IMPROVING THE APPOINTMENT SCHEDULING AT THE DAY-CARE WARD: A SIMULATION STUDY

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Management summary

Problem identification

The day-care ward is the part of a hospital where patients receive treatment and are discharged the same day. This research takes place at the day-care ward of the Gelderse Vallei Hospital (ZGV), which is a peripheral hospital located in Ede, Netherlands. The treatments provided at the day-care ward come from a wide variety of outpatient clinics, and the patients are categorized as either surgical or monitoring patients, depending on their treatment. The surgical patients are patients whose treatment involves surgery while monitoring patients' treatment requires no surgery. Surgical patients are scheduled by the surgical room planners and the monitoring patients are scheduled by the outpatient clinic that requests the treatment.

The day-care ward experiences that the planning process of monitoring patients is not optimal with respect to the fluctuating workload of the nurses and the variability in occupancy, and that there is room for improvement, as reflected in the core problem of this research: "*There is no tactical basis for the scheduling of the day-care ward*". Scheduling on a tactical level gives the guidelines and rules that guide the making of scheduling decisions.

The main research question is:

> *What is a tactical basis for the appointment scheduling of the monitoring patients of the day-care ward, that also improves the performance?*

The performance of the day-care ward is valued by four Key Performance Indicators (KPIs): bed ratio, ward occupancy, percentage of patients transferred to another ward, and the percentage of patients scheduled on another ward. To establish a tactical basis, this study uses three main methods. First, the patient data is analysed to gain insights into the day-care ward and its performance. Second, interventions are generated using literature research. Third, a simulation of the day-care ward is used to test the performance of the interventions in a safe environment.

Data analysis

We use patient data to analyse the treatment types and performance of the day-care ward.

First, the treatment types are established. The level of complexity of this case mix, which is the treatments involved in the day-care ward, is investigated using the classification proposed by Leeftink & Hans (2018), which is based on the duration of treatment (M/C) and the coefficient of variation (S/M) and can be seen in Figure 2. The case mix presents in the lower-left quadrant, as almost all treatments are between 0 and 0.5 for both the duration of treatment and the coefficient of variation. This means that the treatment groups are, theoretically, easy to schedule effectively.

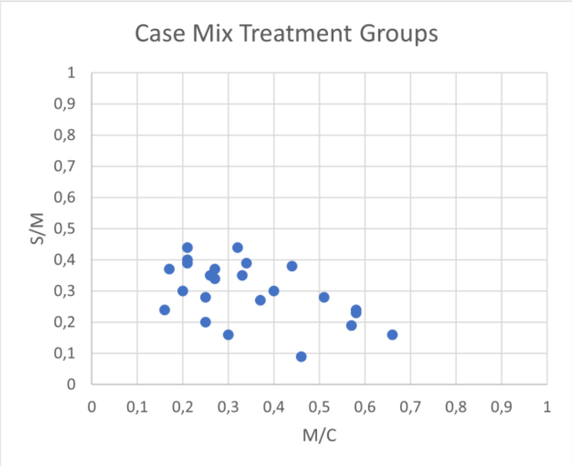

Figure 1: Case mix of treatment groups. S = standard deviation of the treatment time, M = mean treatment time, C = total capacity of the day-care ward.

The performance of the day-care ward is analysed by measuring the four KPIs. The average bed ratio is 1.24, which indicates that each available bed is occupied by 1.24 patients per day. The ward occupancy is 54.3% on average. The percentage of patients scheduled at another ward is on average 8.4% and the percentage of patients transferred to another ward is on average 4.1%.

Simulation experiment design

We build a simulation model that represents the day-care ward of ZGV to test scheduling interventions in a safe environment. The day-care ward is not widely analysed in the current literature, so possible scheduling interventions are derived from other hospital divisions: the OR, outpatient clinic and inpatient ward. This resulted in three different interventions to be tested: sequencing rules, slack (amount and location) and Days until the use of the rules (DuoR). Table 2 presents the scenarios. The identifiers represent the different experiments. The current situation is labelled as F00A0.

Table 2: Interventions and scenarios with their identifier

Intervention	Scenarios	Identifier
Sequencing Rule	First come, first appointment (FCFA)	F
	Low variability at the beginning of the day	L
	High variability at the beginning of the day	H
Slack Amount	0% of the std.dev.	00
	25% of the std.dev.	25
	50% of the std.dev.	50
	75% of the std.dev.	75
Slack Location	After the appointment	A
	At the end of the day	E
DuoR	0 days	0
	3 days	3
	1 week	7

Results

The aim of the simulation study is *"To test which of the interventions gives an improved performance on the four given KPIs compared to the simulated current situation*". Table 3 shows the performance of experiment F00A0 and the experiment H00A7, which was the only one that, compared to F00A0, showed improved performance without any of the KPIs performing worse.

