working of the CCR planning in ETZ. Therefore, the first subquestion is:
1. What is the current scheduling policy of elective patients and how are non-elective patients dealt with?

Since patients who get a surgery at a CCR come from several departments, structuring the relationship between these departments and its characteristics is important to get a clear overview of the process. Their location, functioning and hierarchical relationship matter to get an overall view. Detecting ratios and possible patterns between patients inflows/outflows and the CCR has the potential of forecasting CCR occupancy build on the known behavior of patients flows. The second questions therefore looks into the characteristics of the flow of patients:
2. What are the CCRs patient flows origins and what are their characteristics?

In order for patients to get a surgery, an operating room and cardiologist should be available. In the ideal situation capacity and demand are in line. Hence, the opening of CCRs corresponds to the surgery requests. To formulate realistic scenarios for the simulation, it will be of critical value to see how the opening of CCRs has been handled in the past.
3. What is the current opening of dayparts, how are they spread over the week and to which cardiologist types are they assigned?

ETZ plans a certain amount of surgeries for elective patients and leaves space for non-elective ones. The importance of the correct division of time between elective and non-elective patients was pointed out in the research of (Bovim et al., 2020). They highlighted the major trade-off between the number of elective surgeries scheduled versus the amount of elective rescheduling needed to deal with the surgeries of emergency patients. Furthermore, the sequencing of patients happens according to a longest case first principle according to the planners. However, observations could not validate the actual use of this approach. The actual sequencing approach used is FIFO; the patients who are planned first are put as first surgery in the morning or first in the afternoon. Patients scheduled next are just simply placed next and so on. In order to discover the correctness of the division of CCR time between elective patients and non-elective patients as well as the scheduling sequence, the fourth research question is formulated:
4. What is the current allocation policy for elective and non-elective patients and how does it perform?

The fifth research question looks into how the data available at ETZ can be useful in order to decide on the amount of dayparts that should be open to serve the different patient types, how these dayparts should be spread over the week and to which cardiologist (type) they should be assigned. Furthermore, how can data help in allocating the CCR-time to elective patients.
5. How can data be used in improving the capacity planning and capacity allocation?

As this is known, a policy on how to sequence elective patients and how to deal with non-elective patients should be created. The sequencing of patients is a hot topic in literature, lea way to improve policies. This daily operational decision making should be managed. Therefore the last sub question was formulated:
6. What is the optimal policy for the scheduling of elective patients once the opening of dayparts and the allocation of CCR time is fixed and how to deal with non-elective patients effectively?

3.4 Research Scope

As the time to perform this Master Thesis is limited, realistic boundaries should be set. Defining a clear scope will allow for a manageable study, valuable for both academic literature and ETZ. Together with both ETZ supervisor and university supervisor the scope was defined (see Table 2) and highlighted here after.

Inside of Scope	Outside of Scope
Tactical and operational decision making	Strategical decision making
Operating Room (OR)	Bed capacity
Surgeries during regular CCR opening hours	Surgeries outside regular CCR opening hours
Cardiologist availability	Medical staff availability
Cardiologist types performance	Individual performance cardiologists

Table 2: Scope of Study

This study will leave out the decisions made on long term, strategical level. Three CCRs are available to perform the surgeries of the cardiology department. These customized operating rooms do not need to be shared with other surgery groups. Hence, the constraints stemming from strategical planning are not applicable to the case.

The research focuses only on the operating rooms, leaving out the recovery rooms. Therefore, bed capacity is outside the scope of this study.

Since the scheduling of elective patient only happens during the regular opening hours (08:30-12:00 and 13:00-17:00) surgeries performed during the weekends or outside the opening hours of the CCR are not taken into consideration. Note, only emergency operations are performed outside of opening hours; staff is not present in the hospital, but are available on a call base.

Medical staff (both nurses and ILTs) availability is left out of scope; it is assumed always enough staff is available on the wards as well as for the CCRs. Except for the presence of the cardiologists, since the planning and scheduling of the CCRs is highly depending on them. For pacemaker (PM) procedures in CCR3 a pacemaker-technician needs to be present; the availability of this medical staff member is also left out of scope. If there are surgeries scheduled on CCR3 during regular opening slots, one can assume a pacemaker-technician is present.

During the study the researcher will make distinction between the three cardiologists types working at the CCRs (interventional, general and device), but no individual performance of cardiologists will be studied. This decision was made due amongst others lack of insight in complexity occurring during operations.

4 Methodology

This chapter describes the design approach of this study. The goal is to provide a structured overview of how the research questions (see section 3.3) will be answered. First the four-phase approach will be shortly introduced, followed by an extensive description of the initial plan to execute each phase.

4.1 Detailed Research Design

The objective of this Master Thesis is to provide ETZ with a policy for an efficient planning and scheduling of their CCRs on both tactical and operational level. In this subsection the four phases (see Figure 6) to structure the research in order to answer the research questions as formulated in Subsection 3.3 are outlined. Relevant qualitative information and quantitative data is gathered, structured and analyzed in the first phase. In the second phase, the design of a scheduling policy is produced and (last-minute) rescheduling rules are formulated. The implementation of this, is done in the third phase via a simulation tool in which several scenarios will be ran. Testing the functioning of the policy and its rescheduling rules is done in the last phase. Furthermore, results are interpreted. Note that there might be overlap between the phases and forward and backward iteration might take place.

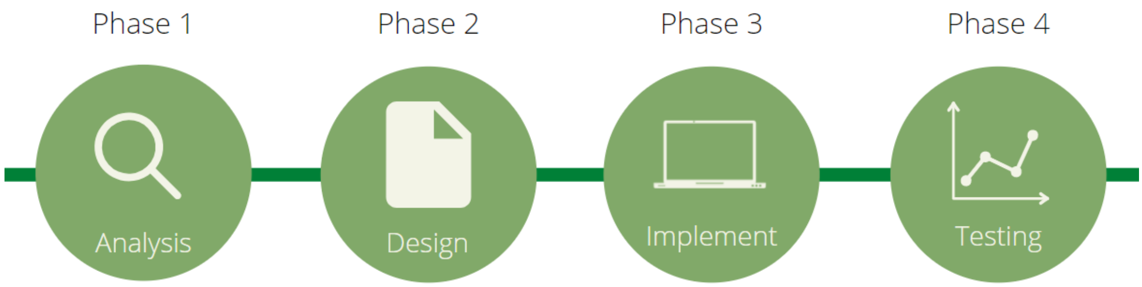

Figure 6: Phases of the Master Thesis study

4.1.1 Analysis

The goal of the first phase is to map the current planning and scheduling framework at ETZ and to analyze the functioning of it based on qualitative and quantitative data gathering. It will answer the first, second, third, fourth and part of the fifth research question. The results of the analysis phase, shortcomings of the current system and opportunities for a new one, serve as input for the design of the actual simulation tool. It is crucial that this step is done thoroughly as it is the basis for the design phase. Qualitative data is obtained by observing, mapping the current way of working and performing several interviews with relevant stakeholders. The Business Intelligence Center (BIC) enables the researcher to get relevant quantitative data.

Qualitative

The formulation of the current way of working will be formulated based on information gathered through interaction with staff members and formative documents composed by ETZ supervisor. Moreover, interviews were conducted to get more insight and professional opinions on the matter. For the purpose of this study the term interview is used as in action research. The questions were asked and answered in the work environment rather than formal interviews in which researcher and respondent sit down for a question and answer session. Different staff members where interviewed, this made for inherent triangulation of data.

Once all relevant qualitative information is gathered an analysis is performed on it. In the qualitative analysis the current way of working will be explained extensively; multiple subtopics are discussed. The use of figures supports the quantitative data's accessibility.

Quantitative
For the quantitative analysis, first general facts will be mapped such as the ratios between elective and non-elective patients at the CCRs, ratios between scheduled and actual duration of surgeries, when spread over a month, week and day surgeries are performed, arrival times of non-elective patients and so on. Furthermore, connections, patterns, relationships and outstanding findings are diagnosed and presented. Mapping all relevant information and findings gathered during the analysis, will serve as input for the design phase. The data availability will be discussed next.

In April 2018 the ETZ changed their software system hospital wide. Nowadays the software system Epic is used, which is a software system primarily used in healthcare. As a result of the software switch, access to historical data is only granted the time ETZ switched their software system. Older data might be able to retrieve, but transforming one system to another is problematic and ceteris paribus cannot be assumed. SQL is the programming language used in Epic. Transferring SQL files to for example Excel can be done by ETZ data staff if asked timely.

4.1.2 Design

In order to find an optimal planning and scheduling policy, six scenarios will be tested in the simulation tool. Per scenario multiple variations are tested. The possibilities of variations to be tested per scenario are immense. Therefore, per scenario, only the variations which are deemed to be most important and relevant for the research will be applied. The scenarios are sequenced in order of importance. The next scenario will be tested with the best version of the previous scenario. But, it might happen some variations can not be ruled out, consequentially more than one 'best performing' variant continues to the next scenario. Moreover, iteration is not excluded.

Scenario 1: Capacity Planning
The first scenario deals with the question how much time should be available for surgery and how this time should be spread over the week and to which cardiologist type and consequentially individual cardiologist it should be assigned. Status-quo, each cardiologist type has a fixed amount of dayparts they are working on the CCR, not fluctuating with the capacity that is needed to serve the demand. As highlighted earlier, among CCR employees there is lots of discussion about the added value of the general cardiologists on the CCR surgeries. In the simulation will be tested what the influence is of closing dayparts, how the dayparts are spread over the week and to which cardiologist type the dayparts are assigned.

Scenario 2: Capacity Allocation
The second scenario will try to find an optimal distribution of the assigned CCR time over elective and non-elective patients. The current division of CCR time over these two patient groups is solely based on experienced based gut feeling.

Scenario 3: Patient Sequencing
As shown in Figure 5, the elective patients are scheduled first in a daypart, complemented by non-elective patients. All non-elective patients are scheduled according to a first-come-first-served (FCFS) policy. Except for the emergency patients, who are treated on the first CCR which comes availableby by an interventional cardiologist. An ILT staff member already suggested if there are two interventional cardiologists working at CCR1 and CCR2, not to schedule two long procedures parallel to each other so emergency patients could be treated if needed. Of all procedures performed on CCR1 and CCR2, CAG and FFR are the only procedures which could be interrupted. Interrupting a procedure is of course something which should be tried to avoid. The influence of not scheduling CAG procedures in the afternoon will be tested in this scenario as well, especially with respect to the DTC bed occupancy.

Scenario 4: Holiday Weeks
Adapting the standard planning, because of the extra closing of CCRs, will be evaluated. A CCR slot being closed occurs for example frequently in the holiday period. In the current situation, the standard planning is always used. The simulation will answer the question if a different planning should be used during holiday periods and what this temporarily planning should be.

Scenario 5: Surgery Length
If a procedure is scheduled, Epic automatically assigns an expected surgery length belonging to the procedure booked. Cardiologists have the opportunity to indicate expected complications, without the system automatically indicating the extra time needed. Hence, the planners can manually adapt the expected surgery length if needed. In the simulation will be tested if the average surgery length values found during the quantitative analysis lead to a better performance.

Scenario 6: Admission and Cancellation Rules
Currently patients are allowed to be scheduled on CCR1 and CCR2 if they are at most the sixth or seventh patient getting surgery on that room and the expected end time is before 16:30. On CCR3 a patient can be scheduled if the amount of wires changed during that daypart is maximum five and the expected end time is before 16:30. The simulation will test what the effect is if patients are allowed to be planned with an expected end time later than 16:30. The cancellation rule deals with the cancellation of operations if the end time deems to be later than 16:30. As already mentioned, currently there are no concrete cancellation rules since the cardiologists personally decide if a surgery should be cancelled or not. Combinations of admission and cancellation rules will be tested, since they are co-dependent.

Performance measures should be calculated in order to compare different scenarios. The outputs presented in Figure 22 correspond with the research objectives. This does not mean those will be the only performance measures in the simulation. All performance measures as stated in Table 3 are strived for to be implemented in order to measure the simulations performance.

Performance Measures	Description
Idle Time	Time no surgeries are performed on the CCR during standard opening hours
Utilization	Ratio between the allocated CCR-time and the actual time used
On Time	Percentage of time patients are served before their due date
Overtime	Time CCR is used more than the actual opening hours
Waiting Time	Difference between the moment a surgery is performed and requested

Table 3: Performance measures used to compare possible scenarios with their description

4.1.3 Implement & Testing

Once the data preparation is finished and the design is ready, in the implementation phase the input parameters and the planning policy are connected in the simulation model. All formulated scenarios are executed. The fifth research question can be answered partly at this point. In the last phase of the Master Thesis (testing), the performance of the different scenarios which have been implemented are discussed. The results of their functioning are compared and conclusions are drawn. Hence, the fifth and sixth research question can be answered.

5 Quantitative Analysis

Chapter 3 presented the qualitative analysis, based on interviews and internal documentation. The present chapter provides the quantitative analysis, based on historical data. It will also build on the knowledge gathered in the qualitative research to support and explain the quantitative findings. By applying the findings of both the qualitative and quantitative analyses, this chapter serves as input for the simulation of realistic and valuable scenario which are introduced in the next chapter. Furthermore, the chapter gives insight in the current performance of the planning and scheduling system and sees if the perceptions of employees at ETZ are in line with the data. Moreover, the analysis makes it possible to answer subquestion two, three and four, which are discussed at the end of this chapter.

The chapter starts with discussing the quality of the data and explains the coupling of the data files. Secondly, several aspects regarding overall information about the CCRs is presented. Thirdly, elective and non-elective patients are compared on multiple elements. In the fourth subsection aspects related to cardiologists are shown and the chapter ends with a summary of the main points from this chapter. Note, only the most important findings are highlighted in this chapter, while in Appendix F more extended information can be found.

5.1 Data Collection and Analysis

Data was requested for all surgeries performed at the CCRs, its characteristics and data related to the patients who got these surgeries, such as their inflow location, consultations at the outpatient clinic or time on the waiting list. The researcher had access to pertinent Excel files ranging from 30-03-2018 till 15-12-2021. If not mentioned differently, this chapters' analysis is performed on the complete data set. The data was linked and the analysis was performed with the help of Excel and Python. Before the data could be interpreted, the quality of it was checked and where needed adapted.

Data Files
The researcher requested and received five data files which contain information about:
1. Surgeries performed on the CCRs
2. Patients waiting list for a CCR surgery
3. Patients who had an appointment at the outpatient clinic
4. Patients who were discussed during an MDO
5. Patients' movements in the hospital
6. Which cardiologist performed which surgery type per surgery.

In Appendix E an overview can be found of the relevant research elements available per data file and what data was requested for but could not be delivered.

5.1.1 Coupling of Databases

The file containing the surgeries which have been performed at the CCRs served as the basis data file. This file has been extended with the data from the other files such as the inflow location of the patient, time on waiting list, check if a patient has had a consultation at the outpatient clinic or was discussed at an MDO and which surgery types were performed during the surgery and which cardiologist performed these. Besides the one-on-one data coupling, there were also elements for which assumptions were needed to be made before the data could be interpreted. The assumptions made to decide on the patient types and start end end time of the surgery can be found in Appendix F.1. The data errors are discussed hereafter.

Data Errors
1. A CIO (Cardiologist in Opleiding/Cardiologist in Training) was head cardiologist on eight surgeries, this situation is impossible and probably an administrative error. The researcher looked up in Epic which cardiologist was responsible for the surgery and this error was manually adapted in the Excel file.

2. Start and end time of surgery. The original data file consisted of 12,084 surgery cases. If the surgery length was smaller than zero minutes (which is impossible) or longer than 500 minutes (unrealistic), they were removed (26 cases).
3. From the 12,056 surgeries remaining, there were 687 duplicates for the session ID as a consequence of a medical act being registered twice. After removing the duplicates 11,369 surgeries remained.

5.2 Overall Information

In order to obtain a deeper understanding regarding the overall functioning of the CCRs, in this section some general information related to the CCRs is presented.

5.2.1 Operation Types

When an order is created, a surgery type is filled in which automatically generates a standard expected surgery duration. In reality, the actual operation type can differ from the one ordered. In total there are 50 operation types to choose from. While only one procedure type can be ordered, multiple procedures can be performed during one surgery. Most surgeries are ordered as a CAG since this procedure is exploratory. If the cardiologist finds something during the CAG, s/he can perform extra procedures to better investigate the finding or/and to solve the discovery. In 65.94% of the times a surgery ordered as a CAG resulted only in a CAG (4,178 times), while in 34.06% of the CAG cases also other procedures where performed (2,158), such as an FFR. This explains why some surgeries are performed more often than they were ordered. Appendix F presents an overview of the operation types, their frequency and the average and standard deviation of their duration. For surgery type CAG and PCI - Eentak a histogram of the actual surgery length can be found in the Appendix as well.

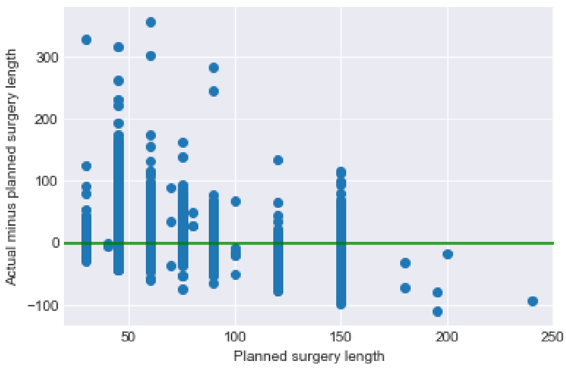

Figure 7: Difference between the actual and planned surgery length

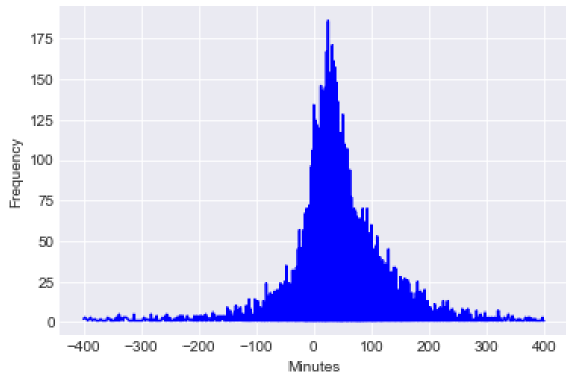

Figure 8: Difference in minutes between the actual and the planned start time in minutes (delay time)

Overall surgeries were 3 minutes and 34 seconds longer than the planned surgery time (see Figure 7) and on average surgeries start 33 minutes and 47 seconds too late as shown in Figure 8 (delay time). It is important to notice the frequency of occurrence is not represented accurately in Figure 7. It might seem as if the actual minutes with a planned surgery length of 45 minutes differ a lot, but 45 minutes is the most common planned surgery length. A representation of the frequency of the difference between the actual and planned surgery length for surgeries with a planned time of 45 and 150 minutes are presented in Appendix F. The planners always schedule the first surgery at 08:30, observations and data show surgeries almost never start before 09:00. Subsequently, a standard delay of 30 minutes is a logical finding (see Figure 46 and 47 in Appendix F). Note, Figure 8 is cropped at -400 and +400 minutes.

5.2.2 Surgery Amount

The amount of patients who got a surgery at one of the CCRs per month per year is shown in Figure 40. From the research data available, no impact of COVID-19 could be detected on the total amount of surgeries performed. The cardiology department was never closed during the pandemic and has been open as usual. The first hard lockdowns started in March 2020, a lower amount of surgeries over the remaining of 2020 can be detected compared to the other years. However, the amount of surgeries in the beginning of 2020 were already relatively lower. On the contrary, the overall surgery amount of 2020 is the lowest of the data available, while in 2021 the amount is again higher even though 2021 contained several lockdowns as well. Staff members perceive a correlation between the amount of patients on the CCRs and the lockdowns. According to them elderly people whom during lock down were not able to sport or engage in physical activities, are also less likely to get heart problems. Following this hypotheses, during the hard lockdowns in 2020 and 2021 their should be less patients, but this is not the case. As the findings show no logical pattern, no conclusions about the impact of COVID-19 can be deducted. The perception of some of the staff members is that the CCRs over the year faced a growth in the amount of surgeries performed, but data refuted this. The total amount of surgeries performed per day is presented in Figure 10. The peak in surgeries on Thursday is in line with the opening slots as presented in Appendix C.

Figure 9: Amount of patients that got a surgery per month per year

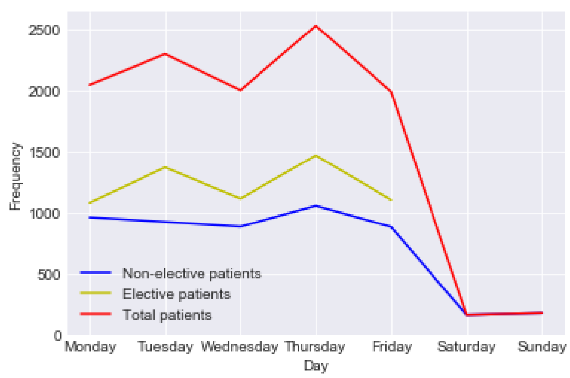

Figure 10: Total amount of surgeries per day

5.2.3 Occupancy Degree

The occupancy of the CCRs in the morning and afternoon are shown in Figure 11 and 12 respectively. The occupancy degree is only measured on the dayparts a CCR was open. During lunch time (12:00 - 13:00) the occupancy is relatively low. If the start time of a surgery was between 08:30-12:30 the surgery was allocated to the morning, if a surgery started between 12:30-17:00 it was allocated to the afternoon. The assumption is made that if one or more surgeries were performed during a daypart, the CCR was open. The amount of dayparts the CCRs were open per cardiologist type per week on average over the whole data set during normal and holiday weeks respectively are 12.48 and 10.29 for interventional cardiologists, 2.93 and 1.04 for general cardiologists and 5.54 and 4.36 for device cardiologists. This results in an average opening of 20.95 dayparts per week during a regular week and 15.67 in a holiday week. This actual amount of openings during a regular week is not in line with the amount of openings according to the standard opening as shown in Appendix C. The difference of on average two dayparts can be explained by the fact that the standard planning is based on the optimal situation. In essence, if a cardiologist is not available for his/her regular shift

Day	Morning	Afternoon
Monday	77.28%	64.53%
Tuesday	78.94%	60.00%
Wednesday	89.72%	67.32%
Thursday	79.74%	62.02%
Friday	79.91%	60.01%
Overall	81.01%	62.79%

Table 4: Average percentage of time used per daypart per weekday

(holiday, conference, sick, etc.), the cardiologist whom is responsible for the planning tries to assign the shift to a different cardiologist. However, in reality replacing every absent shift is impossible and leads to less dayparts being open than wished for.

There was no difference in occupancy degree between regular and holiday weeks. The amount of daypart openings over the years are shown in Appendix F.5. In the morning the available surgery time is 210 minutes and in the afternoon 240. Since the time between 12:00-13:00 is split between the morning and afternoon daypart, but not included as available surgery minutes, the occupancy might be a bit higher than the actual situation. The average percentage of time used per daypart per weekday is presented in Table 4. The occupancy degree of the afternoon is significantly lower than in the morning. This could be explained by the fact that there are less elective patients scheduled in the afternoon. The planners start by filling the morning daypart with non-elective patients before they put non-elective patients on the schedule for the afternoon. Furthermore, employees motivation, focus and concentration is relatively higher in the morning than in the afternoon. Hence, most cardiologist will try to perform most surgeries before they take their lunch break. Also, every Thursday from 12:30-13:30 the interventional cardiologists have a meeting. Consequently, the program starts later than 13:00. Overall, meetings are mostly planned during the afternoon.

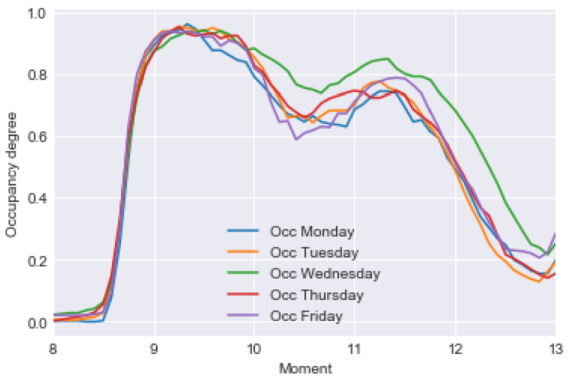

Figure 11: Occupancy of CCRs during the morning

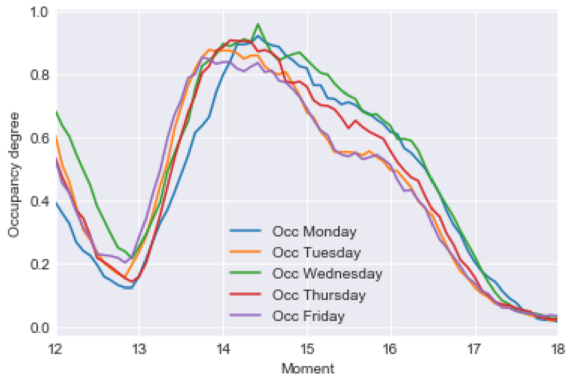

Figure 12: Occupancy of CCRs during the afternoon

5.2.4 Patient Flow

The complete list of inflow locations of the patients who got a surgery at the CCRs can be found in Table 23 (Appendix F). Most patients came from either the cardiology department (4,690) or the daycare department (4,316). Of the total 11,369 surgeries performed, 4,840 of the patients entered the hospital via the SEH or EHH and 3,269 per ambulance. Note, a non-elective patient should normally always first visit the EHH or SEH before s/he is hospitalized, which explains the high amount of patients that visited the SEH or EHH (4,714 out of the 5,138 non-elective patients). Of the 3,269 patients which arrived at the hospital per ambulance 480 were first at the Elisabeth location. In total 898 patients had first been at Elisabeth prior to their surgery. In some exceptional cases, there was no inflow detected, which means the patients first movement in the hospital was registered after the patients surgery started. If the surgery type of these patients was 'PCI - STEMI', which are patients that had a heart attack, it means the patient was moved directly from the ambulance to the CCRs, without being placed in a bed on the EHH department.

5.2.5 MDO

The data was checked if a patient whom needed surgery from a general or interventional cardiologist was discussed in an MDO no longer than 14 days after his/her surgery. Of the surgeries performed, 25.65% of them were discussed in a MDO (2,315 cases). 39.83% of the patients discussed in MDO got a new surgery within 35 days (922 cases). If a patient was discussed at an MDO and came back for his/her surgery, the average time between the MDO and the patient having his/her second surgery is 13.33 days. Treating the medical complaints with medicine instead of performing surgery, no need for a second surgery, or the death of a patient are examples for reasons a patients did not get his/her surgery after being discussed in a MDO. However, when the data is checked for all cases which have been discussed in an MDO and got a surgery within 35 days, this are 945 cases (which is more than the 922). This means there is also a small group of patients that gets a surgery because his/her case was discussed at an MDO, but the patient did not have a 'first' surgery 14 days before the MDO. Directly discussing a patients file in an MDO without having a first surgery can happen after a consultation at the outpatient clinic a patients file or if a patient is hospitalized.

5.3 Elective versus Non-elective Patients

In this subsection commonalities and differences between elective and non-elective patients are investigated. The elective patients account for 54.81% of the patients (6,231 out of 11,369). The percentage of time the CCRs where actually used, the elective patients counted for 57.52% and the total time assigned to elective patients was 58.33%. The utilization between the assigned and actual time used for elective patients is 71.34% and is 73.79% for the non-elective patients. The amount of surgeries belonging to non-elective patients is 5,138, 45.19% of the total surgeries. 41.66% of the available CCR time was assigned to non-elective patients. From the actual CCR time used, 42.48% was for non-elective patients.

5.3.1 Available versus Used CCR-time

The assumption is made that during weekdays if CCR1 is open, the complete opening time is assigned to elective patients. In those circumstances there are always three elective patients scheduled in the morning and three in the afternoon. If CCR2 is open on Monday or Friday morning, a 45 minutes slot is reserved for elective patients. If CCR2 is open on Tuesday, Wednesday or Thursday, two times a 45 minutes slot is reserved for elective patients. If CCR2 is open in the afternoon, always 45 minutes are reserved for elective patients. The remaining time on CCR2 is assigned to non-elective patients. If CCR3 is open for a daypart, 60% of the time is assigned to elective patients and 40% to non-elective patients.

Looking at the historical data, this means the overall occupancy degree has been 72.36% (Table 5). The highly fluctuating arrival of non-elective patients that need surgery of a device patient, could be an explaining factor for the relative lower percentage between time assigned and time used of the non-elective patients of CCR3.

Patient Type	Assigned Time	Used Time	Percentage
Elective Patients CCR1/2	6,059	4,301	70.99%
Non-elective Patients CCR1/2	4,438	3,431	77.31%
Elective Patients CCR3	2,333	1,686	72.27%
Non-elective Patients CCR3	1,555	991	63.73%
Total	14,385	10,409	72.36%

Table 5: Assigned versus used CCR time per patient type in hours

5.3.2 Waiting List

Figure 13 shows the amount of patients per patient type on the waiting list over time. In Figure 14 the amount of patients on the waiting list is presented again, but here a distinction is made between the patients treated at CCR1/CCR2 or CCR3. Remarkable is the increasing amount of patients on the waiting list over the year for surgeries at CCR3. While the average amount of patients on the waiting list over the year for surgeries at CCR3 increases, the average amount of dayparts for device cardiologists remained the same (see Appendix F).

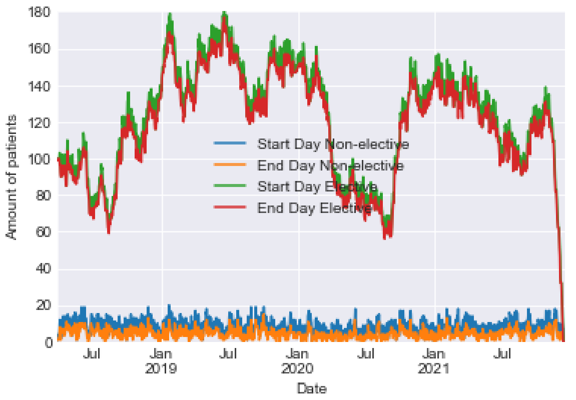

Figure 13: Amount of patients on waiting list over time per patient type

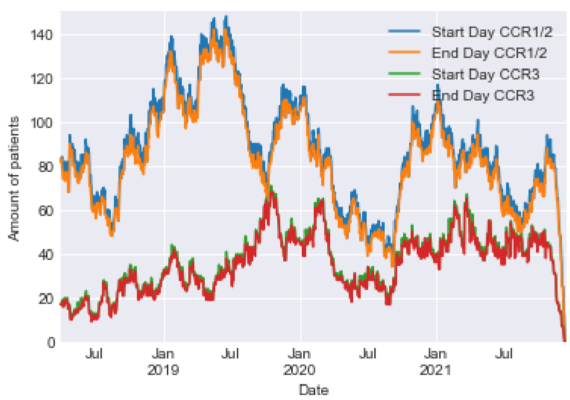

Figure 14: Amount of patients on waiting list over time per CCR

Over all data, the average time elective patients need to wait is 26.1 days and the average time non-elective patients needs to wait is 1.2 days. For both patient types the waiting time is well within the time range of 35 days and 48 hours. But, the average waiting time of elective patients by device cardiologists in the year 2020 and 2021 is higher than the maximum allowed waiting time (35.11 and 37.47 respectively, see Appendix F.6). This finding is in line with the increasing amount of patients on the waiting list as shown in Figure 14. The relatively higher waiting time for non-elective patients whom got surgery of a device cardiologist (see Table 6) can be explained partly by the fact that no surgeries are performed by device cardiologist on Friday. Moreover, as already mentioned the available time to treat patients which need a surgery from a device cardiologist was not aligned with the amount of surgery requests.

Cardiologist Type	Elective	Non-elective
Interventional	24.50	1.03
General	23.45	1.22
Device	31.75	1.82

Table 6: Overall average waiting time in days per cardiologist type per patient type

5.3.3 Elective patients

In total 4,589 patients had a physical consultation at the outpatient clinic before their surgery in the CCR (3,791 where elective patients and 798 non-elective patients). So, 60.84% of the elective patients have had an outpatient consultation in the eight weeks before his/her surgery. During COVID-19, lots of the outpatient clinic consultations were performed via phone, which covers a huge part of the remaining 40% of the patients. Furthermore, if a patient visits the EHH a surgery order might be created. Or a patient is hospitalized and a new surgery order is made during their stay. Also, the surgery of a patient simply could just have been performed longer than eight weeks after his/her outpatient consultation.

5.3.4 Non-elective Patients

The request for surgery of a non-elective patient during the day is significantly higher in the morning than in the afternoon (see Figure 15). An explaining factor for this could be because every day at 09:00 a cardiologist starts his/her shift at the cardiology department by visiting all patients hospitalized. If needed, a request for a surgery will be made, these are immediately requested and the planners are notified about this request by phone. Around 12:00 the responsible cardiologist is done with his/her visitations. If during the afternoon a doctor-assistant thinks a surgery should be requested, s/he will consult a cardiologist before a request will be made. The number of patients for which a surgery was requested per day are shown in Figure 16. Same results were found if looked at the request day per year. This finding is not in line with the current policy executed. Currently, on Fridays there is one spot less assigned to elective patients because of the high demand of non-elective patients. However, data shows surgery requests for non-elective patients are lowest on Friday. The arrival time of emergency patients is shown in Figure 17. Their arrival during the day is higher between 09:00 and 16:00. Arrivals between 24:00 and 05:00 are scarce. The arrival of emergency patients spread over a week are stable.

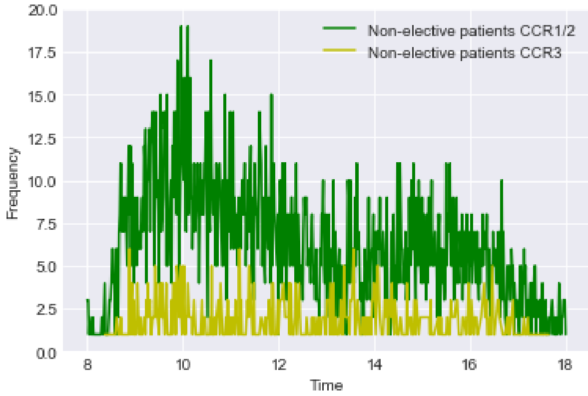

Figure 15: Moment of time during the day surgeries for non-elective patients are ordered

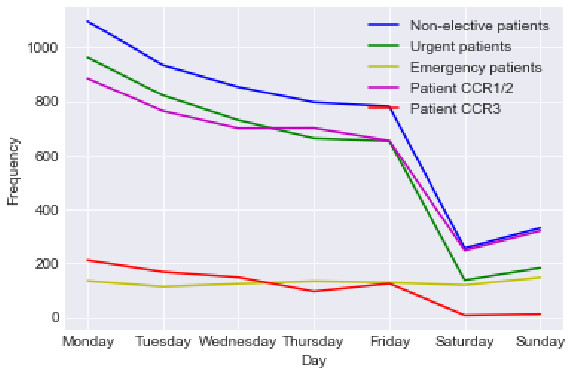

Figure 16: Day at which an order for a non-elective patients was requested during regular week

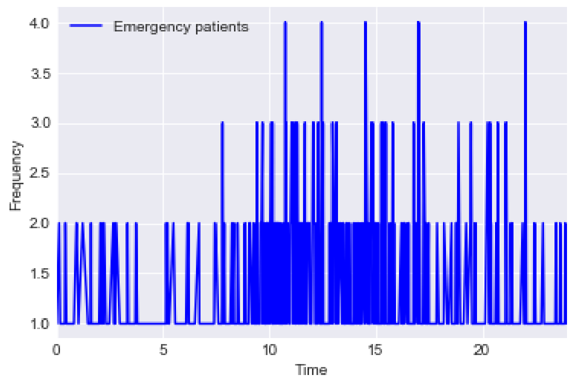

Figure 17: Arrival time during the day of emergency patients

5.4 Cardiologists

In this subsection several aspects related to the cardiologists will be presented. Firstly the difference between two half day sessions (different cardiologist in the morning and afternoon), compared to a full day session (one cardiologist operating in both morning and afternoon), is discussed. Secondly per cardiologists type performance will be evaluated. Thereafter it will be checked in how many of the cases a general cardiologist needed the assistance of an interventional cardiologist.

5.4.1 Complete Day or Daypart

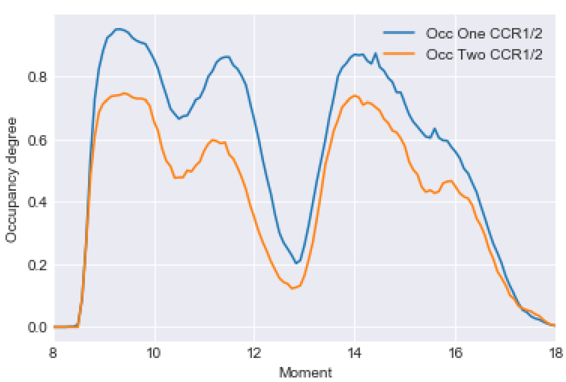

Figure 18: Occupancy of CCR1/2 if one or two cardiologists performed surgery

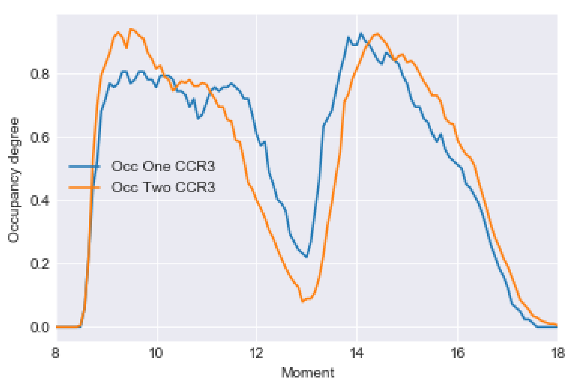

Figure 19: Occupancy of CCR3 if one or two cardiologists performed surgery

919 times a cardiologist was performing surgeries both in the morning and afternoon daypart (838 on CCR1/2 and 81 on CCR3). 733 times in the morning there was a different cardiologist

than in the afternoon shift (533 on CCR1/2 and 200 on CCR3). The average amount of minutes surgeries were performed when there was one cardiologist operating the whole day on CCR1/2 is 332.83 minutes. If there was a different cardiologist in the morning and afternoon on CCR1/2, on average only 251.28 minutes of operation took place. For CCR3 this is 322.57 minutes if there is one cardiologist operating a whole day and 312.29 minutes if there are two different cardiologists. This difference in minutes in surgery can also be detected in the occupancy of the CCRs for both situations as shown in Figure 18 and 19. This difference in occupancy can be explained by three factors;

- Firstly, if a different cardiologist is scheduled in the afternoon than in the morning, 60 minutes are reserved for a cardiologist to have both lunch break and travel time. In case a cardiologist is working a complete day on the same department, the lunch break is only 30 minutes. This simply makes the available time for surgery is 30 minutes longer or shorter depending on the scheduling of the cardiologists.
- Secondly, if a cardiologist needs to work in the afternoon in a different department, s/he will probably not start a surgery anymore if this surgery is deemed to end after 12:00 since the cardiologist should also be on time on his/her consultation in the afternoon. The influence on decision making because of being scheduled for one daypart or a complete day was confirmed by a cardiologist.
- Thirdly, a cardiologist which is scheduled for both dayparts is more flexible in taking the 30 minutes lunch break which has a positive effect on the efficiency. This flexibility is experienced as pleasant by cardiologists.

5.4.2 Difference per Cardiologist Type

Figure 20 shows the frequency of the surgery length per daypart per cardiologist type. If a CCR was open both in the morning and afternoon, it can be that the same cardiologist was performing the surgeries in the morning as well as the afternoon, or a different cardiologist performed surgeries in the afternoon than the one in the morning. The total surgery length if a CCRs was open both in the morning and the afternoon, is presented in Figure 21.

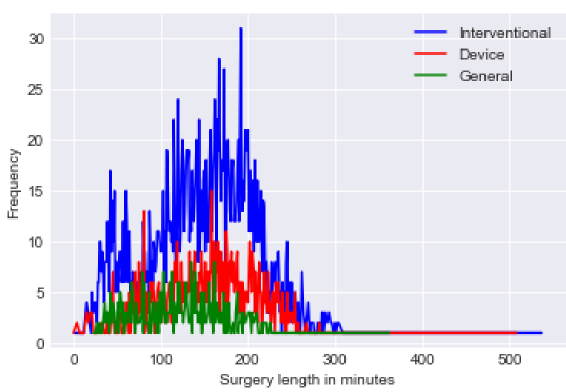

Figure 20: Total surgery length per daypart per cardiologist type

Figure 21: Total surgery length if complete day open

In total, 7,679 of the surgeries were performed by an interventional cardiologist, 1,346 by a general cardiologist and 2,342 by a device cardiologist. The average amount of minutes per daypart an interventional cardiologist was performing surgery is 148.59 minutes, 125.09 minutes for a general cardiologist and 152.97 minutes for a device cardiologist. The relatively lower surgery minutes of the general cardiologists can be explained because of two reasons. Firstly, general cardiologists are only allowed to perform a selection of CAG procedures. Consequentially, if there are no such procedures available, less surgeries will be scheduled during the daypart of a general cardiologist. According to ETZ staff all CAG procedures which can be scheduled by a general cardiologist, are scheduled by a general cardiologist. Of the 6,336 surgeries which have been booked as a CAG, 24.02% (1,227) of the cases have been performed by a general cardiologist. Secondly, general cardiologists never handle emergency patients.

5.4.3 General Cardiologist Requires Assistance from Interventional Cardiologist

In Appendix B a flowchart can be found, presenting the possible scenarios which can occur if a general cardiologist performs a surgery. According to the hospitals' standing operating procedures if a general cardiologist is performing a surgery and needs help from an interventional cardiologist two things can happen; either an interventional cardiologist enters the surgery and performs the procedure immediately or there is no interventional cardiologist available and the patient needs to come back later. As described earlier, regretfully the request for help of an interventional cardiologist is not noted in the system. So, the second scenario when a patient needs to come back because there was no interventional cardiologist available at that moment is not documented. The data was checked for patients which initially received a surgery from a general cardiologist, whether this was followed up by a surgery from an interventional cardiologist within eight weeks. In 135 surgeries (10.03%), an interventional cardiologist stepped in at a surgery where a general cardiologist was head surgeon. 189 times a patient came back for a surgery performed by an interventional cardiologist within eight weeks (14.04%). In 39.23% of the cases (71 surgeries), the patient came back for a FFR surgery. To compare; 1,251 times a patient came back within eight weeks when his/her first surgery was performed by an interventional cardiologist (16.29%). In 15.30% of the surgeries performed by a general cardiologist for sure support was needed of an interventional cardiologist. Comparing the frequency of patients coming back after a procedure per cardiologist type remains tricky since generally speaking interventional cardiologists perform more complicated procedures compared to general cardiologists and the need for a second procedure is more plausible.

5.5 Chapter Summary

This chapter ends with explaining the most important findings of the quantitative analysis. Thereafter, subquestion two, three and four are answered based on the data of both the quantitative and qualitative research.

5.5.1 Findings Quantitative Analysis

- The delay time of surgeries (actual start time surgery minutes planned start time surgery) is almost 34 minutes on average, which might be lead back to the consequent late start in the morning.
- The actual surgery length is on average 3 minutes and 34 seconds longer than the scheduled surgery length. The difference between planned and actual surgery length differs strongly per procedure type. The biggest differences are for procedures of device cardiologists.
- The utilization of the CCRs is on average 72.35% with the occupancy degree being significantly lower in the afternoon (62.79%) than in the morning (80.01%).
- In order to increase the overall occupancy degree to 85.0%, the amount of dayparts per week would should be approximately three less compared to the past situation.
- In 25.65% of the surgeries performed, the patient was discussed at an MDO 14 days after their surgery. Of these patients discussed, 39.83% came back for a new surgery and these were on average 13 days after their case was discussed in the MDO.
- The total percentage of time assigned to elective and non-elective patients (58.33% and 41.66% respectively) is in line with the percentage of actual surgery performed (57.51% and 42.48%).
- The waiting time for patients that need surgery by a device cardiologist are significantly higher than a surgery by an interventional or general cardiologist. In 2020 and 2021 the average waiting even exceeded the maximum allowed waiting time. There was an out of balance relation between capacity and demand with respect to surgeries of device cardiologists.

- The waiting time for patients that got discussed in an MDO is way shorter as they get prioritized compared to patients which have not been discussed in an MDO.
- The request for surgeries of non-elective patients decreases over the workweek. This is not in line with the current policy where more space is reserved for non-elective patients on Friday.
- The amount of requests for surgery per week correlates with amount of dayparts the CCRs where open; during holiday weeks less surgeries are requested compared to regular weeks.
- A cardiologist who is scheduled for both the morning and afternoon leads to a higher occupancy rate than when there are two different cardiologists.
- Per daypart interventional cardiologists are on average operating 23 minutes more than general cardiologists.
- 24.02% of the ordered CAG procedures could be performed by a general cardiologist.
- In minimum 15.30% and maximum 24.07% of the surgeries a general cardiologist performed, s/he needed support from an interventional cardiologist. Subsequently either an interventional stepped in to support immediately or a patient needed to come back.

5.5.2 Research Questions

- *Subquestion 2: "What are the CCRs patient flows origins and what are their characteristics?"*
  The second subquestion is mainly answered in 5.2.4. Special attention should be paid to elective patients who need to be discussed at an MDO. If an elective patient is discussed at an MDO, ETZ strives to perform the new surgery within two weeks. However, as the planners schedule surgeries of the elective patients two or three weeks in the future, no time slots are available. Currently, ETZ is already experimenting with allocating slots for these elective patients who need surgery after an MDO on short notice.
- *Subquestion 3: " What is the current opening of dayparts, how are they spread over the week and to which cardiologist types are they assigned?"*
  The time put available for surgery is more than needed in order to serve the patients, resulting in under-utilization. More important is the amount of dayparts the CCR is open per cardiologist type not being in line with the amount of patients on the waitinglist. Furthermore, the spreading of the dayparts over the week is the contrary of the arrival pattern. A cardiologist performing in both morning and afternoon surgeries instead of two different cardiologist resulted in a significantly higher occupancy degree.
- *Subquestion 4: "What is the current allocation policy for elective and non-elective patients and how does it perform?"*
  There is very little difference between the percentage of time assigned to both patient types an the ratio of the percentage of time used. However, the utilization is, definitely in the afternoon, far from optimal.
- *Subquestion 5: "How can data be used in improving the capacity planning and capacity allocation?"*
  All information gathered during the quantitative analysis helps to better understand the way of working at the CCRs. It either confirmed or rejected the perception that ETZ employees had about its functioning. For the purpose of this study, the findings with regard to the performance of the CCRs provided by the quantitative analysis above forms the basis for the scenarios of the simulation.

In the next chapter it will be discussed in more detail how the findings of the quantitative analysis are transformed to realistic and meaningful scenarios for simulation for which the historical data provided will be used as input variables. Consequently, the answer to subquestion 5 will be extended. After the simulation is performed, Chapter 8 will give answer to the last subquestion. Hence, the main research question can be answered.

6 Simulation Model

In the simulation model several scenarios of the planning and scheduling policy are tested to see how they influence the CCRs' performance. These scenarios will be explained in the chapter following. First, in this chapter the simulation model will be introduced. The chapter starts with the model development, in this section the input variables are explained which are based on the data discussed in Chapter 5. Also, the planning method is illustrated and the assumptions that have been made prior to the construction of the simulation model are mentioned. Furthermore, the output measures are discussed. After the introduction of the model, the model configuration such as the amount of runs, warm up time and the number of runs is discussed. The chapter ends with verification and validation of the simulation model in order to be sure the model behaves as it is intended and whether the model is reasonable with respect to reality.

6.1 Model Development

In order to answer the fifth and sixth sub-research question, a Discrete Event Simulation (DES) is developed in Python. Discrete Event Simulation is a way of modeling the system in which events occur overtime. DES technique has been an effective tool to approach a wide variety of health care issues (Zhang, 2018). The technique is of high value in a healthcare environment because of its ability to deal with complex flows and policies. Appendix H shows the overview of the model in the form of a flowchart. The model consists of several sub-processes, which are described separately in order to reduce complexity. A quick overview of the input, planning method and output of the model is presented in Figure 22 and will be discussed next.

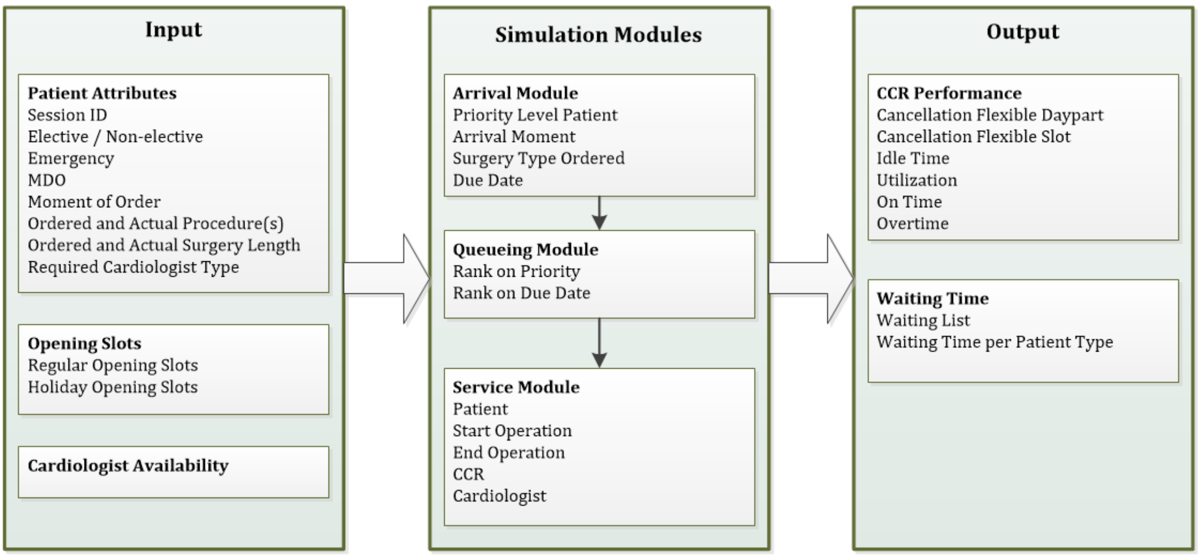

Figure 22: Input, simulation model and output

6.1.1 Input variables

Input for the simulation model consists of three parts: patient demand with their characteristics, opening slots and cardiologist availability. The patient characteristics are based on the historical data, while the opening slots and cardiologist availability are procedural restrictions.