Table 3: Results of experiments F00A0 and H00A7.

Experiment	Bed Ratio	Ward occupancy	Patients Scheduled Elsewhere	Patients Transferred
F00A0	2.547	78.9%	29.4%	4.6%
H00A7	2.539	79.5%	29.7%	3.6%

Best value
P-value > 0,05 of the best value
Worst value

From the data in Table 3, we can see that the simulated current situation, F00A0, performs not significantly different from H00A7 at the KPIs bed ratio, ward occupancy and the percentage of patients scheduled at another ward, but performs the worst of all experiments at the percentage of patients transferred. The experiment that has an overall improvement compared to F00A0 is H00A7. It performs not significantly different at ward occupancy, bed ratio and percentage of patients scheduled at another ward compared to F00A0, but has a significantly better percentage of patients transferred, showing a decrease of 21.7% transferred patients.

We also observe that the bed ratio, ward occupancy, and percentage of patients scheduled at another ward are highly correlated, indicated by their absolute value of correlation coefficient R above 0.67. Bed ratio and the percentage of patients scheduled at another ward are even very highly correlated (R=-0.9998). This effect is also visible in the results shown in Table 3, as for F00A0, the bed ratio and the percentage scheduled at another ward both perform the best out of all experiments.

Furthermore, the interventions also show correlations with the KPIs. The bed ratio, ward occupancy and the percentage of patients scheduled at another ward highly correlate with the slack amount, with an R of -0.7352, 0.8996 and 0.7390 respectively. The percentage of patients transferred highly correlates with the location of the slack (R=-0.8309).

Conclusion

To conclude, a tactical basis for the scheduling of monitoring patients that improves performance is provided by experiment H00A7, which includes the sequencing rule that schedules high variability at the beginning of the day and a DuoR of 7.

When implementing these rules for the day-care ward at ZGV, we first advise labelling treatments that have an average treatment time under 6.5 hours (half the opening time of the day-care ward) and that are not impacted by limitations, such as specific days or part of the day, either as high variability or low variability. Second, the DuoR of 7 days can be implemented in combination with the sequencing rule. DuoR longer than 7 days have not been tested, but can also be considered with further research. Third, this solution does not involve scheduling slack. However, if there is a need to lower the percentage of patients that are transferred to another ward, regardless of the slight worsening of the other KPIs, adding slack can be beneficial.

Next to the practical implications, this research also has theoretical implications. This research went into detail on the day-care ward's characteristics and how they relate to other parts of the hospital, the OR, outpatient clinic and inpatient ward. It also shows how the several known planning models and methods perform in the day-care ward and how they influence the KPIs.

This research also has its limitations. The main limitation is that the surgical patients were excluded, as this was outside the scope. The scheduling of the day-care ward involves both types of patients and these processes are connected. By separating them for this research, the simulation was limited and the results only give a partial view. However, this research gives the day-care ward a tactical basis on which they can build onto.

Preface

This thesis on improving the appointment scheduling at the day-care ward at ZGV is the final phase of my bachelor's degree in Industrial Engineering and Management. I hope you enjoy reading this thesis, but I would first like to thank a few people.

I would first like to thank my supervisors at the University of Twente, Gréanne Leeftink and Erwin Hans. Gréanne Leeftink has helped me by brainstorming together and providing valuable feedback and suggestions. She supported me and gave me confidence during difficult times. I also want to thank Erwin Hans, with who I had wonderful conversations about academic writing.

I also want to thank my supervisors at ZGV, Michel Zeilmaker and Nori Batterink. Their enthusiasm and expertise made me motivated to work on this thesis. I enjoyed our weekly meetings, for which they took time in their busy schedules, and I value the discussions we had. They showed me the workings of the capacity management department and what it is like to work there. It made me interested in the field and I now aspire to work in health care after my studies.

Last, I want to thank my family, friends and co-workers. My family supported me during hard times and I could count on them whenever I was stuck. My co-workers at the UT Writing Centre helped me with my thesis writing and helped me stay motivated. My friends were always cheering me on and gave me confidence in my work.

I want to truly thank everyone that helped and supported me.