Patient Attributes

The data gathered and analysed in the previous chapter serves as input for the simulation. In order to run the simulation for a longer period of time and get a more reliable simulation output, the input data gets selected randomly from a selected group of the data. The criteria to group the data is based on the day the order was requested and whether or not the order was placed during a holiday week. In the previous chapter it became clear no hard conclusions could be made with respect to seasonal effects. This finding was also confirmed by professionals. The data file which has been used for the analysis in the previous chapter will serve as the input file (11,369 surgeries). The simulation will mimic the situation and randomly selects from the input file all surgeries which have been performed on a day in line with the matching group, so called bulk arrival. Hence, the historical data is split into 14 groups: Day (7) x Holiday week or not (2) = 14. So, if for example the current moment in time in the simulation is Monday the 28th of January (which is not in a holiday week), it will select randomly all the surgery requests that have been placed on a day of the group with the characteristics: Monday and No-Holiday. Subsequently, all real-time identified fluctuations are taken into account.

The input (patients arrived) contain several attributes. The first patient attribute is the session ID of the surgery. This unique number is defined as patient attribute to distinguish the operations. The following three patients attributes (elective/non-elective, emergency indication and MDO) decide what priority level a patients gets assigned. The patients that arrive in the system have one of the four priority levels, which is important for the queueing module. The class of non-elective patients can be further disaggregated in two priority classes which vary in terms of urgency:
- Priority Level 1; the patient should be operated as soon as possible (< 30 minutes).
- Priority Level 2; the patient should be operated on short notice (< 48 hour).
Elective patients are also split into to two groups bases on the urge for surgery:
- Priority Level 3; the patient should be operated after an MDO (< 2 weeks).
- Priority Level 4; the patient should be operated after a consultation (< 5 weeks).
The remaining patient input attributes are used to reflect reality as closely as possible.

Opening Slots
Basically, the CCRs can be open on every daypart during the working week. However, there are a couple of restrictions. First, every workday (except for holiday days) at least one interventional cardiologist should be working in the morning and afternoon in order to perform surgery on emergency patients. Second, during holiday weeks maximum two out of three CCRs are decided, by internal agreement, to be open at the same time. Third, during holiday weeks on at least four out of the five working days CCR3 should be opened in the morning or/and afternoon. Fourth, if CCR3 is open on Friday, this means a device cardiologist should come back on Saturday to be able to discharge the patients that got a surgery on Friday. Otherwise, the patient has to stay in the hospital until Monday. Since it is not standard for device cardiologist to have a shift on Saturday, this should be seen as a real-time restriction.

The simulation will check every Friday if there are non-elective patients in the hospital whom are waiting for a pacemaker surgery performed by a device cardiologist. As happens in reality, they prefer not to leave these patients in the hospital waiting for a surgery until Monday as the medical risk is too large. So, these patients will get their surgery on Friday if possible to arrange; last-minute a daypart will be opened to perform surgery on these patients and a device cardiologists needs to work on the CCR on Friday. In reality this happens approximately once a month, which is in line with the findings in the simulation.

Cardiologist Availability
The availability of each individual cardiologist can be found in Appendix G. Every single cardiologist has at least two dayparts per week on which s/he is not available to work at the hospital. For almost every cardiologist this means having a complete day off on either Monday, Wednesday or Friday. Although the cardiologists have no preference for their shift(s) on the CCR during the week, in the current planning they all have a number of dayparts on which they are scheduled most frequently. For this study, the only restriction is not to schedule cardiologists on their day off.

6.1.2 Planning Method

The simulation model is divided into three modules (arrival, queueing and service module) which determine the planning for both elective and non-elective patients on the CCRs. A couple of assumptions have been made prior to the design of the simulation model:

- Patients are scheduled by a predefined cardiologist type.
- Patients should never be scheduled by a specific cardiologist.
- A surgery that started, can never be interrupted.
- Elective patients can have their surgery earliest two days after the surgery was requested because of medical preparations.
- There is one hour lunch break (12:00 - 13:00) if there is a different cardiologist in the afternoon than in the morning and half an hour lunch break (12:30 - 13:00) if a cardiologist operates in both morning and afternoon.
- A patient and cardiologist are always present on the assigned slot.
- Public holidays are neglected (Christmas, Easter, ...).

Arrival Module
The function of the arrival module is to load the patients into the system. For the arrival module, the patients attributes are crucial as they will decide how an arrival is classified. Based on the priority level of the patient and the moment of arrival, the due date is set. The output of this module will serve as the input for both the queueing and service module.

Queueing Module
The queueing module consists of both elective and non-elective patients for whom a surgery is ordered, but did not receive their surgery yet. Hence, these patients are on the waiting list. The capacity of patients on the waiting list is infinite. Every time an arrival event occurs, the queueing module will be triggered. Seven waiting lists will be created in the simulation, which are a combination of the patients priority level and needed cardiologist. A patient needing surgery from an interventional cardiologist can have all four priority levels, patients for a general cardiologist always have priority level 4 and the patients of a device cardiologist have either priority level 2 or 4. Each queue has its own logic and rules, commonly called a queueing discipline. The waiting discipline defines which patients from the queue are selected to be served. Since a distinction on their priority level is already done by assigning them to different queues, the queueing module only prioritizes the queues based on the patients' due date. If patients in a queue have the same due date, they are ranked on a FCFS basis. The order of the patients in the queueing module serve as input for the service module.

Service Module
In the service module patients are selected from the matching queue according to the queueing discipline. If an interventional cardiologist is working, the first step of the service module is to check if there is an emergency patient waiting for surgery. If this is the case, the emergency patient gets served. If there is no emergency patient, the patient which is ranked first in the matching queue is selected to be served first, provided that the surgery meets the allocation criteria. The allocation criteria are;

1. The allowed amount of regular elective patients.
2. The allowed amount of short-term elective patients.
3. The allowed amount of planned surgery length minutes for elective patients.
4. The total available time for surgery.
5. The total amount of time passed; both surgery and idle time.
6. The allowed amount of wires.

The elective patients with priority level 4 count as a regular elective patients, while the patients with priority level 3 are seen as short-term elective patients. But, the planned surgery length of both patient groups counts for the allowed amount of minutes for elective patients. If for example, the allowed amount of elective patients is one, the allowed amount of short-term elective patients is also one and the allowed amount of minutes for elective patients is 150. The planned surgery length of the short-term elective patients was 120 minutes, this means an elective patient still might be treated, but its planned surgery length should be less than or equal to 30 minutes. If there is a patients meeting this allocation criteria, this patient gets surgery. After the two elective patients have been handled, the simulation will spent the remaining available time on treating non-elective patients. If there is no patient in the queue meeting the allocation criteria for a second elective patient, the simulation will immediately start serving non-elective patients if there are any.

Where the allocation criteria for elective patients is based on their planned surgery length, the allocation of the non-elective patients is based on the actual amount of minutes passed. Moreover, to reflect reality, elective patients can only be served if they have been on the waiting list for longer than two days. This restriction mimics the minimum of two days in advance the planners need to schedule a patient.

An emergency patient can only be helped by an interventional cardiologist. If an emergency patient arrives during the regular opening times, this patient will be served by the first available interventional cardiologist. But, if a patient arrives during the lunch break the patient should be treated as well. Therefore, if an emergency patient arrives during the lunch break, a dummy cardiologist will perform surgery on CCR2. Consequentially, no new surgery can start on CCR2 before the surgery of the emergency patient is finished.

In reality, the priority level 3 patients are scheduled on the first available slot for elective patients, which is mostly around two weeks. Hence, the priority level 3 patients get priority over the priority level 4 patients. As the patients get no timeslot assigned beforehand in the simulation, this way of planning could not be mimicked. In accordance with ETZ staff, assigning three slots per week to priority level 3 patients, is the policy applied in the basic scenario. This policy is in line with the desired policy for future use, by making use of fixed slots for priority level 3 patients.

The service module is separated into three blocks. Per block and per CCR, in the simulation parameters can be adjusted to accurately reflect the planning and scheduling policy. The values of the parameters at the moment a service is finished decide if and which service will be performed next. In consultation with the researcher's supervisors and based on the findings of the quantitative analysis it was decided to split the CCR-time into three blocks as illustrated in Figure 23 (morning, optional and afternoon). During the discussion it became clear that the actual opening time of the CCRs is only till 16:30 and not 17:00. Formally, the CCRs are open till 17:00, but surgeries rarely will end after 16:30. The team needs some time to clean up the CCR and to replenish the stock which takes approximately 10 minutes. So, the working day of the ILT staff will end at 17:00. If a cardiologist is operating in both morning and afternoon, the optional block will be opened and the morning block is extended with 30 minutes and their 30 minutes lunch break takes place between 12:30-13:00.

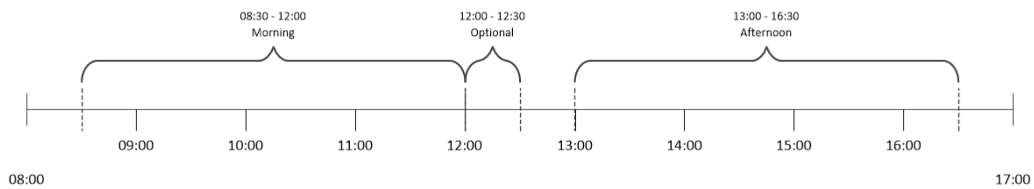

Figure 23: Division of the CCR opening time in time blocks

6.1.3 Output

Finally, the performance measures listed in Table 3 are computed by using the output of the simulation. At the end over every simulation run the performance measures are given. On basis of the results for the performance measures, different opening slots, capacity allocations, patient sequencing, holiday periods, surgery lengths and cancellation rules, can be compared and contrasted.

6.2 Model Configuration

In order to get reliable values for the performance measures, the start position, warm-up period, simulation length and number of replications should be determined which is discussed next.

6.2.1 Start Position

As it would be unrealistic to start with an empty waiting list, at the start of the simulation patients will be put on the waiting list. The amount of patients on the waiting list at the start of the simulation will be based on the historical data. In Figure 14 in Chapter 5 can be seen that the average amount of patients on the waiting list is around 125 patients, of which 85 patients need surgery from an interventional or general cardiologist, while the remaining 40 patients are waiting for a surgery of a device cardiologist.

6.2.2 Warm-up Period

A simulation rarely starts in steady state, meaning at the start of the simulation the model does not correctly reflect the normal condition of the system. Since we are interested in the steady-state waiting times, overtime, idle time, utilization and on time service a warm-up interval is used. In order to determine what length to use for the warm-up interval Figure 26 was constructed. In the figure, the amount of patients on the waiting list of queue interventional - priority 4 are shown. From the figure can be concluded that it is hard to find a moment in time a steady-state is reached. The fluctuating arrival of demand makes that the amount of patients on the waiting list, for every patient type, is irregular. Hence, it can be concluded no warm-up period or cool down period is required for this simulation. But, because there were no non-elective patients at the start of the simulation and the simulation starts in a holiday week, it is decided to use a warm-up interval of 7 days, meaning that only results will be registered after this moment in time.

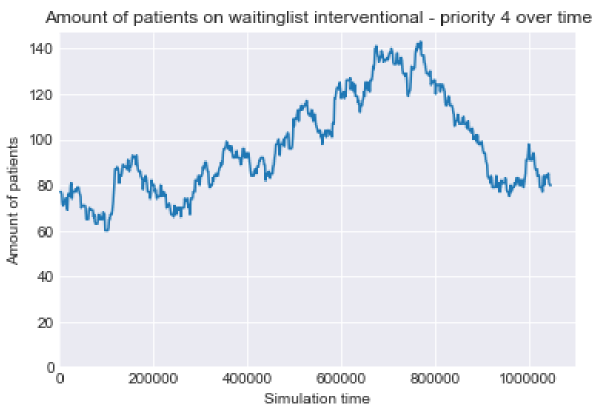

Figure 24: Estimation warm-up period

6.2.3 Simulation Length

The simulation length was chosen to be quite long because we want to study the steady-state behavior and also see the holiday and waiting list development influences, while still keeping the time it takes to run the simulation between reasonable bounds. Hence, the simulation ran for two full years (104 weeks), of which the yearly week numbers 1, 7, 18, 19, 30 - 35, 43 and 52 are holiday weeks (12 out of the 52 weeks). These holiday weeks are in line with the official holiday weeks in the Netherlands; hence in the hospital.

6.2.4 Number of Replications

A rule of thumb is to perform at least three to five replications (Kyle et al., 2000). The confidence intervals for the three CCRs when running the simulation for 10 runs (under the basic policy) are shown below in Table 7. As can be seen, 10 runs provide small confidence intervals for the utilization in both morning and afternoon while the time to run the simulation is of an acceptable duration. It produces satisfying intervals due to the decision for a quite long simulation run. Furthermore, the utilization in the afternoon is relatively lower than in the morning, which reflects reality.

CCR	Utilization overall	Utilization morning	Utilization afternoon
CCR1	(0.7392, 0.7574)	(0.7863, 0.8033)	(0.6819, 0.7068)
CCR2	(0.7194, 0.7294)	(0.7838, 0.7940)	(0.6533, 0.6635)
CCR3	(0.7055, 0.7211)	(0.7818, 0.7954)	(0.6179, 0.6419)

Table 7: Confidence intervals for the average utilization per CCR

6.3 Verification and Validation

Before analyzing the scenarios the model is verified and validated by checking whether the model behaves according to that what it is intended to do, and whether the assumptions are reasonable with respect to the real system.

6.3.1 Verification

During verification it is checked if the simulation model is made as intended. In order to do so, Law (2007) and Kleijnen (1995) describe several verification techniques. Tracing, stepwise executing the simulation to see if it is operating as intended, is one of the most powerful and obvious techniques to use. During the process of building the simulation, the simulation is verified continuously, by checking step-by-step if the simulation worked properly. During the model building, several stepwise runs where performed to check whether the model retrieved arrivals correctly, assigned patients to the correct queues, removed patients from the queues, assigned the correct values for the performance measures and so on.

In addition to the trace technique it was checked if the system respected the boundaries. An example of a system boundary is that the total time allocated cannot be more than the total available time per day. Also, it is not possible to assign multiple cardiologist to one daypart, or to open a daypart which should have been closed. It led to the conclusion that the simulation did not violate any of the system boundaries.

Running the system under extreme situations was the last way of verifying the simulation. By doubling the arrival of patients, it is expected no steady-state can be reached as the amount of patients on the waiting list will keep on increasing until the system explodes. Also, assigning not enough capacity to handle the demand results in a waiting list which keeps on growing. As shown in Figure 25, indeed the amount of patients on the waiting list keeps on growing up to a point where almost no elective patients are treated within their due date or can be scheduled any time soon.

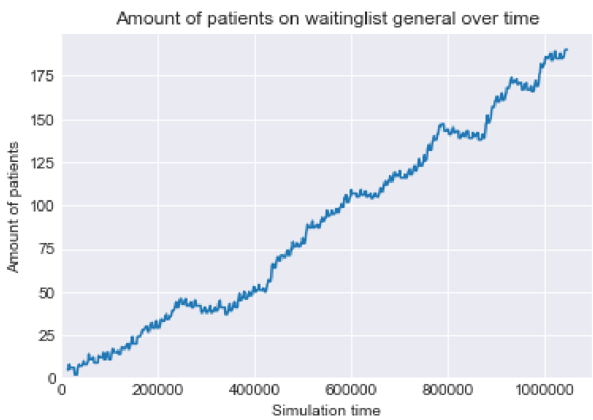

Figure 25: Patients on waiting list overtime in extreme situation

6.3.2 Validation

In order to prove the model reflects reality and is an accurate representation of the system under study, the simulation was validated. Again, models can be validated in different ways. Note, there is no absolute model validity according to Law (2007), but there are techniques to increase the validity of the model. First of all, high-quality information and data is collected. During the project, the researcher has been frequency present at the cardiology department and has observed the way of working. Interactions and close cooperation with planners, cardiologists and ILT staff enhanced mapping the situation as-is. Additionally, findings or assumptions were frequently discussed and confirmed or rejected by the researchers supervisors. Second, the historical data is used as input; reflecting reality as closely as possible. Third, the model was validated by an expert (employee of ETZ). Last, the base model was simulated and its performances where compared to the actual historical performance which where analysed in Chapter 5 and the qualitative research.

Even though most of the performance indicators and the behavior of the system are in line with the real situation, there are also some differences. The waiting time of the interventional - level 4 patients is significantly higher than the waiting times found during the quantitative analysis. This difference can be explained by the strict allocation policy applied in the simulation. Scheduling more elective patients than the planning policy prescribes happens frequently, reducing the waiting time. Loosening the allocation policy for elective patients just a bit already produces better results; these variations in allocation will be tested in the next chapter.

7 Scenarios for Simulation

In the previous chapters the current way of working was analysed. Even though the analysis is already of high value for the hospital, it is also interesting to know how they would function if some parameters are adapted. Therefore, several variations of six main scenarios are worked out, which have been developed in agreement with ETZ staff. In Figure 26 are the scenarios to be tested presented in order of importance. The next scenario will be tested with the best variant of the previous scenario in order to keep a manageable amount of scenarios to test. The definition of the scenarios is discussed in the upcoming subsections. Good to note is that there will be overlap between the variations within in the capacity planning and capacity allocation scenario and iteration between the variations may be necessary.

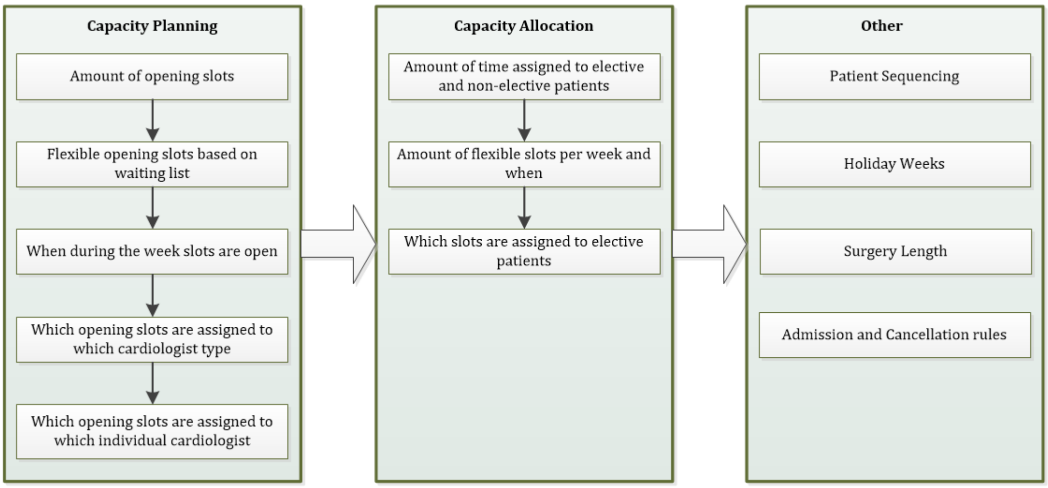

Figure 26: Scenarios for simulation

7.1 Capacity Planning

In the previous chapter the conclusion was drawn that less dayparts might be needed in order to increase the average utilization from the current 72 percent to the desired and suggested 85 percent. According to Vissers and Beech (2005) an average of 85 - 90% utilization is a target often used in operating theatre departments. This utilization level still leaves some room to handle urgent patients inside regular operating hours. As the ratio between the assigned and used time between elective and non-elective patients was in line, reducing the available time in order to increase the utilization is a promising approach. It is important to match capacity and actual requirement since both under and over utilization of an operating room are expensive (Agnetis et al., 2014). With capacity planning it will be thrived to determine the quantity of resources necessary to meet demands in a cost-effective way (Choi & Wilhelm, 2014).

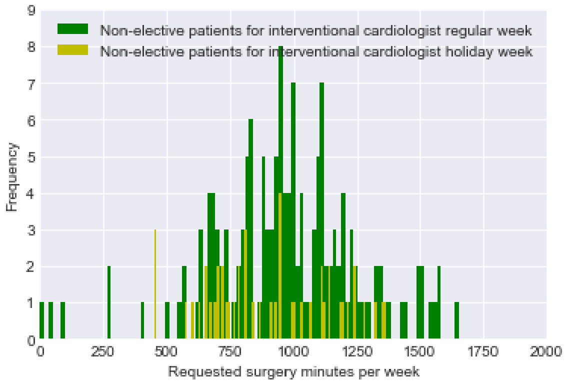

Figure 27: Requested surgery minutes for non-elective patients of cardiologist type interventional per week

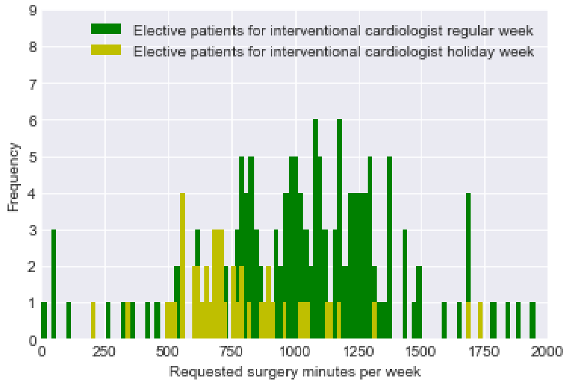

Figure 28: Requested surgery minutes for elective patients of cardiologist type interventional per week

In Figure 27 and 28 the requested surgery minutes per week for both non-elective and elective patients of patients that needed surgery of an interventional cardiologist are presented. Similar figures for device and general cardiologists can be found in Appendix I. Remarkable is that the requested surgery minutes for both interventional and device non-elective patients per week have the same distribution in regular and holiday weeks. While, for elective patients, the requested surgery minutes in holiday weeks is less. This can be explained by the fact that during holiday weeks the outpatient clinic is opened less. Hence, less surgeries will be requested. Therefore, in the simulation it will be important to keep the minutes put available for non-elective patients on a constant level during both regular and holiday weeks in order to cover the requested demand accurately. Based on the findings, the minimum amount of dayparts for interventional, general and device cardiologists respectively are 11, 6 and 2. Since there is no correlation between the patients handled by the different cardiologist types, the variations can be tested independently. With the hospitals' constraints (see Appendix I) taken into consideration, the variations to be tested are;

- Interventional regular week 10 dayparts, holiday week 10 dayparts.
- Interventional regular week 11 dayparts, holiday week 10 dayparts.
- Interventional regular week 12 dayparts, holiday week 10 dayparts.
- Interventional regular week 13 dayparts, holiday week 11 dayparts.
- General regular week 1 daypart, holiday week 1 daypart.
- General regular week 2 dayparts, holiday week 1 daypart.
- General regular week 1/2 alternately daypart, holiday week 1 daypart.
- Device regular week 4 dayparts, holiday week 4 dayparts.
- Device regular week 5 dayparts, holiday week 4 dayparts.
- Device regular week 6 dayparts, holiday week 4 dayparts.

Suggested frequently in literature is the use of flexibility in order to increase utilization (Van Riet & Demeulemeester, 2015). The introduction of a flexible daypart, might bring capacity closer to demand. Note, the complete time of the flexible daypart is used to treat elective patients if the flexible daypart is opened. Two weeks beforehand, it will be decided if the flexible dayparts will be used based on the amount of patients on the waiting list. If the flexbile daypart is closed, no surgeries take place. In this situation, it is assumed the cardiologist is planned to have a shift on the CCR. When decided the daypart is not needed, there is sufficient time to assign other duties to the cardiologist affected.

Another finding from the quantitative analysis was that the overall utilization was significantly higher if only one cardiologist was scheduled in both morning and afternoon instead of two different cardiologists. Besides the better performance, cardiologists also experience being scheduled in both morning and afternoon as pleasant as this gives them more flexibility. Consequentially, in the simulation a cardiologist working a complete day is stimulated.

7.2 Capacity Allocation

In the simulation, seven variations (see Appendix J) will be tested with respect to the capacity allocation of the interventional cardiologists. They vary in the amount of time assigned to elective and non-elective patients and how this time is spread over the day and week. Moreover, two flexible slots are introduced.

The study has shown that the ratio between the assigned and used time for elective and non-elective was quite similar to the actual time used for elective and non-elective patients. Consequently, it will be aimed to have a distribution of time between these two patients times with approximately a 60/40 (elective/non-elective) ratio. The filling of the allocated time slots is done according to a bin-packing principle, which is a commonly used model in OR planning (Zhu et al., 2019). This means if the patient ranked first according to the queueing discipline does not fit in the available slot, the simulation will keep on searching for a patient that does fit. Note, this is not the case for priority level 1 patients, whom are always treated on the first available CCR with the appropriate type of cardiologist.

The surgeries for non-elective patients are mostly ordered during the morning, when a cardiologist is checking on all patients hospitalized. The orders start trickling in from approximately 09:00 till 11:00. Therefore, it would be logical to respectively allocate more time for non-elective patients in the afternoon than in the morning. An option is to assign the amount of slots per patient type based on the day of the week. The surgery requests for non-elective patients is significantly higher at the beginning of the week. Therefore, assigning less slots to elective patients on the first day(s) of the week could cover the increased amount of non-elective patients due to the weekend.

In the simulation the implementation of two flexible slots for elective patients of both interventional and device cardiologists will be tested as well. In consultation with ETZ staff, these flexible slots will be on Thursday. The flexible slot patients are informed beforehand that their surgery can be cancelled Wednesday morning at the latest, if there are too much non-elective patients hospitalized. The time of the flexible slots is than put available to perform surgery on the non-elective patients. If the surgery of the patients from the flexible slots does not take place, they are guaranteed a new slot within one week. This way of working is already applied in different departments of the ETZ and experienced as pleasant for both ETZ employees and the patient. It gives employees more flexibility and patients are informed properly and guaranteed a slot on short-term either way.

7.3 Patient Sequencing

In the current situation, both elective and non-elective patients are scheduled according to a FCFS policy. A break-in of the schedule only takes place in case of an emergency arrival. Planning elective patients with a FCFS policy makes that it can occur that two cardiologists are operating in parallel on a long procedure, which causes the cardiologists and medical staff anxiety due to the inflexibility of covering an emergency arrival. Therefore, the first modification is that on CCR1 and CCR2 never two non-CAG procedures are scheduled parallel. By applying this rule, a decrease in the waiting time for priority level 1 patients can be expected. The second modification is to schedule CAG procedures of elective patients only in the morning.

7.4 Holiday Weeks

During holiday weeks, only two out of three CCRs are allowed to be open per day. This because both cardiologists and ILT staff need to have the possibility to go on holiday. The overarching rule that at every daypart during the week (10 in total) an interventional cardiologist should be scheduled in order to deal with emergency patients remains. Moreover, at least four out of five days CCR3 should be opened at least one daypart. The modifications to be tested are; (1) assigning two slots less to elective patients during the holiday week(s), (2) opening one daypart extra the first week after a holiday period and (3) a combination of the first two modifications.

7.5 Surgery Length

To see if the historical data can improve the planned surgery length a first variation of the scheduled surgery length would be to take the average of the surgery length of the quantitative analysis as the scheduled surgery length and round these number up to the nearest five minutes. The other option is to round off to the nearest five minutes. In the previous chapters it was highlighted that the average surgery length for most of the procedures is in line with the current planned surgery length, but some procedures are significantly shorter or longer. As the current surgery lengths are not based on data, adapting the planned surgery length might lead to a more reliable planning.

7.6 Admission and Cancellation Rules

Planning patients until the end time (16:30) is the current admission rule. Furthermore, it is allowed to plan maximum five 'wires' per daypart on CCR3 according to hospitals' standing operating procedures. In the simulation admission and cancellation are treated as one concept. Variations on the admission and cancellation rule is to allow patients to be planned if the expected end time is at the latest 16:45 or 17:00 and to plan maximum six wire changes per day. The argument for this policy is that it would be fairly unrealistic to cancel a surgery just because it would take five minutes longer than the regular opening hours. The expectation of relaxing the admission and cancellation rule leads on the one hand to a higher occupancy degree, less idle time and on the other to more overtime.

In Figure 29 an overview of the scenarios to be tested in the simulation is represented. Per cardiologists type the variations per scenario are shown.

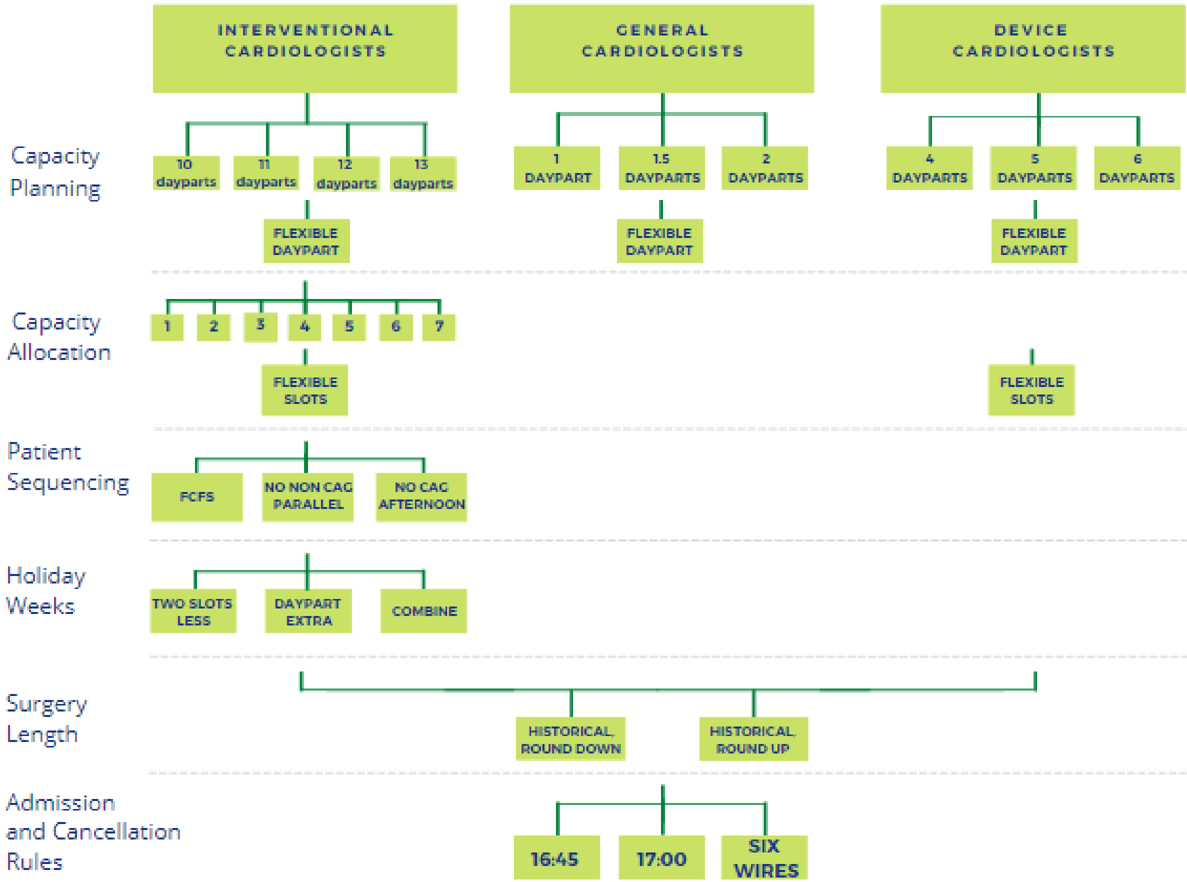

Figure 29: Scenarios for simulation

8 Results

In the previous chapter, the scenarios and its variations for simulating where described; capacity planning, capacity allocation, patient sequencing, holiday weeks, surgery length and admission and cancellation rules. This chapter is ordered based on these scenarios accordingly and per scenario will discuss the results of the simulation model. The scenario sequencing is based on a continuation of the best performing variations of the previous scenarios. Where some (variations of) scenarios are applicable to all three cardiologist types, others are only relevant to one or two of the cardiologist types. The complete overview of the performance indicators for the results presented in this chapter can be found in Appendix K.

8.1 Capacity Planning

The first scenario to be tested, gives an answer to the questions how much time should be made available per week, how the opening of the dayparts should be spread over the week and to which cardiologist type these should be allocated. Note, the waiting time for patients with priority level 1 and 2 are in hours (h), for the remaining patient types the waiting time is in days (d). The overtime and idle time are in minutes (m). The definition of the performance measures has been explained in Table 3.

8.1.1 Interventional Cardiologist

Under the basic planning and scheduling policy no desired outcomes are achieved with less than 13 dayparts, as the waiting time for priority level 4 patients exploded. However, this finding is mostly caused by faulty capacity allocation. In all four variations (10, 11, 12 and 13 dayparts), the on time service for non-elective patients is really high and the idle time is almost one hour. As there is enough potential to obtain good results with less than 13 dayparts and 11 dayparts is the minimum, the upcoming scenarios will be ran with 12 dayparts. Simulating these variations with a flexible daypart under the current capacity allocation has no added value. So, the implementation of a flexible daypart will be tested later on, once the optimal allocation criteria is found.

8.1.2 General Cardiologist

Three variations of the general cardiologists were tested; (1) One daypart during regular and holiday weeks, (2) During regular weeks, the opening of two and one daypart alternate and one during holiday weeks and (3) Two dayparts during regular and one during holiday weeks. The results clearly show that one daypart is too little, but two is too much (see Figure 30 and Table 8). In Table 8 the performance indicators of five variants are presented.

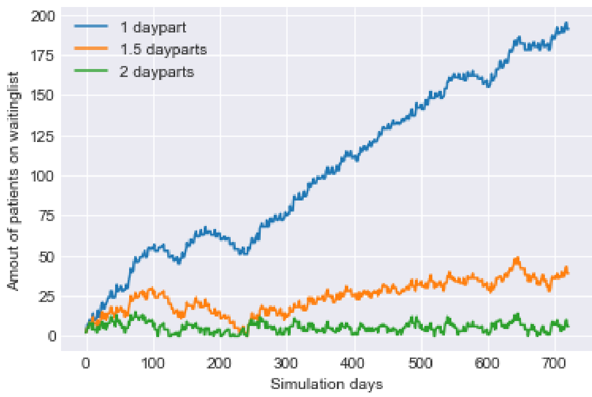

Figure 30: General patients on waiting list overtime

In the third and fifth variant as presented in Table 8, the weeks when two dayparts would be open, one daypart is transformed to a flexible daypart which is only open if the waiting list is longer than 15 patients two weeks beforehand. The fifth variant responds more accurately to the demand, while the amount of openings per year is on average only five more compared to the third variant. Therefore, all further modifications on the planning and scheduling policy are simulated based on the amount of dayparts for general cardiologist being two during regular weeks and being one during holiday weeks including a flexible daypart.

Performance Indicators	Amount of dayparts per regular week				
	1	1.5	1.5 (+flex)	2	2 (+flex)
Utilization General	0.9412	0.9281	0.9371	0.7901	0.9336
Utilization CCR1	0.8257	0.8341	0.8359	0.7850	0.8379
Overtime General (m)	9.24	8.65	9.12	5.67	9.01
Overtime CCR1 (m)	5.07	5.34	5.35	4.38	5.51
Idle Time General (m)	21.57	23.75	22.39	49.75	22.96
Idle Time CCR1 (m)	41.66	40.17	39.82	49.53	39.54
Waiting Time - General (d)	132.12	35.69	50.04	7.90	22.92
On Time - General	10.58%	52.88%	26.11%	99.70%	91.44%
Cancellation Flexible Daypart	-	-	5.70%	-	40.13%

Table 8: Results of performance indicators under the scenario capacity planning - general dayparts with flexible daypart

8.1.3 Device Cardiologist

As can be seen in Table 9 having five or six dayparts are the two most promising variations for the device cardiologist. Even though the average idle time under the first variant is almost 50 minutes and therefore leaves room for improvement, it does not provide enough capacity to serve the patients on time. This finding is in line with the suggested of minimum five dayparts in the previous chapter. In Appendix I, the three variations can be found with the allocated time for elective patients. The third variant has a significantly higher idle time than the second variant as well as a significant lower utilization, but has significantly better on time rates. For the results of this table, a cardiologist was never performing surgery in both morning and afternoon.

Performance Indicators	Amount of dayparts per regular week		
	4	5	6
Utilization CCR3	0.7722	0.7754	0.7341
Overtime CCR3 (m)	1.90	2.15	1.88
Idle Time CCR3 (m)	49.73	49.31	57.73
Waiting Time Device - Level 2 (h)	97.72	99.16	51.55
Waiting Time Device - Level 4 (d)	130.93	53.58	31.93
On Time Device - Level 2	36.98%	39.16%	57.40%
On Time Device - Level 4	4.24%	23.83%	65.48%

Table 9: Results of performance indicators under the scenario capacity planning - device dayparts

The simulation ran again with the scenario of five and six dayparts, but with a cardiologist working a full day on Thursday for the variant with five dayparts being open (variant 1) and Monday and Thursday if six dayparts are open (variant 2). Also the simulation was ran with the cardiologists working a whole day in combination with the introduction of a flexible daypart during regular weeks. This additional flexible daypart is scheduled on Tuesday afternoon and will be closed if the waiting time for level 4 patients is below 20 patients. This makes the total weekly amount of dayparts becomes six and seven (variant 3 and 4). If the flexible daypart is open, the complete available time is assigned to treat elective patients.

Performance Indicators	Amount of dayparts per regular week			
	5 (Var. 1)	6 (Var. 2)	6 (Var. 3)	7 (Var. 4)
Utilization CCR3	0.7657	0.7100	0.7680	0.6971
Overtime CCR3 (m)	1.95	1.73	2.85	2.31
Idle Time CCR3 (m)	52.26	64.52	52.74	67.99
Waiting Time Device - Level 2 (h)	78.10	44.57	66.55	41.93
Waiting Time Device - Level 4 (d)	53.55	31.81	15.79	12.83
On Time Device - Level 2	45.29%	63.09%	50.97%	65.86%
On Time Device - Level 4	23.81%	65.99%	98.01%	99.55%
Cancellation Flexible Daypart	-	-	53.04%	63.92%

Table 10: Results of performance indicators under the scenario capacity planning - device dayparts with flexible daypart

By comparing the results of Table 9 and 10, the conclusion can be drawn that by scheduling a cardiologist a complete day instead of two different cardiologist resulted in significantly better on time service rate for the non-elective patients, but also a slightly lower utilization. Overall, the most promising results were obtained under the policy with six dayparts during regular weeks (four during holiday weeks) with a flexible daypart on Tuesday afternoon. In the next chapter the on time rate for the non-elective patients will be tried to improve by the introduction of flexible capacity allocation to the elective patients.

8.2 Capacity Allocation

For the interventional cardiologist, multiple variations on how to allocate the capacity are tested. For the general cardiologists, no variations in capacity allocation are applicable as in the previous chapter optimal outcomes were obtained with the allocation of maximum four elective patients per daypart. Changing the amount of time assigned to elective patients and the introduction of a flexible slot are applied for the capacity allocation of the device cardiologists.

8.2.1 Interventional Cardiologist

In contrast to expected results, by allocating less time for elective patients at the beginning of the week, no significant improvement nor deterioration could be confirmed for the on time service of non-elective patients. However, compared to the as-is situation the only difference was having one elective patient in the morning on Tuesday instead of Friday. So probably no big differences could be expected. Assigning two slots more per week to elective patients, resulted in significant more on time service of the level 4 patients, less idle time and more utilization, but the on time service of priority level 2 patients decreased a lot too. The on time for priority level 4 patients increased significantly with the introduction of two flexible slots compared to the same situation without the flexible slots. The on time service of priority level 2 patients decreased, but as well as all other performance indicators no significant difference could be obtained. Spreading the slots for elective patients differently over the day resulted in no better on time service for the non-elective patients.

Interesting to mention is the finding that with the allocation of four elective patients on CCR1, a very high occupancy degree is achieved. If on Monday morning the allowed elective patients are reduced to three instead of four, the utilization drops drastically, while the on time-rate of the non-elective patients remains the same. In the simulation and in reality, elective patients are scheduled based on their expected surgery length, making it almost always possible to schedule four elective patients in one daypart (3.88 patients on average). Whereas, if three elective patients are scheduled, the decision to perform surgery on a non-elective patient afterwards, the fourth patient, is based on the situation at that point. Consequentially, on average only 3.58 patients are handled, resulting in a significant lower utilization and no improvement for the non-elective patients, but a worse on time rate for the elective patients.

As mentioned, the introduction of the flexible daypart for the interventional cardiologist would be implemented once a fitting allocation policy was found. Now, if the amount of elective patients on the waiting list is less than 50, the daypart of CCR1 on Monday morning will be closed. The closing of this daypart, results in a way more stable waiting list (see Figure 31), prevents for a low occupancy degree on CCR1 while the on-time service rate remains the same. For the two allo-

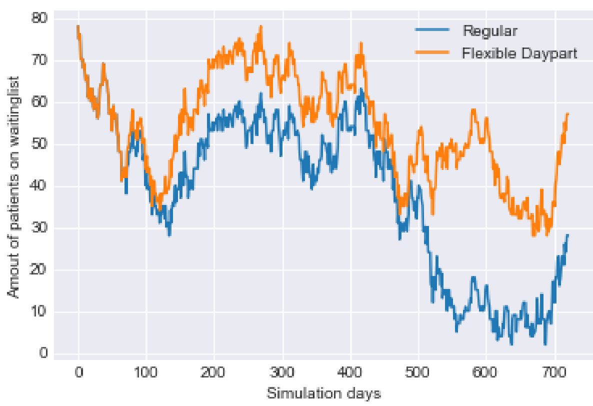

Figure 31: Interventional - priority level 4 patients on waiting list overtime

cation policies that performed best (policy 3 and 6, variant 1 and 2 respectively) the flexible daypart was introduced. It seems, under variant 1 too much time is assigned to elective patients. While running it appeared that it happened quite often patients where cancelled for the flexible slot, while the hospitalized amount of patients on Thursday was really low or even none. Therefore, the simulation was ran again under allocation policy 3, but this time the slots where only cancelled if the patients hospitalized was more than eight and ten instead of five and eight. This policy gave significantly better results for the amount of cancellations of the slot as shown in Table 11 (variant 3). It only slightly impacted the waiting time of the non-elective patients, but no significant changes were found. As it would be undesirable to cancel elective patients' appointments unnecessary, the last policy will be the one to continue with as it has the lowest cancellation frequency.

Performance Indicators	Capacity allocation variations		
	3 (Var. 1)	6 (Var. 2)	3 (Var 3.)
Utilization Interventional	0.8567	0.8343	0.8602
Overtime Interventional (m)	6.04	5.48	6.05
Idle Time Interventional (m)	37.69	39.51	36.90
Waiting Time Interventional - Level 1 (h)	0.4302	0.4252	0.4310
Waiting Time Interventional - Level 2 (h)	36.24	34.29	37.85
Waiting Time Interventional - Level 3 (d)	13.59	13.68	13.60
Waiting Time Interventional - Level 4 (d)	22.52	25.86	21.75
On Time Interventional - Level 1	65.56%	68.07%	65.84%
On Time Interventional - Level 2	71.34%	72.99%	69.75%
On Time Interventional - Level 3	59.45%	58.97%	59.43%
On Time Interventional - Level 4	97.10%	90.76%	98.41%
Cancellation Flexible Daypart	36.08%	20.00%	40.38%
Cancellation Slot	27.66%	-	17.53%

Table 11: Results of performance indicators under the scenario capacity planning - interventional dayparts with flexible daypart

8.2.2 Device Cardiologist

In the previous section, already satisfying results were found with six dayparts and a flexible daypart for the device cardiologists. While the on time service rate of the elective patients was really high, the rate for the non-elective patients could be better. Therefore, two flexible slots for elective patients are introduced; one on Thursday morning and one on Thursday afternoon. If the amount of patients hospitalized on Wednesday morning is equal or bigger than three, one patient is cancelled. If there are five or more non-elective patients, the second flexible patient is cancelled. The following variations where tested; (1) six dayparts with flexible daypart and flexible slots, (2) seven dayparts with flexible daypart and flexible slots and (3) same as variant 1, but time for elective patients on Thursday afternoon is 60 minutes instead of 150.

The results as presented in Table 12 are rewarding. For the first variation, in only 11% of the cases a patients' surgery was cancelled. This led to a significant increase in the on time service of non-elective patients while no significant disadvantage for elective patients was found compared to the policy without flexible slots (Table 10). With the introduction of two flexible slots if the amount of the amount of openings is seven, no significant improvement was achieved (variant 2), compared to the situation without the flexible slots. Compared to variant 1 and 3, variant 2 gives the best on time rates, but the utilization dropped quite much. Variant 3 resulted in a significant better on time service of non-elective patients, less cancellation of the flexible slots and less openings on Friday morning, but did go at the expense of the waiting time of the elective patients and the flexible daypart on Tuesday afternoon was needed more frequently. Hence, the policy to use in the upcoming scenarios will be variant 3.

Performance Indicators	Capacity allocation variations		
	6 (Var. 1)	7 (Var. 2)	6 (Var. 3)
Utilization Device	0.7635	0.6960	0.7454
Overtime Device (m)	3.02	2.35	2.99
Idle Time Device (m)	53.89	68.25	57.54
Waiting Time Device - Level 2 (h)	54.51	40.50	46.78
Waiting Time Device - Level 4 (d)	17.21	13.54	28.10
On Time Device - Level 2	55.69%	66.81%	61.68%
On Time Device - Level 4	96.45%	99.22%	75.88%
Cancellation Flexible Daypart	46.58%	60.01%	20.00%
Cancellation Slot	11.01%	5.13%	7.22%
Opening Daypart on Friday	54.85%	35.73%	41.26%

Table 12: Results of performance indicators under the scenario capacity allocation - device dayparts with flexible slots

As happens frequently in reality, last minute on Friday a device cardiologist should be called upon, which is accompanied by a lot of time spent on arranging this. Running the simulation with the Friday morning always being open during regular weeks, gave no satisfying results for the non-elective patients' on time rate. As the arrival of non-elective patients of device cardiologist is prone to fluctuation, the amount of non-elective patients on Friday is in a lot of the weeks just none. Last-minute arranging the opening on Friday is not ideal, but standard opening on Friday morning gives no improvement.

8.3 Patient Sequencing

For the patient sequencing three variations will be tested; (1) the current situation, handle patient according to a FCFS principle, (2) never schedule two surgeries which are not a CAG, parallel at the start of a daypart on CCR1 and CCR2 and (3) only schedule CAG procedures of elective patients in the morning. No significant changes could be found between the first and the second policy. Note, this is a logical finding since it happens only once or twice a week CCR1 and CCR2 are opened parallel. As most procedures are CAG's, the change of scheduling two non CAG's parallel at the start of the day is minimal. There was an improvement for the on-time rate of non-elective patients, but this improvement is probably because less elective patients where scheduled in the afternoon and not because of not scheduling CAG's in the afternoon. Despite the slightly better results for scheduling no CAG's in the afternoon, further modifications of the planning and scheduling policy are simulated with the restriction to never schedule two non CAG's parallel as it is known this way of working is preferred by staff members.

8.4 Holiday Weeks

For the scenario dealing with holiday weeks, no significant improvements where found. It was expected that assigning less elective patients during the holiday weeks, would result in a better on-time service for the non-elective patients. Contrary to expectations, only a minimal increase (70.56% vs 71.38%) was detected for the non-elective patients, while the on-time service for the elective patients dropped quite much (98.35% vs 93.61%). Moreover, the flexible daypart could be cancelled significantly less (41.14% to 28.73%). Therefore, no modifications are made with respect to the holiday weeks.

8.5 Surgery Length

In this scenario, the planned surgery length is adapted to the average surgery length found in the quantitative analysis. The currently used surgery length gives the best results on all performance indicators except for the on time of the device level 2 patients. Finding no improvement could be because the best modification of the previous scenarios have been chosen based on the currently used surgery length. The most common and biggest deviation between the currently used and surgery length modification are for procedures of the device cardiologists (see Appendix F.3). Therefore, it is a logical finding that changing the planned surgery length influences the patients of device cardiologists the most. Despite overall no better results were found, reevaluating the standard planned surgery length is highly recommended. The reevaluation should take place in cooperation with cardiologists and ILT staff. Special attention should be paid to the procedures performed by the device cardiologists.

8.6 Admission and Cancellation Rules

The results of the last scenario to be tested, the modifications of the admission and cancellation rules showed that loosing the admission and cancellation rules logically results in more overtime, but this is only slightly more. Allowing surgeries to be scheduled with an expected end time of 16:45 already improved the on time rate, for in particular the non-elective patients. The biggest improvements where found, especially for the device cardiologists' patients, if the admission was loosened to 17:00. It increased the on time service of the non-elective device patients even significantly with 10% and also made sure the Friday daypart needed to be open 15% less of the time, while the overtime increased, but not significantly. The on time rate for the priority level 2 patients of the interventional cardiologists' increased with 15% and the flexible slot was needed to be cancelled significantly less. Allowing six instead of five wires to be handled per daypart of the device cardiologist resulted in no noticeable improvement. This is a logical finding as the time restriction makes it almost impossible to schedule six wires in a daypart.

8.7 Summary

In Figure 32 the modifications simulated are presented once more, this time the best variations are encircled. For the scenarios holiday weeks and surgery length, there was no improvement found. Hence, the current policy was used for the scenarios following.

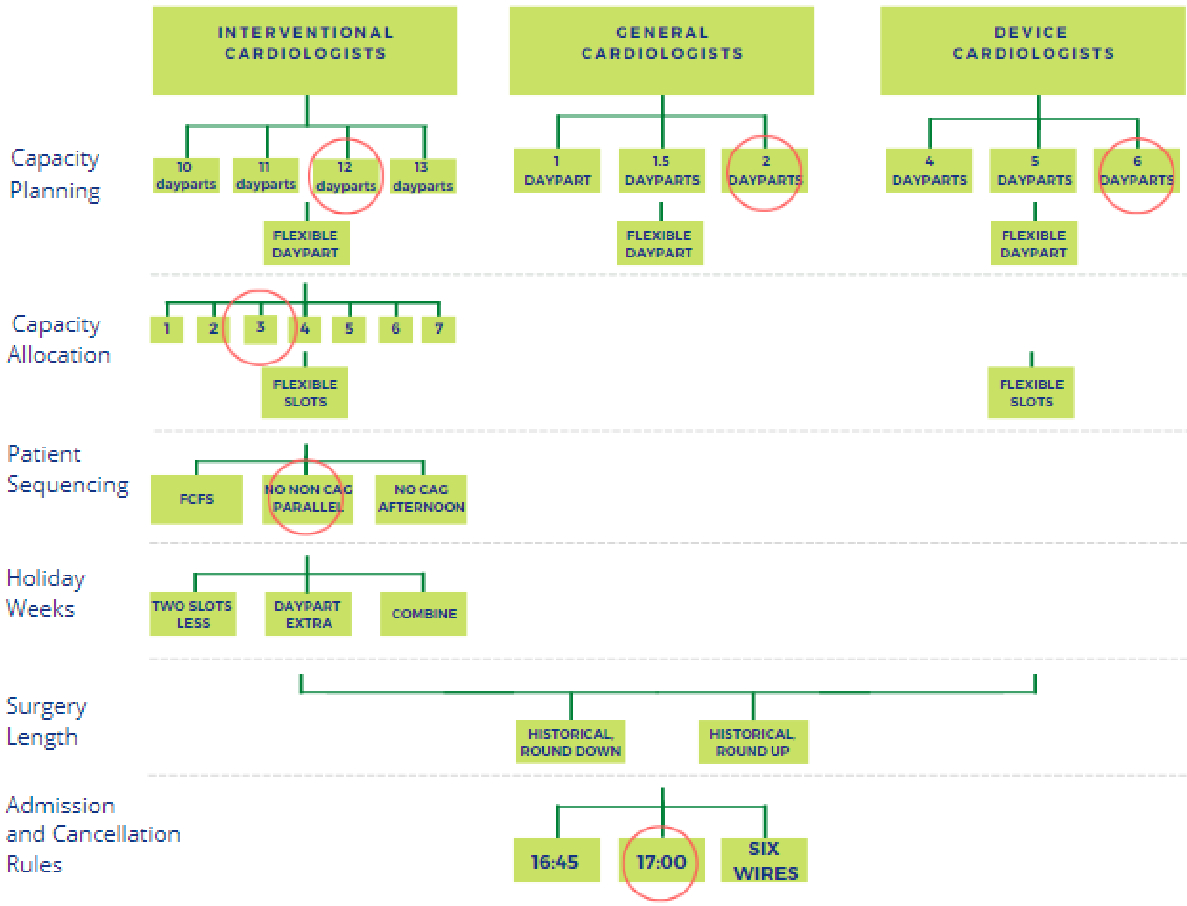

Figure 32: Scenarios for simulation

To summarize the finding of this chapter, optimal results per cardiologist type can be obtained by applying the following planning and scheduling modifications:

- *Interventional cardiologists*: Compared to the as-is situation, allocating more time to elective patients. Reserving three slots per week to priority level 3 patients, these flexible slots on Thursday are cancelled if there are too many patients hospitalized on Wednesday morning. If CCR1 is open allocate the complete daypart to elective patients. Stimulate a cardiologist working a complete day instead of two different cardiologists on CCR2.
- *General cardiologists*: Open two dayparts per week during regular weeks, one during holiday weeks. In approximately 40% of the regular weeks, one of the two dayparts can be closed when the amount of patients on the waiting list is limited.
- *Device cardiologists*: Loosen the admission rule till 17:00 and reconsider the planned surgery length of the procedures. As with the interventional cardiologists, the introduction of two flexible slots on Thursday and maximize cardiologists working a complete day.

In Table 13, the as-is situation is compared to the best policy. In the as-is situation, the opening of dayparts for interventional, general and device is 13, 6 and 2 respectively, while in the optimal situation it is 12, 6 and 2. Note, in the optimal situation, for all three cardiologist types, one of the dayparts is flexible and might be closed. Also, the allocation policy of the optimal policy is put to 17:00 instead of 16:30 and these results are compared to the as-is situation.

Performance Indicators	Planning and Scheduling Policies				
	As-is	Optimal	Difference	17:00	Difference
Utilization Interventional	0.7605	0.8539	+ 12.28%	0.8588	+ 12.93%
Utilization General	0.7766	0.9317	+ 19.97%	0.9317	+ 19.97%
Utilization Device	0.7412	0.7526	+ 1.54%	0.7759	+ 4.68%
Overtime Interventional (m)	4.35	5.96	+ 37.01%	11.31	+160.00%
Overtime General (m)	5.26	8.26	+ 57.03%	8.26	+ 57.03%
Overtime Device (m)	2.23	3.27	+ 46.63%	5.81	+160.53%
Idle Time Interventional (m)	57.14	38.22	- 33.11%	42.11	- 26.30%
Idle Time General (m)	52.17	22.59	- 56.67%	22.59	- 56.67%
Idle Time Device (m)	56.59	56.31	- 0.50%	54.07	- 4.45%
Waiting Time Interventional - Level 1 (h)	0.3688	0.4401	+ 19.33%	0.4458	+ 20.87%
Waiting Time Interventional - Level 2 (h)	16.38	34.19	+108.73%	16.23	- 0.92%
Waiting Time Interventional - Level 3 (d)	13.06	12.55	- 3.91%	12.55	- 3.91%
Waiting Time Interventional - Level 4 (d)	37.26	22.62	- 39.29%	21.56	- 42.14%
Waiting Time General (d)	6.88	21.67	+214.97%	21.67	+214.97%
Waiting Time Device - Level 2 (h)	52.69	47.23	- 10.36%	34.39	- 34.73%
Waiting Time Device - Level 4 (d)	33.07	28.66	- 13.33%	26.57	- 19.66%
On Time Interventional - Level 1	71.47%	66.65%	- 6.70%	67.58%	- 5.44%
On Time Interventional - Level 2	91.53%	72.99%	- 20.26%	90.91%	- 0.68%
On Time Interventional - Level 3	63.35%	65.63%	+ 3.60%	65.55%	+ 3.47%
On Time Interventional - Level 4	48.58%	96.53%	+ 98.70%	97.74%	+101.20%
On Time Time General	99.97%	94.02%	- 5.95%	94.02%	- 5.95%
On Time Device - Level 2	56.84%	58.36%	+ 2.67%	70.30%	+ 23.68%
On Time Device - Level 4	66.01%	74.17%	+ 12.36%	79.22%	+ 20.01%
Cancellation Flexible Daypart Int.	-	32.03%	-	35.44%	-
Cancellation Slot Int.	-	12.90%	-	2.15%	-
Cancellation Flexible Daypart Gen.	-	43.03%	-	43.03%	-
Cancellation Flexible Daypart Dev.	-	17.72%	-	21.01%	-
Cancellation Slot Dev.	-	8.99%	-	3.29%	-
Opening Daypart on Friday Dev.	44.90%	35.73%	- 20.42%	23.59%	- 49.69%

Table 13: Results of performance indicators under the as-is situation compared to the optimal situation

In the optimal scenario as presented above in Table 13, the amount of dayparts in comparison to the as-is situation is reduced, while the performance for almost all performance measurements increased drastically. The only negative effect in performance measures worth mentioning is the waiting time for the non-elective patients of the interventional cardiologists. However, by loosening the allocation criteria of the optimal policy to 17:00, the on time rate increased significantly, at the expense of overtime, though it increases efficiency.

In Chapter 3 the standard planning of the as-is situation was presented. In Figure 33 the weekly planning scheme is presented once more, but this time with the best performing policy according to the simulation results. In the scheme, the green slots present the flexible dayparts and the yellow ones the flexible slots. Note, if a flexible daypart is closed this means the CCR time is not used at all. While, if a flexible slot is closed, the surgery of an elective patient is cancelled and this time becomes available for non-elective patients.

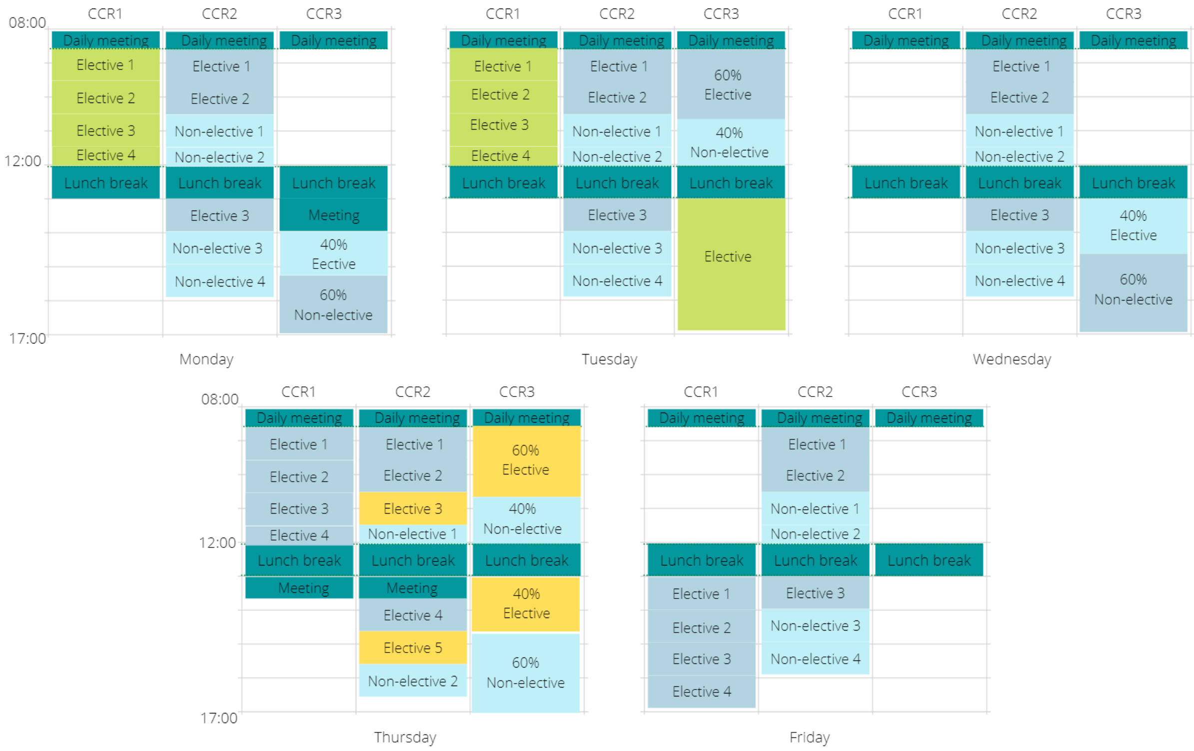

Figure 33: Recommended standard planning of elective and non-elective patients per week day

With the outcome of the simulation model the fifth and sixth question can be answered;

- *Subquestion 5: "How can data be used in improving the capacity planning and capacity allocation?"*
  Not only did data function as a reliable tool to get better insight in the past performance, it also gave insight into several relationship and causalities and supports decision making.
- *Subquestion 6: "What is the optimal policy for the scheduling of elective patients once the opening of the dayparts and the allocation of CCR time is fixed and how to deal with non-elective patients effectively?"*
  Throughout this chapter, the answer to subquestion six has been formulated. For each cardiologist type extensive research has been performed to find the optimal planning and scheduling policies. The best performing policy on cardiologist level differs. Overall, the current scheduling and planning policy is fixed and lacks flexibility, the introduction of more flexibility (flexible dayparts, flexible slots, scheduling a cardiologist a complete day) resulted in a far better performance.

9 Conclusions and Implementations

In this chapter an overview of this research is provided. The main insights and findings are summarized, moreover two concrete suggestions for implementations are formulated.

9.1 Conclusions

This research focused on the planning and scheduling policy of the CCRs, more specifically how they have performed in the past and what improvements could be made in the future. In Chapter 3 the research questions of this study have been introduced and which are summarized next.

The first four sub questions focus on the current scheduling policy, patient characteristics, capacity planning and capacity allocation. Hence, the overall functioning of the CCRs in the past. A qualitative analysis was conducted in combination with a quantitative analysis. A summary of the findings of the quantitative analysis as well as the answers to the first four sub questions have been formulated in section 5.5. After the analysis phase, it has been observed that decision making at the cardiology department is not data driven. Furthermore, the current planning and scheduling policy is static and lacks flexibility, which can and should be improved.

Important to mention is that during the research, the importance of validating the data was considered of utmost importance. With the complexity of the working environment, drawing conclusions from data without validating the data with medical staff is strongly discouraged. Also for future use of data, close cooperation between data staff and medical staff should take place for valuable and appropriate use of data. The fifth research question concentrates on the use of data in order to improve the capacity planning and capacity allocation. With the insights gained during the quantitative analysis, realistic scenarios for the simulation have been formulated and the last sub question could be answered in section 8.7. The findings per scenario tested in the simulation are discussed next.

Firstly, as can be concluded by the simulation model, promising results can be obtained with the opening of less dayparts per week compared to the as-is situation. Positive effects have been found with the implementation of (1) one flexible daypart per cardiologist type, which resulted in substantial improvement of the utilization of the CCRs and a stabilized waiting list and (2) maximizing cardiologists working a full day session, which has a positive effect on the amount of patients that can get their surgery and comes with more flexibility. Despite the beds on the DTC department being out of scope for this research, it would be good to align the evening openings of the DTC department with the openings of the CCRs. The standard opening of CCR3 on Friday morning during regular weeks compared to the situation in which it is only opened if there are still non-elective patients hospitalized was of no added value if the goal is to reduce the waiting time of the non-elective patients.

In the second scenario, the allocation of the capacity was tested. It is an insurmountable situation that demand is highly fluctuating and it is simply impossible to serve all patients on time if not operating 24/7. The question management should ask themselves is; what is the type of risk they are willing to take? Currently, the main focus is serving the non-elective patients on time, even though this might go at the expense of the on time service of elective patients. In line with the findings the research of Vissers and Beech (2005), the main learning points for the cardiology organisation is to rise above the level of ad hoc solutions for the short term and to investigate lasting solutions for the future. During busy periods, the natural reaction seems to be to schedule less elective patients in the period following. This phenomena can be explained by the fact that we tend to make decisions based on negative more than on positive information (Cacioppo et al., 2014). People consistently place greater weight on negative aspects of an event than they do on positive ones (Kahneman & Tversky, 1984). The negative experience of a busy week in which not all non-elective patients could be served as quickly as wanted, seems to lead to overcompensation in the weeks following if not in the overall decision making.

The most remarkable effects where obtained with (1) the introduction of flexible slots for patients of interventional and device cardiologist, which showed substantial improvements for the on time service of the elective patients and increased the utilization, with no significant disadvantage for the non-elective patients. Patients scheduled on the flexible slots only needed to be cancelled approximately 10% of the time. (2) If an interventional cardiologist is working on CCR1, with the current planning and scheduling policy three elective patients are treated so there is still time to serve a non-elective patient. However, treating a fourth patient under this policy happens only in 48.88% of the cases, whereas if four elective patients are scheduled in 82.74% of the time four patients are served.

Compared to the as-is situation, with the modifications of the capacity allocation as suggested throughout the study, the idle time could be reduced immensely for the interventional and general cardiologist (approximately 20 and 30 minutes less). Regardless of the amount of dayparts available and capacity allocation policy, the idle time of CCR3 remains quit much and the on time service of the non-elective patient is not as high as wanted. The relatively long procedure lengths make it hard to fit the surgeries, resulting in a lower utilization rate than aimed for. Thereby, the arrival rate of patients for non-elective device cardiologists is substantially wide spread.

In this research it has not been proven that applying a different policy for the scenarios patient sequencing, holiday weeks and surgery length leads to improvements. However, for patient sequencing it is recommended not to schedule two non-CAG procedures on parallel on CCR1 and CCR2, as this gives (a perception of) flexibility to cover emergency patients. Despite that there was no consequent improvement with a different planned surgery length, it is recommended to reconsider them, especially for the device cardiologist.

Lastly, by varying the admission and cancellation rules, significant improvements were obtained regarding the on time service of patients. If surgeries where allowed to be scheduled with an expected end time of 17:00 instead of 16:30, an 24.56% increase in the on time service of non-elective patients of interventional cardiologists was obtained and an increase of 20.46% for the non-elective patients of device cardiologists, while the over time increased with just 5.35 and 2.54 minutes respectively. According to internal policy, only five wires are allowed to be scheduled per daypart. The research showed that loosening this restriction to six wires makes no difference if the planning and scheduling policy is time based, since only a small amount of procedure combinations can be made in which five wires are treated in one daypart.

9.2 Implementations

The main difference between the as-is situation and the improved capacity planning is that less capacity should be made available and some capacity should be made flexible. Flexibility can be created by (1) the introduction of flexible dayparts, (2) planning cardiologists working a full day session and (3) the introduction of flexible slots. Furthermore, if ETZ wants to open more capacity for non-elective patients, it is recommended to open an extra daypart on Monday (afternoon) as the arrival of non-elective patients is highest at the beginning of the week. In other words, align capacity and demand, smoothing out the workload over the week. Moreover, standard reserving three slots per week for priority level 3 patients should tackle the requests for short term surgeries of elective patients. With the redistribution of capacity, the time CCRs are open is used more efficiently which goes hand in hand with cost savings.

In order to improve the scheduling and planning policy, the introduction of priority classes is a must, as the recommended scheduling policy follows different rules per patient priority class. By standardizing this, a more unambiguously and efficient work environment will be created and analyzing data will be easier. As in the simulation, it is recommended ranging the patients on the waiting list according to their priority level in combination with FCFS.

10 Limitations and Recommendations

This last chapter discusses the limitations of this research. Moreover, the limitations will guide direction for future research. This study ends with highlighting four recommendations.

10.1 Limitations

In total seven limitations have been identified, which are reflected upon next, in more detail.

- **Practical Environment**
  Although this research is innovative regarding the research goal, it strictly took into account the organizational constraints communicated, leading to a local optimization. Loosening these practical restrictions could have led to a more global and scientific optimization.
- **Data Quality**
  The researcher worked with real-life data provided. During the research, the data files have been merged manually, for which lots of assumptions had to be made. Assumptions made were always in cooperation with ETZ staff, reflecting reality as close as possible. But, some aspects were fairly difficult to make unambiguous assumptions about due to administrative inconsistencies. On patient level administrative errors could be found, but were hard, if not impossible, to find on a large scale.
- **Staff Availability**
  The scope of this research was limited to the availability of the cardiologists, leaving out the availability of other critical employees such as the ILT staff members and pacemaker-technicians. Future studies might benefit of incorporating all types of critical staff as a potential bottleneck.
- **Individual Performance**
  During this study, the performance of cardiologists on an individual level was not taken into account. Mapping these differences and making these differences open for discussion could lead to more efficiency. A more accurate planning and scheduling policy could be created if the expected surgery length is adapted to the historic performance of an individual cardiologist. Moreover, it was brought to notice whether or not a surgery is being ordered is highly depending on the cardiologists who sees and therefore judges a patient's medical condition. For future research it would be interesting to see if this is actually the case and what the motivations are for cardiologists to order a surgery or not.
- **Other Departments**
  The scope of this research is limited to the CCR, neglecting the impact of decision making on other ETZ departments. The CCR has a central role in the hospital, as many departments are depending on it. In future research, having a broader scope would be valuable for the hospital wide efficiency.
- **Seasonal Influence**
  In this study no seasonal influences have been taking into account. There was made a distinction between regular and holiday weeks. However, returning patterns of fluctuations on a monthly base have been identified during the quantitative study. Therefore, in cooperation with a person with medical knowledge should be investigated on more detailed level if there is a (medical) explanation for this fluctuation. If so, adapt the planning and scheduling policy to this returning pattern. This could lead to more and different variants in planning and scheduling policies than the ones suggested in this research.
- **Costs**
  Even though for decision making, costs is one of the important performance measurements, these have not been included in the simulation. Despite no exact numbers are included, some effects on finances can be retrieved from the research. The exact financial interests in the hospital are extremely complex and therefore out of scope for this research.

10.2 Recommendations

Finally, we would like to make the following recommendations to ETZ:

- **Data Registration**
  Observations brought to notice the inconsistency of the way of working throughout the various departments related to the CCR. For some topics, it seems to be unclear whom is responsible for and how certain things should be registered correctly. Therefore, it is recommended for management (in collaboration with data staff), to define who is responsible for which administrative task and how the responsible staff should register these tasks correctly. For mandatory data, it should be insured that a pop-up appears. If implemented, this should be communicated thoroughly to all departments involved, leading to an unambiguous way of working.
- **Surgery Length**
  For as long as known, the scheduled surgery lengths have remained unchanged. It is recommend for management to sit down with ILT staff and cardiologists and have a close look at these scheduled times. Moreover, it would be more beneficial if the request for additional time would be a build in feature in the surgery request form in the software system and the system automatically processing this. Furthermore, there are procedures which cannot be booked as they are no part of the procedure category. Subsequently, these have to be ordered as if they were a different procedure, resulting in poor data quality. Hence, these procedures need to be introduced into the system.
- **Planning Policy**
  Interfering with the planning, mostly with good intentions or out of need, happens on a daily basis. This should be tried to avoid, as it causes unnecessary additional work. If decided upon a new planning and scheduling policy, it is highly recommended to communicate this policy with all staff members involved, leaving no room for personal interpretation.
- **Dashboard**
  For this research, the data first needed to be downloaded, saved as input files and assumptions about the linking of data needed to be made. It would be faster and more accurate to link the data in the software system. Even better, would be the introduction of a real-time dashboard, which helps to monitor the healthcare KPI's in a dynamic and interactive way. A dashboard aims to give a holistic view of analytics data with global insights to enhance the decision-making process. It would enable the hospital to increase its overall performance, also has a positive effect on patient satisfaction and costs.

In Appendix L the extensive overview is provided with additional work-related recommendations.

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Appendices

A Cardiologists Specialism

Cardiologist	Specialisation	Sub-specialisme
Dr. A	Intervention cardiologist	-
Dr. B	Intervention cardiologist	CTO, IVUS, Rotablator
Dr. C	Intervention cardiologist	CTO, IVUS
Dr. D	Intervention cardiologist	-
Dr. E	Intervention cardiologist	-
Dr. F	Device cardiologist	-
Dr. G	Device cardiologist	ICD, S-ICD
Dr. H	Device cardiologist	ICD
Dr. I	Device cardiologist	ICD
Dr. J	General cardiologist	Rechts katheterisatie
Dr. K	General cardiologist	-
Dr. L	General cardiologist	-
Dr. M	General cardiologist	-

Table 14: Cardiologists with their specialism and sub-specialism

All cardiologists can perform a Venogram and Pericardpunctie. For this procedure a cardiologist is not even necessary, the ILT staff could perform this procedure. Rechts katheterisatie is always performed by Dr. J., since this is his speciality. Only if he is not available, an intervention cardiologist will perform this procedure.

All intervention cardiologists can perform: CAG, FFR, PCI, Rechts kathetherisatie
All device cardiologists can perform: ILR, PM
All general cardiologists can perform: CAG (if simple procedure)

B General Cardiologist Needs Assistance of Interventional Cardiologist

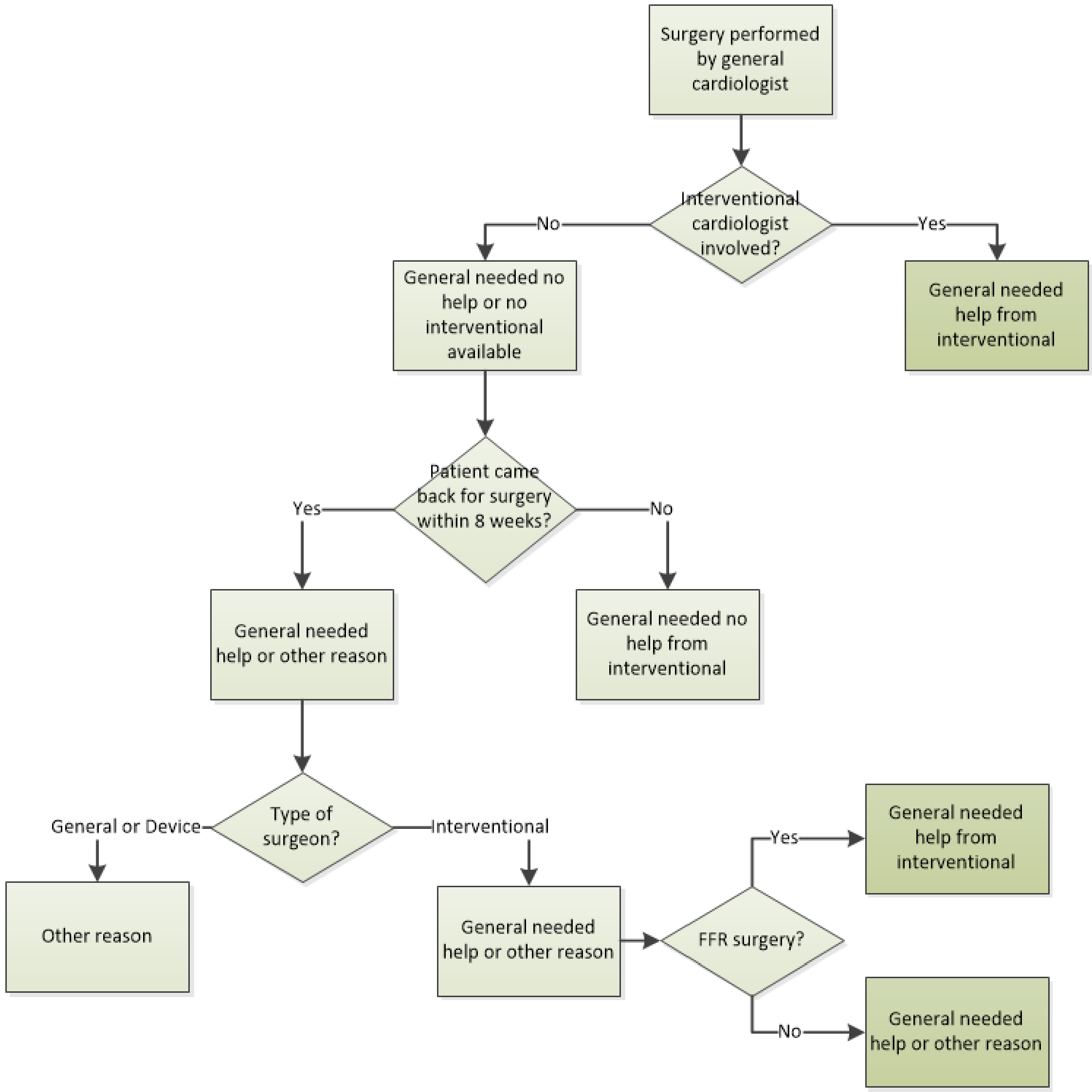

Figure 34: Decision tree if general cardiologist needed assistance of interventional cardiologist

C Opening Slots CCRs

CCR	Mon-m	Mon-a	Tue-m	Tue-a	Wed-m	Wed-a	Thu-m	Thu-a	Fri-m	Fri-a
CCR1	X		X	X			X	X	X	X
CCR2	X	X	X	X	X	X	X	X	X	X
CCR3		X	X		X	X	X	X		

Table 15: Basis opening slots (morning - afternoon) CCRs

D Standard Durations Planned

Surgery Type	CCR	Duration Planned	Leave or Stay?
CAG	1/2	45	L
FFR	1/2	60, 60	L
IVUS	1/2	60	S
OCT	1/2	60	S
PCI	1/2	60, 60, 60 150, 60, 60, 60, 120	S
Rechts katheterisatie	1/2	45	L
Rotablator	1/2	60	S
Pericardpunctie	1/2/3	45	S
ICD	3	60, 45, 75, 45, 150, 45, 45, 150, 90	L/S
ILR	3	30	L
PM	3	60, 45, 75, 45, 150, 45, 45, 45, 150, 90	L/S
S-ICD	3	120, 45	L/S
Venogram	3	30	L

Table 16: Surgery types with the CCR on which they can be performed and the standard duration planned in minutes

Sometimes for a surgery type multiple values for duration planned are given. These represent variations in procedures which belong to a same surgery type. For column leave or stay, an L indicates the patients leaves the same day. A treatment which makes patients to stay overnight are marked with an S.

E Data Elements

1. Surgeries performed on the CCRs
    - Patient ID (anonymized)
    - Session ID
    - Patient type
    - Ordered surgery type / Medical discipline
    - Amount of surgery types performed
    - CCR
    - Planned and actual surgery start and end time
    - Arrival time in hospital
    - Surgery performed during regular CCR opening hours
    - Surgery performed on holiday day
    - Emergency
    - Time closing blood vessel
    - Time stitching
    - Time enters via sluice
    - Time leaves via sluice
2. Patients waiting list for a CCR surgery
    - Patient ID
    - Session ID
    - Surgery type / Medical Discipline
    - Date patients order is created in the system
    - Date patients surgery is planned
    - Date surgery is removed
    - Date procedure is performed
3. Patients who had an appointment at the outpatient clinic

- Patient ID
- Date

4. Patients who were discussed during an MDO
    - Patient ID
    - Date

5. Patients movements in the hospital
    - Patient ID
    - Patient type
    - Treating specialty
    - DBC code
    - Current, previous and next department location
    - Start and end time on location

6. Cardiologist(s)s who performed a CCR surgery
    - Cardiologist
    - Head cardiologist
    - Surgery type(s) performed
    - Session ID

A couple of elements the researcher requested could not be delivered:
1. Opening of the CCRs. There is no data available whether a CCR was open in the morning or afternoon and which cardiologist was scheduled on this daypart. Therefore, the assumption is made that if a surgery took place on a CCR during standard opening times, the CCR was open during this daypart.
2. The reason for rescheduling is not always recorded accurately. If a surgery is put back on the waiting list or moved to a later moment in time, the reason for rescheduling is often not filled in accurately. Was the surgery moved to next day because the cardiologist was tired? Or because the nurses forgot to stop the medication of the patient on time? Or was the patient sick? Though the system gives various options as rescheduling reason, the planners almost always enter 'other'.
3. Patients are put back on the waiting list. Sometimes patients are put back on the waiting list without the reason for this being communicated. This can make the time between an operation being requested and actually performed seem quite long. As the reason for putting a patient back on the waiting list is not recorded, it is hard to draw conclusions about this phenomenon.
4. Reason for second surgery. It is not always registered why a patient needed to come back for a second surgery. Reasons could have been for example because his/her case first needed to be discussed in an MDO or because there was no interventional cardiologist available to step in on the surgery of a general cardiologist.

F Additional Information Quantitative Analysis

F.1 Data Assumptions

Patient Type

In order to find the correct patient type, first some indicators where created. Each patient either met the criteria for such an indicator or s/he did not.
1. Movement. Patient whom during their stay were first located at the daycare department and then moved to the cardiology department (inpatients).
2. Ambulance. Patients whom arrived at the hospital per ambulance.
3. EHH/SEH. Patients that arrived either via the SEH or EHH.
4. Elisabeth. Patients that have been on the Elisabeth location before their surgery.
In the data two patient type indications are coupled to one surgery. The first patient type is the one linked to the request, the second patient type is linked to the patients' movements in the hospital. Most of the time, the patient type of the request and the patient type of the patients' movement are the same, but this is not always the case. With the help of the indicator movement, the inflow location, the two patient types and professionals opinions per surgery of a patient type was established. It was also agreed upon that if a patient is marked as elective or non-elective, only the patient type 'Clinical' is a non-elective patient. The seven different patient types are described in F.2.

Start end End Time Surgery

Epic automatically registers the start and end time of a surgery if the required data is present. In 11% of the surgeries, no end time was registered. Epic takes the registered time of 'Patient enters room' and 'Patient leaves room' as start and end time. But this is not a time that is required to be filled in which explains the missing data. If everything would be registered correctly, the order of registration would be: arrival time sluice, patient enters room, close blood vessel/stitching, patient leaves room and leave time sluice. In principle, a patient will only enter via the sluice if the CCR his/her surgery will take place on is free. So, the time between arrival time sluice and patient enters room should be minimal. The time between closing blood vessel/stitching and patients leaving the room/leave via sluice is the time to move the patient from the operating bed to his/her normal bed and to wait for the nurses to come and pick up the patient. If the patient needs to wait to be picked up this can either be in the CCR itsself or in the hallway. In order to find the correct start ('Enter Time') and end time ('Leave Time') of the surgery, the researcher made the following assumptions:
- If start time Epic < arrival time sluice, the 'Enter Time' is the start time Epic. Otherwise, the 'Enter Time' is the arrival time sluice.
- If the end time Epic < leave time sluice, the 'Leave Time' is the end time Epic. Otherwise, the 'Leave Time' is the leave time sluice.
- If there is no end time Epic registered, the leave time sluice is the 'Leave Time'.
- If there is no end time Epic registered and no leave time sluice, the 'Leave Time' is the time of close blood vessel (+ 11 minutes) or stitching (+17 minutes). The 11 and 17 minutes are the average times between closing blood vessel/stitching and the leave time sluice.
- If there is no end time, no leave time sluice and no time for close blood vessel or stitching, the 'Leave Time' is the 'Enter Time' plus the planned surgery length.

F.2 Patient Types

Resulting from the mentioned data inconsistency in Chapter 5, seven patient types where identified. The different patient types used in the analysis are:
- Clinical: Patients which were hospitalized when surgery took place.
- Daycare: Patients who stay in the daycare department and leave the hospital the same day.
- DayMove: Daycare patients which moved from the daycare to the cardiology department but did not stay the night.
- DayClinical: Daycare patients which moved from the daycare to the cardiology department and stayed the night.
- DayClinicalOther: Daycare patients which moved from the daycare to a different department than the cardiology and stayed the night.
- DayOther: Daycare patients which were located at a different department than the daycare department.
- DayHistory: Before the daycare department existed, daycare patients where located at the cardiology department.
- Hospitalized: Clinical patients with a waiting time longer than seven days, which are assumed to be elective patients initially

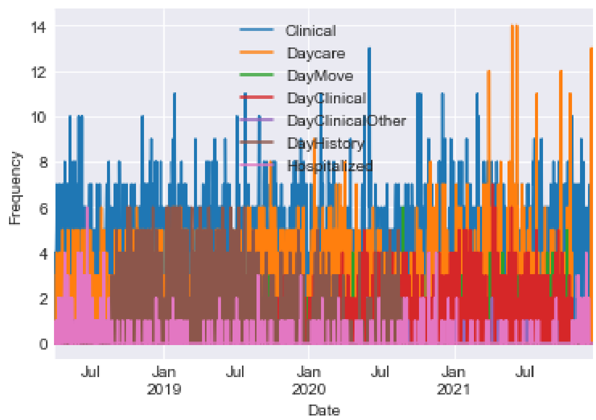

Figure 35: Amount of patients per patient type that got a surgery over time

Earlier, all daycare and inpatients where located at the cardiology department on two specific rooms. Later, the daycare department was created and the daycare and inpatients where located over here. Only the inpatients where moved at the end of the day to the cardiology department. In order to find which patients have been inpatients in the past, the data was checked if a patient first had been located on the daycare department and later that day was moved to the cardiology department (indication Movement). However, this indication could not be applied to the previous situation where all daycare and inpatients where always located on the cardiology department. Therefore, elective patients who stayed in the two specific rooms on the cardiology department got the patient type "DayHistory". Figure 35 shows that these DayHistory patients appeared in the period of 2018 till half 2020. From that moment on, patient get the label DayClinical. Only patients with patient type 'clinical' are non-elective patients, all others are elective patients. Within the clinical patients a distinction can be made between emergency and urgent patients. Emergency patients have the value 'Yes' for the indication 'Emergency', while urgent patient consist of 'No'.

F.3 Surgery Types

Surgery Type	Amount Ordered	Amount Performed	Standard Duration	Average Length and Standard Deviation
Afgebroken procedure cardiovasculair	43	48	-	42.79 (19.60)
Afgebroken procedure elektrofysiologie	5	5	-	43.20 (18.27)
Aortaboog	2	5	45	54.50 (6.36)
Catheterisatie linker en evt. rechter hart	6.338	6.409	45	51.16 (22.14)
Catheterisatie rechter hart	72	79	45	58.83 (17.37)
CFR/IMR/FFR	7	16	60	58.43 (6.37)
Fractional Flow Reserve	333	1.441	60	59.18 (22.58)
IABP plaatsen	1	1	60	39.00 (0.00)
ICD (1 kamer) - Implementatie incl. elektroden	68	69	60	75.54 (15.73)
ICD (1 kamer) - Wissel exlc. elektroden	30	30	45	55.53 (14.50)
ICD (2 kamer) - Implementatie incl. elektroden	93	94	75	93.88 (29.83)
ICD (2 kamer) - Wissel exlc. elektroden	40	40	45	64.50 (31.65)
ICD (3 kamer) - Implementatie incl. elektroden	73	73	150	145.86 (33.05)
ICD (3 kamer) - Wissel exlc. elektroden	40	40	45	60.32 (20.37)
ICD (3 kamer) - Upgrade	34	35	150	126.53 (30.41)
ICD verwijderen zonder terugplaatsing	4	5	45	80.00 (16.35)
ILR implementatie	264	266	30	32.20 (23.49)
ILR verwijderen	138	202	30	36.47 (13.76)
Index of microcirculatory resistance	14	28	60	63.50 (17.06)
Intravasculair ultrasound	6	34	60	78.17 (26.10)
Linker ventrikel angiografie (LV-angio)	3	12	-	33.00 (10.82)
Optical coherence tomografie	18	122	60	76.94 (21.28)
PCI - Ad-hoc	7	432	60	77.00 (26.42)
PCI - CTO	121	128	150	122.26 (37.80)
PCI - Eentak	755	852	60	65.28 (32.03)
PCI - Graft	28	36	60	70.04 (19.87)
PCI - Hoofdstam/meertaks	298	321	60	78.28 (26.28)
PCI - N-stemi/instabiele AP	77	940	60	57.19 (21.59)
PCI - Stemi	768	773	60	49.40 (23.35)
Pericardpunctie op HCK	36	36	45	47.39 (13.19)
PM (1 kamer) - Implementatie incl. elektroden	101	107	60	66.92 (14.82)
PM (1 kamer) - Wissel exlc. elektroden	90	91	45	51.71 (11.27)
PM (2 kamer) - Implementatie incl. elektroden	777	783	75	81.56 (17.87)
PM (2 kamer) - Wissel exlc. elektroden	296	296	45	54.45 (15.05)
PM (3 kamer) - Implementatie incl. elektroden	43	43	150	136.91 (39.83)
PM (3 kamer) - Wissel exlc. elektroden	35	35	45	54.80 (20.98)
PM (3 kamer) - Upgrade	15	15	150	107.27 (32.62)
PM verwijderen zonder terugplaatsing	8	9	45	51.13 (12.18)
Reparatie/repositie pacemaker elektrode	63	64	45	83.86(31.32)
Revisie sbucutane pocket	18	20	90	65.11 (19.48)
Rotablator	15	19	60	122.80 (23.41)
S-ICD implementatie	28	28	120	105.93 (18.58)
S-ICD-wissel	4	4	45	76.50 (10.38)
Shockwave	9	41	120	108.67 (46.85)
Uitwendige pacemaker aansluiten	80	144	45	36.65 (16.92)
Venogram	70	157	30	31.41 (35.61)

Table 17: Amount of times each surgery type was ordered, actually performed and its average length

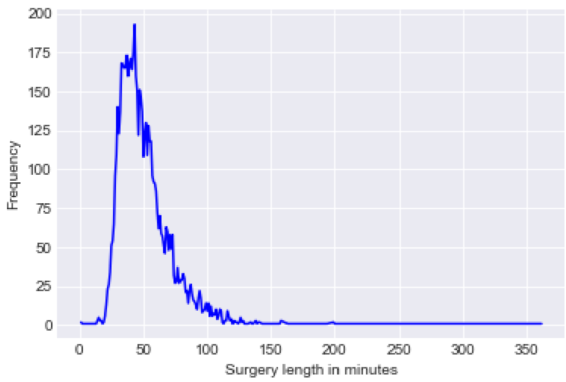

Figure 36: Surgery length of a CAG procedure

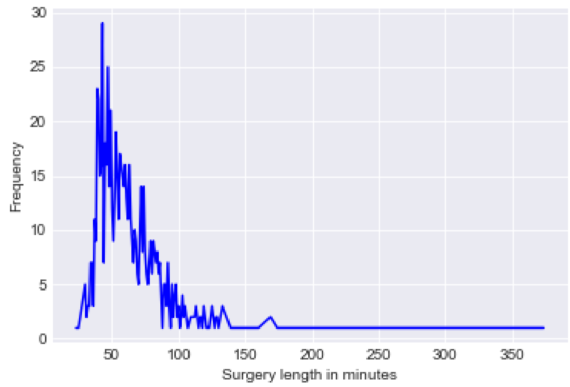

Figure 37: Surgery length of a PCI - Eentak procedure

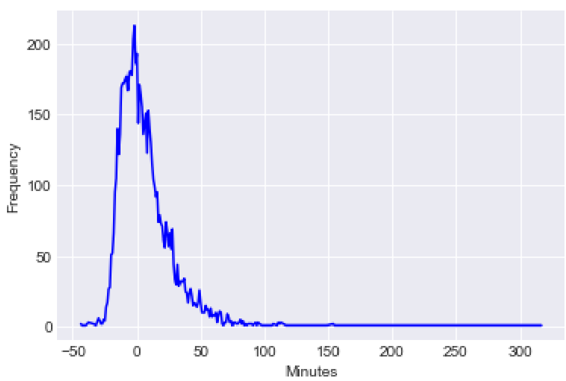

Figure 38: Difference between actual and planned surgery length in minutes with a planned time of 45 minutes

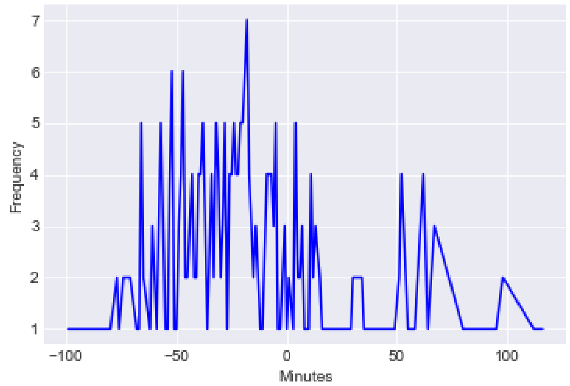

Figure 39: Difference between actual and planned surgery length in minutes for surgeries with a planned time of 150 minutes

F.4 Surgery Amounts

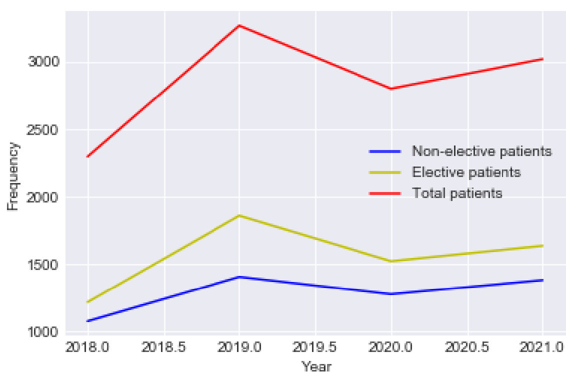

Figure 40: Amount of surgeries performed per patient type per year

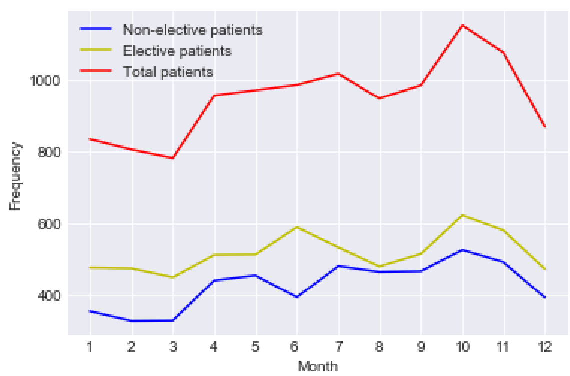

Figure 41: Amount of surgeries performed per patient type per day

Note, Figure 40 and 41 show the total amount of surgeries. The data starts on 30-03-2018 and ends at 15-12-2021, so some data in the year 2018 and 2021 is missing.

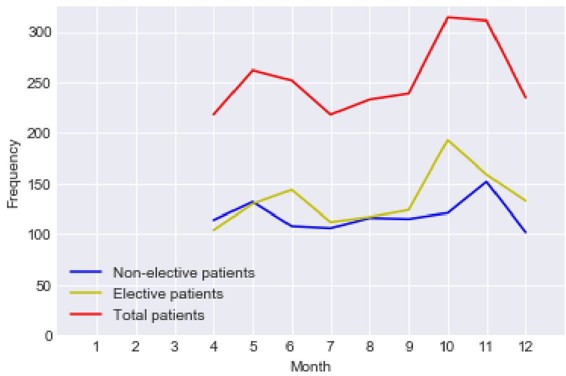

Figure 42: Amount of surgeries performed per patient type per month in 2018

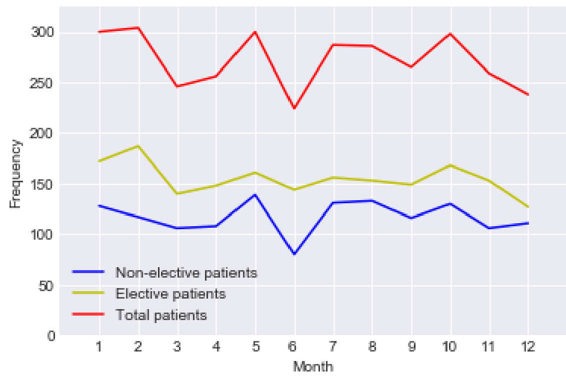

Figure 43: Amount of surgeries performed per patient type per month in 2019

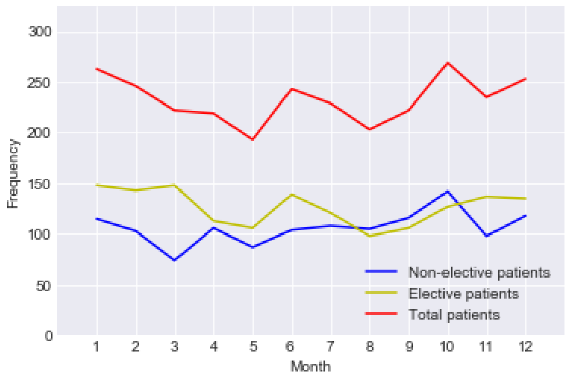

Figure 44: Amount of surgeries performed per patient type per month in 2020

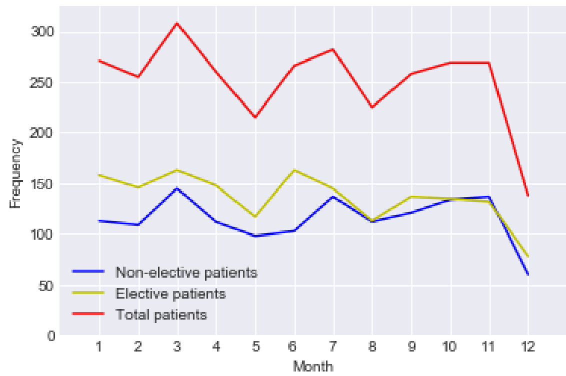

Figure 45: Amount of surgeries performed per patient type per month in 2021

Day	Total	Elective Patients	Non-elective Patients
Monday	973	1,093	2,066
Tuesday	942	1,400	2,342
Wednesday	902	1,133	2,035
Thursday	1,067	1,490	2,557
Friday	900	1,115	2.015
Saturday	169	0	169
Sunday	185	0	185

Table 18: Amount of surgeries performed per day per patient type

F.5 Time of Surgery

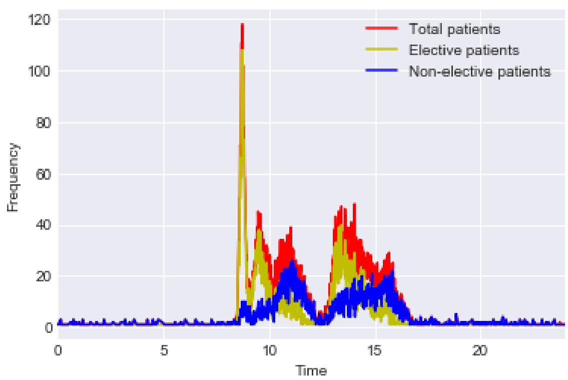

Figure 46: Time at which surgery started during the day per patient type

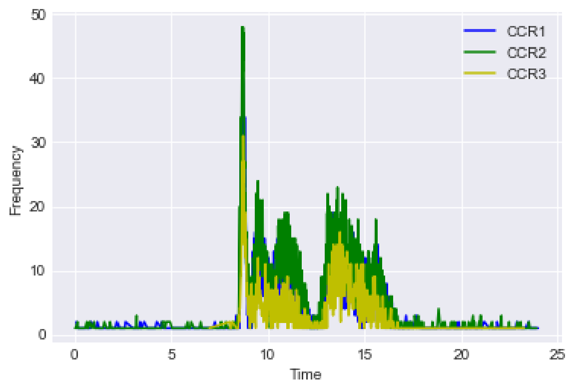

Figure 47: Time at which surgery started during the day per CCR

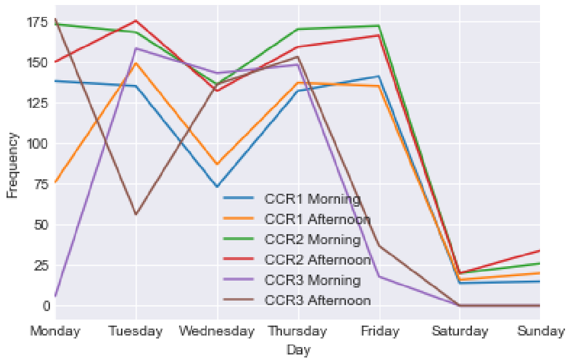

Figure 48: Amount of openings of the CCRs per daypart per day

Figure 49: Occupancy over a whole day

Day	CCR1-Mor	CCR1-Aft	CCR2-Mor	CCR2-Aft	CCR3-Mor	CCR3-Aft
Monday	138	76	173	150	6	176
Tuesday	135	149	168	175	158	56
Wednesday	73	87	136	132	143	136
Thursday	132	137	170	159	148	153
Friday	141	135	172	166	18	37

Table 19: Amount of times a daypart was open per CCR

Figure 50: Amount of dayparts open per week in 2018

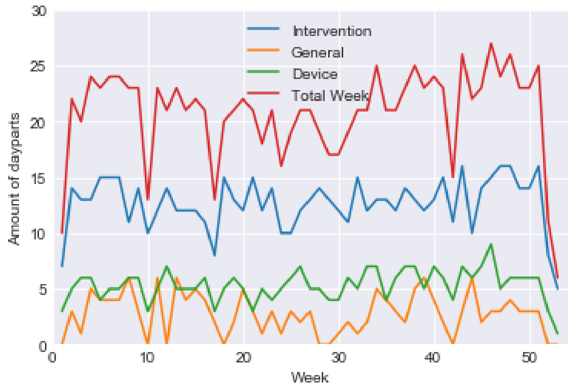

Figure 51: Amount of dayparts open per week in 2019

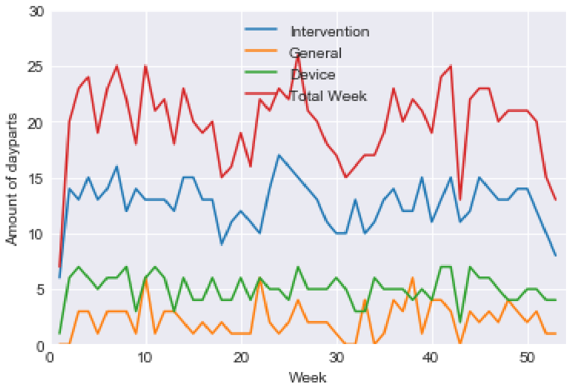

Figure 52: Amount of dayparts open per week in 2020

Figure 53: Amount of dayparts open per week in 2021

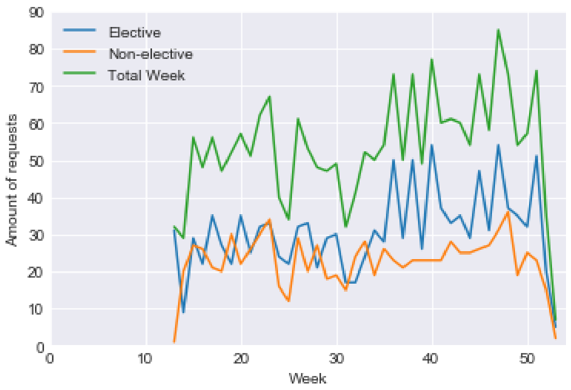

Figure 54: Amount of surgery requests per week in 2018

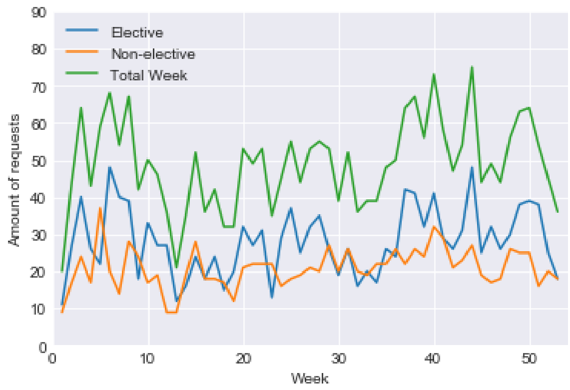

Figure 55: Amount of surgery requests per week in 2019

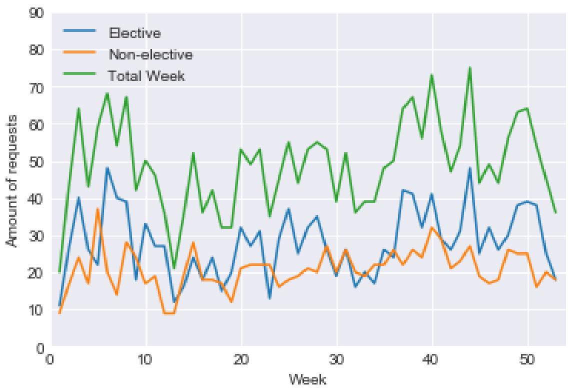

Figure 56: Amount of surgery requests per week in 2020

Figure 57: Amount of surgery requests per week in 2021

Day	CCR1-Mor	CCR1-Aft	CCR2-Mor	CCR2-Aft	CCR3-Mor	CCR3-Aft
Monday	75.07%	64.40%	80.03%	66.29%	48.65%	63.10%
Tuesday	79.25%	60.99%	79.16%	60.81%	78.44%	54.86%
Wednesday	94.56%	68.47%	92.41%	68.42%	84.70%	65.51%
Thursday	79.59%	59.01%	83.59%	60.31%	75.47%	66.50%
Friday	79.66%	60.58%	84.42%	63.62%	38.68%	42.68%

Table 20: Percentage of time used per daypart per CCR

F.6 Waiting Time

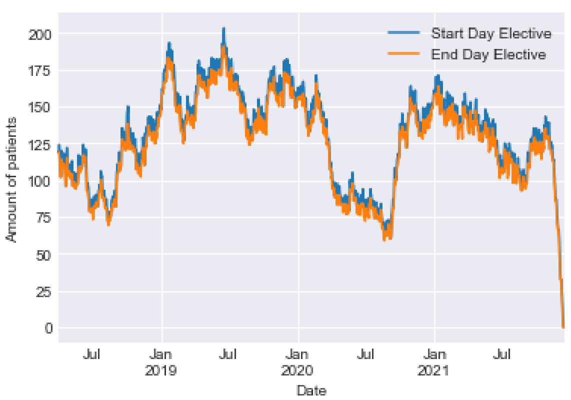

Figure 58: Amount of elective patients on the waiting list for a surgery

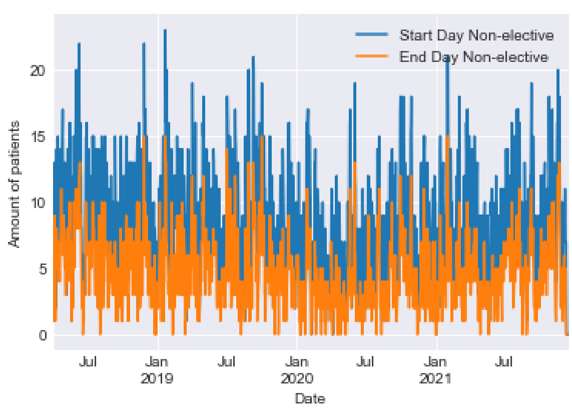

Figure 59: Amount of non-elective patients on the waiting list for a surgery

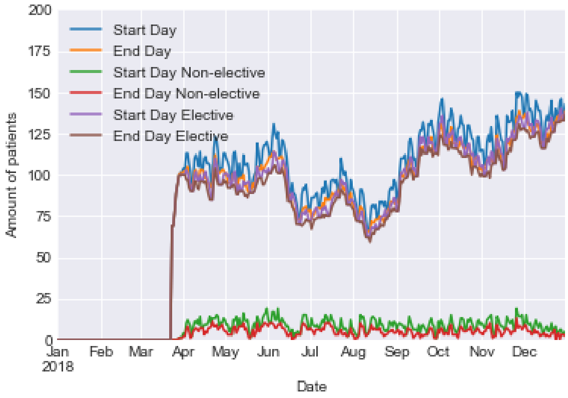

Figure 60: Amount of patients on waiting list in 2018

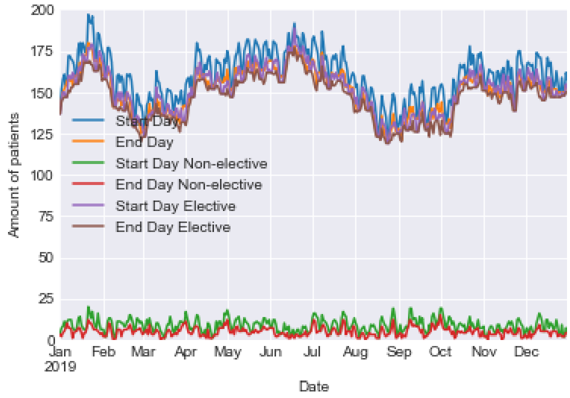

Figure 61: Amount of patients on waiting list in 2019

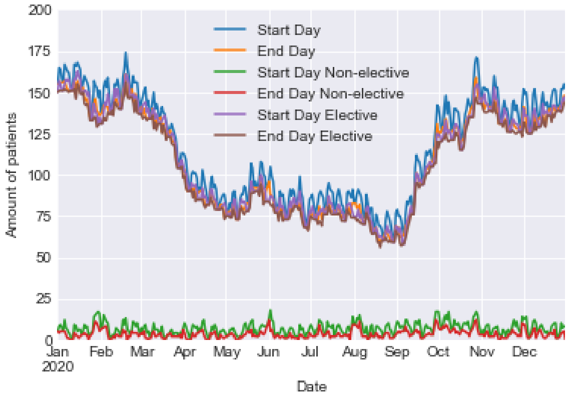

Figure 62: Amount of patients on waiting list in 2020

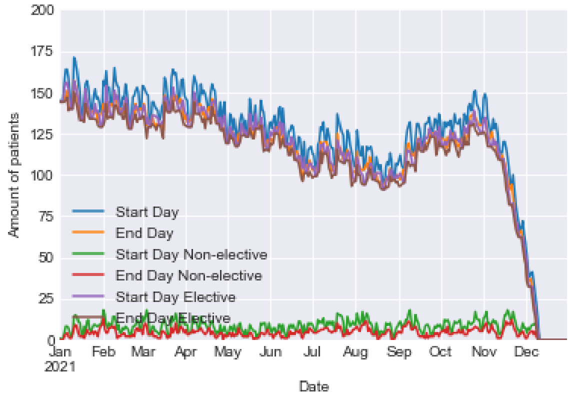

Figure 63: Amount of patients on waiting list in 2021

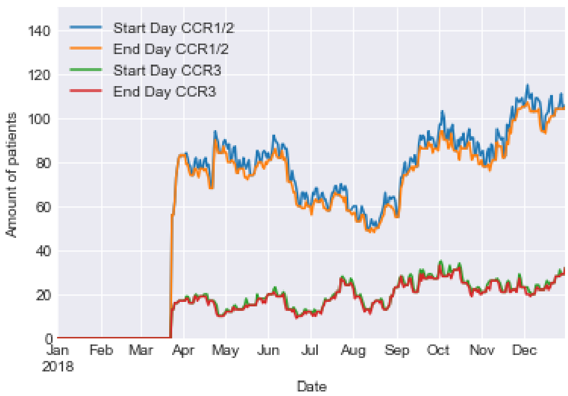

Figure 64: Amount of patients on waiting list per CCR in 2018

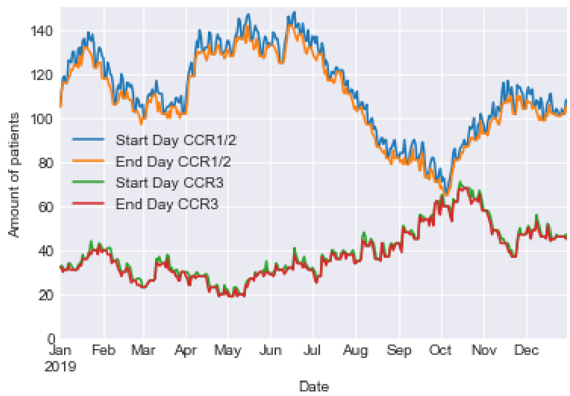

Figure 65: Amount of patients on waiting list per CCR in 2019

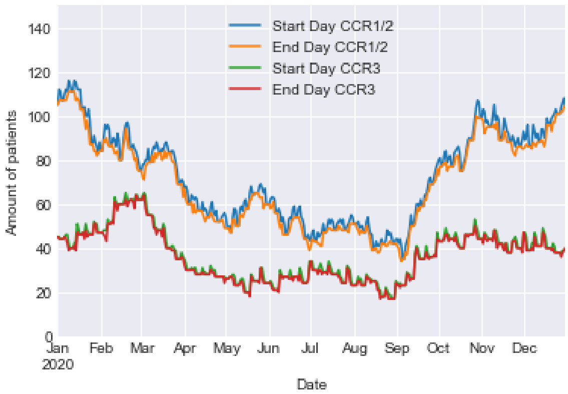

Figure 66: Amount of patients on waiting list per CCR in 2020

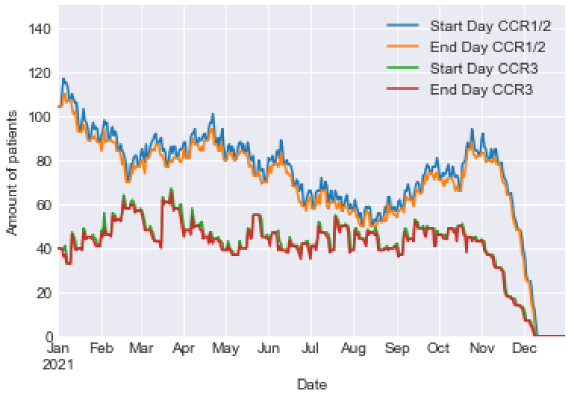

Figure 67: Amount of patients on waiting list per CCR in 2021

Year	Interventional	General	Device	Overall
2018	21.29	18.84	19.73	20.50
2019	27.58	29.46	29.87	28.49
2020	24.05	20.68	35.11	26.43
2021	24.04	21.02	37.47	27.22

Table 21: Average waiting time for elective patients in days per cardiologist type per year

Year	Interventional
2018 - No MDO	22.93
2018 - MDO	16.92
2019 - No MDO	29.76
2019 - MDO	23.16
2020 - No MDO	25.74
2020 - MDO	20.85
2021 - No MDO	25.86
2021 - MDO	19.44

Table 22: Average waiting time for elective patients (MDO or not discussed in MDO) in days per year

F.7 Patient Flow

Department	Elective	Non-elective	Total
Elisabeth	1	42	43
T EHH	1	883	884
T CCU	259	904	1,163
T Daycare	4.311	5	4,316
T IC	0	37	37
T Cardiology	1,575	3,115	4,690
T Other department	8	9	17
Unknown	76	143	219

Table 23: Direct inflow location of elective and non-elective patients

F.8 Cardiologists

Amount of surgeries	CCR1/2 One cardiologist	CCR1/2 Two cardiologists	CCR3 One cardiologist	CCR3 Two cardiologists
1	1	80	1	3
2	16	34	8	8
3	35	56	13	42
4	79	61	23	54
5	145	105	17	59
6	242	93	12	16
7	208	67	7	10
8	88	31	0	5
9	19	6	1	0
10	5	0	0	3
11	1	0	0	0

Table 24: Amount of surgeries performed if a CCR was open both in morning and afternoon

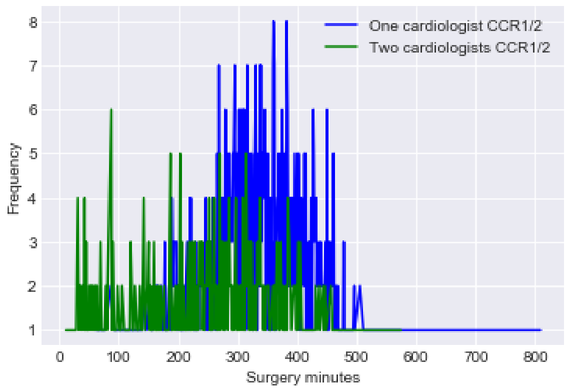

Figure 68: Total surgery length if CCR1/2 complete day open

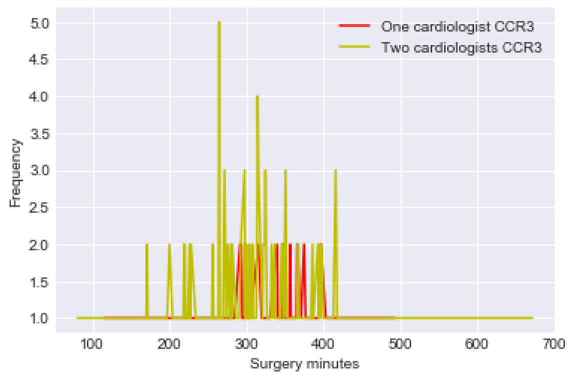

Figure 69: Total surgery length if CCR3 complete day open

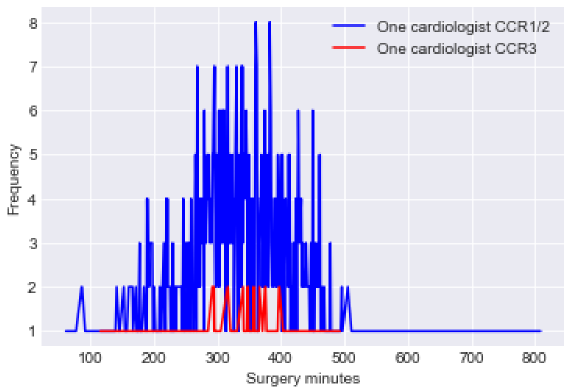

Figure 70: Total surgery length if one cardiologist on complete day

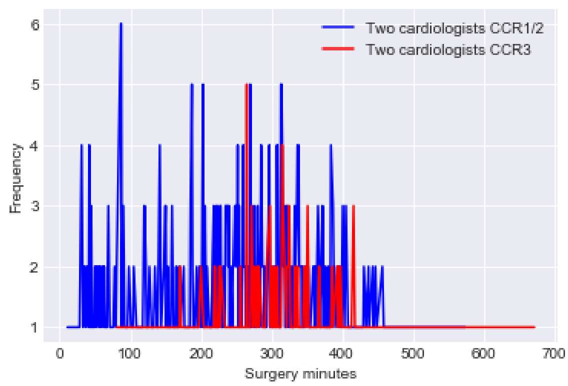

Figure 71: Total surgery length if two cardiologists on complete day

Amount of surgeries	Intervention	General	Device	Total
1	535	110	255	900
2	527	143	421	1,091
3	1,002	207	306	1,515
4	537	74	58	669
5	68	4	5	77
6	3	0	2	5
7	1	0	3	4
8	0	0	1	1

Table 25: Amount of surgeries performed per daypart per cardiologist type

G Availability Cardiologists

Cardiologist	Mon-m	Mon-a	Tue-m	Tue-a	Wed-m	Wed-a	Thu-m	Thu-a	Fri-m	Fri-a
Dr. A	X	X	X	X			X	X	X	X
Dr. B	X	X	X	X	X	X	X	X		
Dr. C			X	X	X	X	X	X	X	X
Dr. D			X	X	X	X	X	X	X	
Dr. E	X	X	X	X			X	X	X	X
Dr. F	X	X	X	X			X	X	X	X
Dr. G	X	X	X	X	X	X	X	X		
Dr. H	X	X	X	X			X	X	X	X
Dr. I	X	X	X	X	X	X	X	X		
Dr. J			X	X	X	X	X	X	X	X
Dr. K	X	X	X		X	X	X	X	X	
Dr. L	X	X	X	X			X	X	X	X

Table 26: Availability of cardiologists per daypart

The dayparts with an X are the dayparts cardiologists are available to work at the hospital.

Cardiologist A - E are interventional, F - I are device and J - L are general cardiologists.

Tuesday and Thursday afternoon always one intervention cardiologist needs to do the MDO.

H Simulation Flowchart

H.1 Main Module

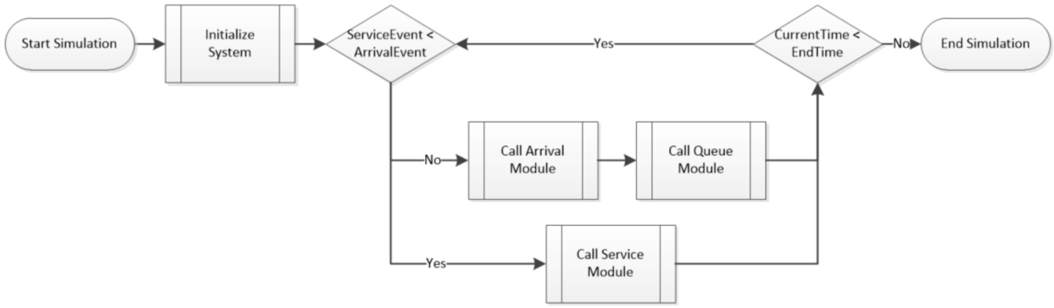

Figure 72: Flowchart of the main module

H.2 Initialize System

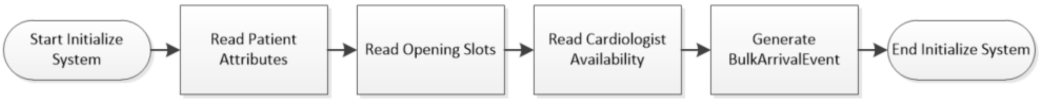

Figure 73: Flowchart of initializing the system

H.3 Arrival Module

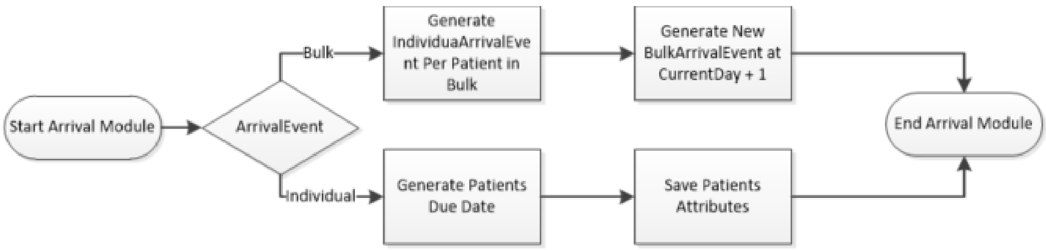

Figure 74: Flowchart of the arrival module

H.4 Queueing Module

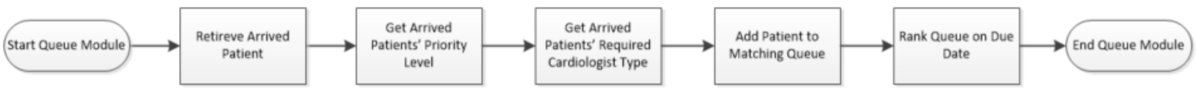

Figure 75: Flowchart of the queueing module

H.5 Service Module

Figure 76: Flowchart of the service module

I Capacity Planning

I.1 Requested Surgery Minutes

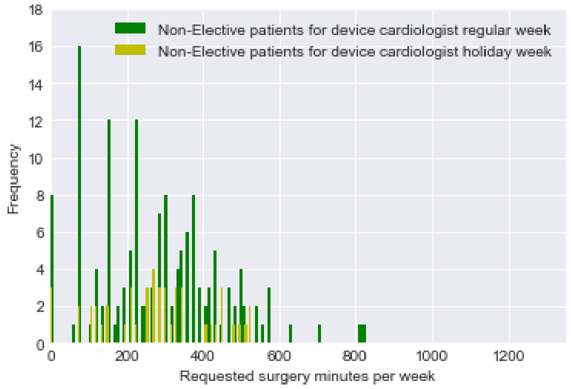

Figure 77: Requested surgery minutes for non-elective patients of cardiologist type device per week

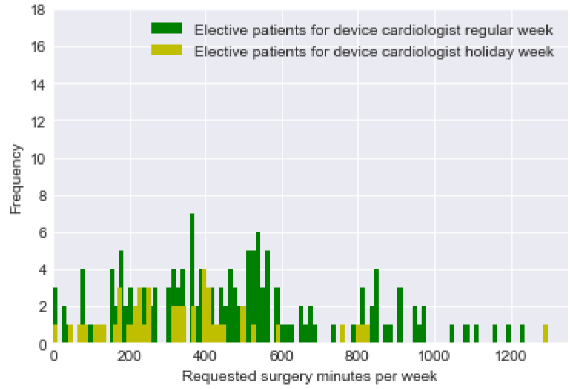

Figure 78: Requested surgery minutes for elective patients of cardiologist type device per week

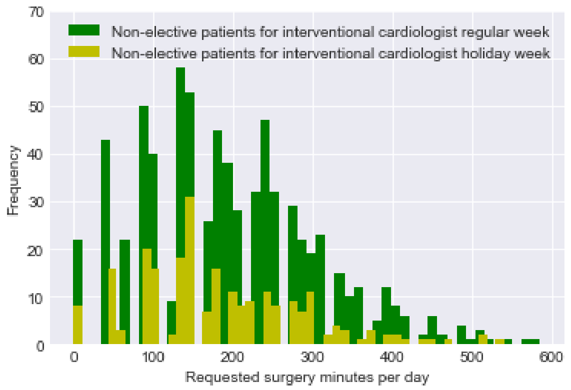

Figure 79: Requested surgery minutes for non-elective patients of cardiologist type interventional per day

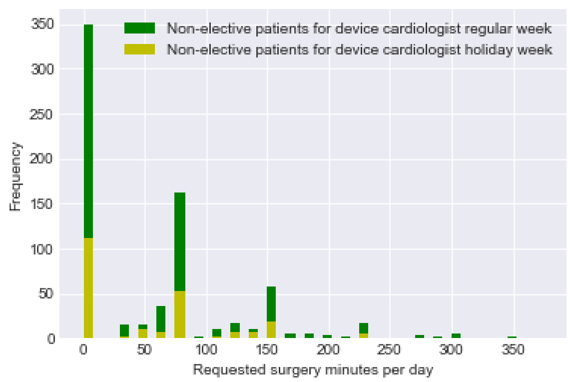

Figure 80: Requested surgery minutes for non-elective patients of cardiologist type device per day

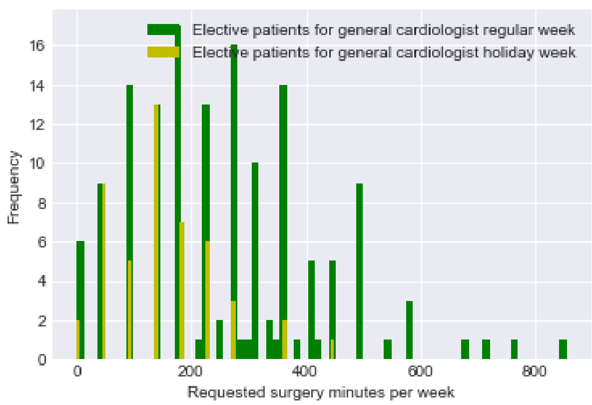

Figure 81: Requested surgery minutes for elective patients of cardiologist type general per day

Confidence interval	Interventional Elective	Interventional Non-elective	Device Elective	Device Non-elective	General
95%	1085	1016	519	304	288
90%	1076	1009	512	300	284
85%	1070	1004	507	297	281
80%	1065	1000	503	295	279

Table 27: Time needed in minutes during regular week to meet the confidence intervals

I.2 Constraints Capacity Planning

- The minimum amount of dayparts per week for interventional cardiologist is 10, since every day of the week an interventional cardiologist should be available in both morning and afternoon. This way, always an interventional cardiologist is available to help emergency patients.
- A minimum of four days per week a device cardiologist is working.
- During the holiday period, only two out of three CCRs are allowed to be open simultaneously.

I.3 Basic Opening Dayparts

CCR	Mon-m	Mon-a	Tue-m	Tue-a	Wed-m	Wed-a	Thu-m	Thu-a	Fri-m	Fri-a
CCR1	E	-	J	-	-	-	B	C	-	L
CCR2	B	B	A	A	C	C	D	D	E	E
CCR3	-	G	H	-	G	I	F	H	-	-

Table 28: Basis scenario during regular week

CCR	Mon-m	Mon-a	Tue-m	Tue-a	Wed-m	Wed-a	Thu-m	Thu-a	Fri-m	Fri-a
CCR1	-	-	-	-	-	-	-	C	-	L
CCR2	B	B	A	A	C	C	D	D	E	E
CCR3	-	G	H	-	-	I	F	-	-	-

Table 29: Basic scenario during holiday week

I.4 Opening of Dayparts Device Cardiologist

Table 30, 31 and 32 show the opening of the device dayparts over the week and the amount of minutes available for elective patients.

CCR	Mon-m	Mon-a	Tue-m	Tue-a	Wed-m	Wed-a	Thu-m	Thu-a	Fri-m	Fri-a
CCR3	-	G 60	H 150	-	-	I 60	F 150	-	-	-

Table 30: Basic scenario if 4 dayparts device cardiologists

CCR	Mon-m	Mon-a	Tue-m	Tue-a	Wed-m	Wed-a	Thu-m	Thu-a	Fri-m	Fri-a
CCR3	-	G 60	H 150	-	-	I 60	F 150	H 150	-	-

Table 31: Basic scenario if 5 dayparts device cardiologists

CCR	Mon-m	Mon-a	Tue-m	Tue-a	Wed-m	Wed-a	Thu-m	Thu-a	Fri-m	Fri-a
CCR3	I 150	G 60	H 150		-	I 60	F 150	H 60	-	-

Table 32: Basic scenario if 6 dayparts device cardiologists

J Variations in Capacity Allocation

Current situation
If CCR1 is open with an interventional cardiologist, three elective patients slots in both morning and afternoon. If CCR1 is open with a general cardiologist, four elective patient slots in both morning and afternoon. If CCR2 is open on Monday and Friday one slot for elective patients in the morning and one in the afternoon. On Tuesday, Wednesday and Thursday, two slots for elective patients in the morning and one in the afternoon.

Variant 1
If CCR1 is open, four elective patients slots in both morning and afternoon, unless estimated end time with less patients is already later than 12:00. On CCR2 on Monday and Tuesday one slot for elective patients in the morning and one in the afternoon. On Wednesday, Thursday and Friday, two slots for elective patients in the morning and one in the afternoon on CCR2.

Variant 2
Same situation as variant 1, but always two elective patient slots on CCR2 in the morning and one in the afternoon, with a maximum of 150 minutes.

Variant 3
Continue with same situation as variant 0, 1, or 2, depending on which one performs best and the allowed amount of elective patients on Thursday morning on CCR2 becomes three and on Thursday afternoon two. The third surgery in the morning and the second in the afternoon are flexible. The flexible slots are meant for priority level 4 patients. If the waiting list for non-elective patients on Wednesday morning is longer or equal to five patients, the surgery of one of the priority level 4 patient is cancelled and used for non-elective patients. If the waiting list is equal or longer than eight patients, both elective patients are cancelled.

Variant 4
If there are in total three dayparts open out of four and all of them are interventional cardiologists, on the morning dayparts two elective patients are scheduled, on the afternoon only one. If there are in total three dayparts open out of four and on of them is an general cardiologist, the daypart of the general cardiologist gets assigned four elective patients. The remaining morning dayparts get two elective patients and the afternoon one. If there are only two dayparts open and both are interventional, the morning daypart gets two elective patients and the afternoon one.
- If two slots are assigned the second slot is not filled with an elective patient if the expected surgery time of first slot is longer than 150 minutes.
- If four slots are assigned the fourth slot is not filled with an elective patient if the expected surgery time of the four slots together is longer than the available time (210 minutes in the morning, 240 minutes in the afternoon).

CCR	Morning	Afternoon
CCR1	I (3)	-
CCR2	I (2)	I (1)

CCR	Morning	Afternoon
CCR1	-	-
CCR2	I (2)	I (1)

CCR	Morning	Afternoon
CCR1	G(4)	-
CCR2	I (2)	I (1)

CCR	Morning	Afternoon
CCR1	-	G (4)
CCR2	I (2)	I (1)

Variant 5
Same amount of slots to elective patients is allocated as in variant 4, but they are differently spread over the dayparts.
- If two slots are assigned the second slot is not filled with an elective patient if the expected surgery time of first slot is longer than 150 minutes.
- If three slots are assigned the third slot is not filled with an elective patient if the expected surgery time of the first and second slot together are longer than the available time during that daypart.

CCR	Morning	Afternoon
CCR1	I (3)	-
CCR2	I (3)	I (0)

CCR	Morning	Afternoon
CCR1	-	-
CCR2	I (3)	I (0)

CCR	Morning	Afternoon
CCR1	G(4)	-
CCR2	I (3)	I (0)

CCR	Morning	Afternoon
CCR1	-	G (4)
CCR2	I (3)	I (0)

Variant 6
A combination of variant 4 and 5. The difference is that there is one slot extra assigned to elective patients on CCR2 in the afternoon on the days an interventional cardiologist is working on CCR1.
- If two slots are assigned the second slot is not filled with an elective patient if the expected surgery time of first slot is longer than 150 minutes.
- If three slots are assigned the third slot is not filled with an elective patient if the expected surgery time of the first and second slot together are longer than the available time during that daypart.

CCR	Morning	Afternoon
CCR1	I (3)	-
CCR2	I (3)	I (1)

CCR	Morning	Afternoon
CCR1	-	-
CCR2	I (3)	I (0)

CCR	Morning	Afternoon
CCR1	G(4)	-
CCR2	I (3)	I (0)

CCR	Morning	Afternoon
CCR1	-	G (4)
CCR2	I (3)	I (0)

Variant 7
Continue with same situation as option 4, 5 or 6, depending on which one performs best, and the introduction of flexible slots as explained in variant 3.

K Simulation Results

K.1 Interventional Cardiologist

Capacity Planning

Performance Indicators	Amount of dayparts per regular week			
	10	11	12	13
Utilization Interventional	0.7699	0.7712	0.7708	0.7693
Utilization CCR1	0.7819	0.7855	0.7767	0.7771
Utilization CCR2	0.7698	0.7696	0.7707	0.7681
Over Time Interventional	4.46	4.25	4.18	4.12
Over Time CCR1	6.17	5.35	4.77	4.58
Over Time CCR2	4.46	4.30	4.33	4.29
Idle Time Interventional	55.48	54.80	54.67	54.75
Idle Time CCR1	51.98	50.46	51.65	51.38
Idle Time CCR2	55.48	55.41	55.20	55.71
Waiting Time Interventional - Level 1	0.4272	0.4189	0.3960	0.3718
Waiting Time Interventional - Level 2	19.49	19.02	20.48	19.38
Waiting Time Interventional - Level 3	14.69	14.70	14.77	14.70
Waiting Time Interventional - Level 4	195.13	147.80	101.14	40.67
On Time Interventional - Level 1	67.48%	68.85%	71.15%	73.42%
On Time Interventional - Level 2	88.51%	89.37%	87.75%	89.03%
On Time Interventional - Level 3	59.45%	59.45%	58.92%	59.28%
On Time Interventional - Level 4	3.93%	4.13%	5.00%	50.76%

Table 33: Results of performance indicators under the scenario capacity planning - interventional dayparts

Capacity Allocation

Performance Indicators	Capacity allocation variations - 12 interventional							
	0	1	2	3	4	5	6	7
Utilization Interventional	0.7678	0.7955	0.8347	0.8445	0.8093	0.8073	0.8387	0.8435
Utilization CCR1	0.8593	0.9592	0.9571	0.9412	0.9148	0.9236	0.9273	0.8480
Utilization CCR2	0.7646	0.76636	0.81122	0.8284	0.7957	0.7907	0.8258	0.8555
Over Time Interventional	4.34	5.75	5.95	6.10	4.72	5.14	5.64	5.411
Over Time CCR1	6.42	11.06	11.09	10.61	7.21	7.26	7.87	6.65
Over Time CCR2	4.40	4.63	4.85	5.17	4.60	5.07	5.46	5.56
Idle Time Interventional	55.47	51.01	42.39	40.36	46.67	46.74	40.61	39.60
Idle Time CCR1	35.96	19.63	20.10	22.95	25.10	23.31	23.13	38.57
Idle Time CCR2	56.59	56.38	46.27	43.07	49.71	50.33	43.29	37.46
Waiting Time Interventional - Level 1	0.4041	0.4071	0.4143	0.4142	0.4072	0.3820	0.3867	0.4133
Waiting Time Interventional - Level 2	19.97	20.63	29.42	33.60	25.06	23.68	31.64	47.66
Waiting Time Interventional - Level 3	14.25	13.65	13.67	13.59	13.61	13.59	13.66	13.62
Waiting Time Interventional - Level 4	91.20	65.61	26.49	13.26	51.18	50.11	20.21	12.60
On Time Interventional - Level 1	69.51%	69.49%	67.92%	67.87%	69.30%	70.60%	70.00%	67.68%
On Time Interventional - Level 2	87.90%	86.21%	79.17%	73.68%	82.45%	82.99%	75.81%	62.54%
On Time Interventional - Level 3	57.31%	58.89%	58.89%	59.45%	59.35%	59.40%	59.14%	59.21%
On Time Interventional - Level 4	4.63%	10.33%	78.78%	98.69%	22.84%	24.40%	93.30%	99.18%
Cancellation Slot	-	-	-	27.41%	-	-	-	41.54%

Table 34: Results of performance indicators under the scenario capacity allocation - 11 dayparts interventional cardiologists

Patient Sequencing

Variants tested under the scenario patient sequencing:
(1) The current situation, handle patient according to a FCFS principle.
(2) Never schedule two surgeries which are not a CAG, parallel at the start of a daypart on CCR1 and CCR2.
(3) Only schedule CAG procedures of elective patients in the morning.

Performance Indicators	Patient sequencing variations			
	1	2	3	4
Utilization CCR1	0.9557	0.9552	0.9569	0.9574
Utilization CCR2	0.8451	0.8459	0.8141	0.8224
Over Time CCR1	10.68	10.64	10.82	10.36
Over Time CCR2	5.23	5.24	5.32	5.15
Idle Time CCR1	19.98	20.04	19.88	19.58
Idle Time CCR2	39.43	39.26	46.20	44.38
Waiting Time Interventional - Level 1	0.4310	0.4383	0.4354	0.4220
Waiting Time Interventional - Level 2	37.85	36.93	30.45	32.43
Waiting Time Interventional - Level 3	13.60	13.60	13.62	13.62
Waiting Time Interventional - Level 4	21.75	21.59	29.46	26.83
On Time Interventional - Level 1	65.85%	65.54%	69.23%	66.78%
On Time Interventional - Level 2	69.75%	70.56%	76.73%	74.59%
On Time Interventional - Level 3	59.43%	59.60%	59.21%	59.21%
On Time Interventional - Level 4	98.41%	98.35%	65.51%	86.94%
Cancellation Flexible Daypart	40.38%	41.14%	7.47%	15.95%
Cancellation Slot	17.53%	16.64%	12.28%	11.96%
DTC Beds	2.3992	2.4000	2.2878	2.3953

Table 35: Results of performance indicators under the scenario patient sequencing - interventional dayparts

Holiday Weeks

Variants tested with under the scenario holiday weeks:
(1) Assign two slots less to elective patients of cardiologists interventional during the holiday week(s).
(2) Open one daypart extra the first week after a holiday period to handle elective patients.
(3) A combination of variant 2 and 3.

Performance Indicators	Holiday weeks variations		
	1	2	3
Utilization CCR1	0.9579	0.9532	0.9583
Utilization CCR2	0.8347	0.8466	0.8346
Over Time CCR1	11.08	10.52	10.98
Over Time CCR2	5.22	5.42	5.14
Idle Time CCR1	19.92	20.36	19.74
Idle Time CCR2	41.77	39.33	41.72
Waiting Time Interventional - Level 1	0.4663	0.4556	0.4481
Waiting Time Interventional - Level 2	35.86	39.71	35.74
Waiting Time Interventional - Level 3	13.67	13.64	13.65
Waiting Time Interventional - Level 4	23.74	22.93	21.86
On Time Interventional - Level 1	67.15%	65.17%	66.85%
On Time Interventional - Level 2	71.38%	68.23%	71.66%
On Time Interventional - Level 3	59.14%	59.52%	59.58%
On Time Interventional - Level 4	93.61%	99.58%	95.25%
Cancellation Flexible Daypart	28.73%	51.78%	40.00%
Cancellation Slot	16.96%	19.18%	16.52%

Table 36: Results of performance indicators under the scenario holiday weeks

Capacity Planning
Variants tested with under the scenario capacity planning:
(1) One daypart during regular and holiday weeks.
(2) During regular weeks, the opening of two and one daypart alternate and one during holiday weeks.
(3) Two dayparts during regular and one during holiday weeks. Important to keep in mind is the utilization of CCR1 is different from the utilization of only the general cardiologists because also surgeries are performed on CCR1 by interventional cardiologists.

Performance Indicators	Amount of dayparts per regular week		
	1	1.5	2
Utilization General	0.9412	0.9281	0.7901
Utilization CCR1	0.8257	0.8341	0.7850
Over Time General	9.24	8.65	5.67
Over Time CCR1	5.07	5.34	4.38
Idle Time General	21.57	23.75	49.75
Idle Time CCR1	41.66	40.17	49.53
Waiting Time - General	132.12	35.69	7.90
On Time - General	10.58%	52.88%	99.70%

Table 37: Results of performance indicators under the scenario capacity planning - general dayparts

K.2 Device Cardiologist

Performance Indicators	Friday Morning Device	
	Fluctuating	Open Regular Weeks
Utilization Device	0.7470	0.7078
Over Time Device	3.16	1.49
Idle Time Device	57.40	65.09
Waiting Time Device - Level 2	46.33	53.60
Waiting Time Device - Level 4	27.76	17.70
On Time Device - Level 2	61.02%	61.24%
On Time Device - Level 4	75.32%	93.70%
Cancellation Flexible Daypart Dev.	26.20%	51.65%
Cancellation Slot Dev.	8.60%	10.82%
Opening Daypart on Friday Dev.	40.29%	-

Table 38: Results of performance indicators under capacity allocation - device cardiologist

K.3 Surgery Length

Performance Indicators	Planned surgery length		
	Standard	Historical, round down	Historical, round up
Utilization Interventional	0.8607	0.8588	0.8388
Utilization General	0.9337	0.9314	0.7222
Utilization Device	0.7455	0.7240	0.6937
Over Time Interventional	6.04	5.39	4.44
Over Time General	9.04	8.55	1.33
Over Time Device	2.98	2.50	1.61
Idle Time Interventional	36.76	36.57	39.95
Idle Time General	22.95	22.96	59.67
Idle Time Device	57.54	61.70	67.28
Waiting Time Interventional - Level 1	0.4383	0.4746	0.4398
Waiting Time Interventional - Level 2	36.93	44.32	53.50
Waiting Time Interventional - Level 3	13.59	13.65	13.70
Waiting Time Interventional - Level 4	21.59	22.01	28.43
Waiting Time General	22.93	23.06	60.14
Waiting Time Device - Level 2	46.78	42.60	41.48
Waiting Time Device - Level 4	28.10	37.25	59.52
On Time Interventional - Level 1	65.54%	65.82%	68.10%
On Time Interventional - Level 2	70.56%	65.86%	56.126%
On Time Interventional - Level 3	59.60%	59.41%	58.83%
On Time Interventional - Level 4	98.36%	97.99%	81.43%
On Time Time General	91.44%	91.15%	18.99%
On Time Device - Level 2	61.68%	64.86%	65.68%
On Time Device - Level 4	75.88%	55.62%	23.45%
Cancellation Flexible Daypart Int.	41.40%	39.62%	12.66%
Cancellation Slot Int.	16.65%	21.46%	28.67%
Cancellation Flexible Daypart Gen.	40.13%	39.75%	7.22%
Cancellation Flexible Daypart Dev.	20.00%	6.20%	7.21%
Cancellation Slot Dev.	7.22%	6.39%	6.01%
Opening Daypart on Friday Dev.	40.29%	37.09%	35.92%

Table 39: Results of performance indicators under the scenario surgery length

K.4 Admission and Cancellation Rules

Performance Indicators	Admission and cancellation time		
	16:45	17:00	Six wires
Utilization Interventional	0.8635	0.8643	0.8607
Utilization General	0.9313	0.9312	0.9337
Utilization Device	0.7575	0.7675	0.7453
Over Time Interventional	7.27	8.77	6.05
Over Time General	8.62	8.59	9.04
Over Time Device	3.89	5.10	2.97
Idle Time Interventional	37.62	39.11	36.77
Idle Time General	23.04	23.05	22.95
Idle Time Device	55.98	55.19	57.56
Waiting Time Interventional - Level 1	0.4605	0.4540	0.4381
Waiting Time Interventional - Level 2	28.03	21.97	37.14
Waiting Time Interventional - Level 3	13.65	13.70	13.59
Waiting Time Interventional - Level 4	20.92	20.86	21.59
Waiting Time General	22.96	22.96	22.93
Waiting Time Device - Level 2	39.29	34.99	46.10
Waiting Time Device - Level 4	27.44	26.94	28.18
On Time Interventional - Level 1	66.39%	64.28%	65.66%
On Time Interventional - Level 2	78.84%	85.01%	70.39%
On Time Interventional - Level 3	59.25%	59.14%	59.60%
On Time Interventional - Level 4	98.75%	98.96%	98.35%
On Time Time General	91.52%	91.52%	91.43%
On Time Device - Level 2	67.23%	70.96%	61.79%
On Time Device - Level 4	76.52%	78.08%	75.66%
Cancellation Flexible Daypart Int.	39.87%	44.69%	41.14%
Cancellation Slot Int.	10.13%	10.39%	16.70%
Cancellation Flexible Daypart Gen.	39.49%	39.49%	40.13%
Cancellation Flexible Daypart Dev.	21.27%	22.03%	20.25%
Cancellation Slot Dev.	5.07%	4.05%	6.90%
Opening Daypart on Friday Dev.	33.00%	26.99%	40.58%

Table 40: Results of performance indicators under the scenario admission and cancellation rules

L Practical Recommendations

- *Dashboard Nurses*
  On the cardiology ward, the nurses have an overview of the patients hospitalized at their department. If they want to know if a patient has a surgery scheduled at the CCR, they should look on patient level if a surgery is booked. Having a symbol on the dashboard which represents a surgery is ordered for a patient makes the nurses at a glance know a patient needs to get prepared for surgery (in the upcoming days). This should prevent situations in which nurses are not aware a patient gets surgery and is not ready on time.
- *Reason for Rescheduling*
  In the system the reason for rescheduling is not written down properly, while this information is of high value. If a patient is put back on the waiting list, the system gives a pop-up to fill in the reason for rescheduling. One planner mostly states the reason 'care giver' when hospital staff decided to reschedule the surgery. In the free space she mostly substantiates the actual reason, for example certain medical values which where not sufficient. Other options mostly used by the planners are 'no-show' or 'other'. The system provides a wide variety of reasons for rescheduling, but are not used. For data quality improvement it is recommended the planners fill in the best fitting reason.
- *Treating Specialty*
  It is unclear who is responsible for changing the responsible specialism of a patient in the system, if a patient is moved to a different department. A patient can be moved to a department which differs from his/her treating specialism because s/he needs to be treated by this new specialism, or because there are no beds available at his/her current specialism. Consequentially if the treatment speciality is not the same as the location a patient has a bed, the system automatically registers this as an 'wrongly located' patient. This indeed can be the case, or the patients' responsible specialism has not been changed correctly. Management should create a responsibility protocol for this matter.
- *Reason Surgery*
  For data analysis it would be interesting to know what the reason is for a patient to get his/her surgery. Currently, this information can only be found if on patient level the outcomes of letters and medical consults are requested. This reason for surgery could be added as a field to the surgery request, with options such as consult, hospitalized, follow-up operation.
- *CCR as Location*
  Having a surgery at the CCR is no location in the system yet, whereas this is the case if a patient gets a surgery at the OR. It would be beneficial for data analysis if the CCR is a location and therefore a modification in the system.
- *Explore Software System*
  The overall administration linked to patients should be used way more efficient. Epic provides much more functionalities than are known by the ETZ staff. Correct and better use of software's systems functionality will contribute to the value of the data.

L.1 Dashboard CCR

At the moment the introduction of a dashboard to monitor the CCR is in the pipeline. The aspects in this dashboard are limited to the procedures performed. The dashboard will present the overall amount of procedures performed and per individual cardiologist. Furthermore, for the device cardiologists the company of the implemented PM or ICD is given. It is recommended to extend the dashboard with the following information. A filter should make sure for all elements can be filtered on period (year, month, day, daypart, hour), cardiologist type, individual cardiologist, procedure (group) and patient type.

- The (average) surgery length.
- The (average) waiting time.
- The (average) on time.
- The (average) idle time.
- The (average) overtime.
- The (average) utilization.
- The target amount of procedures to be performed.
- The moment during the day surgeries are requested and by whom.
- The patients on the waiting list.
- The opening of the CCRs.
- The amount and type of surgeries performed and on which patient type per day(part).

Ideally elements can be combined in a figure/chart. Presenting for example the amount of patients on the waiting list over time in combination with the openings of the CCR, shows the relationship between capacity and demand.