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Glossary

Term	Definition	Dutch translation
ZGV	Gelderse Vallei Hospital	Ziekenhuis Gelderse Vallei
Day-care ward	Department of the hospital where patients receive treatment lasting less than a day (and thus will be discharged the same day)	Dagbehandeling
Surgery room planning department	Department of the hospital where surgical room schedule is made	Opnameplanning
Surgical patients	Day-care patients that have a treatment that involves surgery	Snijdende patiënten
Monitoring patients	Day-care patients that do not have treatments that involve surgery, such as an IV drip	Beschouwende patiënten
Outpatient clinic	Specialised department of a hospital that focuses on diagnosing and treating patients. These departments generally do not admit patients (and thus do not require a bed).	Polikliniek

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Chapter 1: Problem Identification

This chapter covers the first phase of the Managerial Problem Solving Method (MPSM), which is the problem identification phase (Heerkens & van Winden, 2017). First, the context of this thesis will be described, followed by the problem description. From there, the research questions will be presented, as well as the scope of this research.

1.1 Context

Gelderse Vallei Hospital (ZGV) is a modern hospital located in Ede, and offers health care to patients from West- and Middle Gelderland and East Utrecht (Ziekenhuis Gelderse Vallei, 2020). These areas hold approximately 260000 residents. ZGV currently has 2623 staff members, 180 medical specialists and 400 volunteers, and offers a wide variety of specialisms. ZGV thus fulfils an important regional function. ZGV's motto is *"Driven by knowledge. Focused on health"*.

ZGV is known for its expertise in nutrition and exercise. Nutrition and exercise are important before, during and after a hospitalization. ZGV collaborates with the University of Wageningen to conduct nutrition research. Other important areas of expertise are ultrasound, MRI, intensive care, sleep disorders, and the Woman, Mother and Child Centre.

This research takes place at the day-care ward of ZGV. The day-care ward is a department of the hospital where patients that have a treatment lasting less than a day are cared for. The treatments given come from a wide variety of outpatient clinics. The patients are thus discharged on the same day and do not stay overnight. The day-care ward is open from 07:00 to 20:00, and any patients that are not discharged by 20:00 will be transferred to a clinic.

There is a division in the day-care patients: surgical patients and monitoring patients. Surgical patients are scheduled by the surgical room planners. These surgical room planners do not only schedule day-care surgical treatments but all surgical treatments. Monitoring patients are scheduled by the outpatient clinic where the patient received the request for a day-care treatment. We focus this research on monitoring patients. The day-care ward of the Gelderse Vallei Hospital experiences that the planning process of monitoring patients is not optimal in several aspects (Capacity Management Consultant, 2020):

- The percentage of day-care patients that are in an inpatient ward is perceived as too high.
- The amount of day-care patients is growing, without growth in capacity or a change in the scheduling method. This causes patient scheduling to become more complex and there is a need for low variability in scheduling.
- The current schedule is made by various departments in the hospital. This causes, among other things, a higher workload for the day-care coordinators. Also, with small changes, multiple departments will have to be informed.

With these observations, a project called "Optimisation and centralisation of the day-care ward schedule" was started within the Integrated Capacity Management program. This project has two goals: optimisation and centralisation. Optimisation focuses on the effectiveness of the planning process and centralisation focuses on the communication around and the location of the scheduling. This research focuses on the optimisation of the appointment scheduling of the monitoring patient in the day-care ward and is conducted using the Managerial Problem Solving Method (MPSM) (Heerkens & van Winden, 2017), of which the different phases can be seen in Figure 1.1.

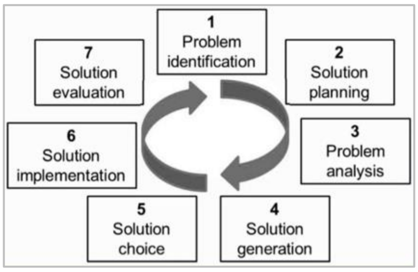

Figure 1.1 The phases of MPSM

1.2 Problem description

To further investigate the perceived problems and bottlenecks, conversations are held with hospital staff from various departments included in the planning process. To get a clear view, a conversation is held with personnel with the following positions:

- Head nurse of the day-care ward
- Manager of the surgical room planners
- Application manager
- Advisor Integral Capacity Management
- Project manager "Optimisation and centralisation day-care ward schedule"

All of these conversations are valuable, as they all give a different perspective on the current planning process and how they think it can improve. Based on the information gathered from these conversations and the project charter, a problem cluster is made. A shortened version is shown in Figure 1.2. This problem cluster focuses on the core problem "There is no tactical basis for the schedule of the day-care ward". The more detailed problem cluster and further explanation of the different problems in the shortened problem cluster can also be found in Appendix A.

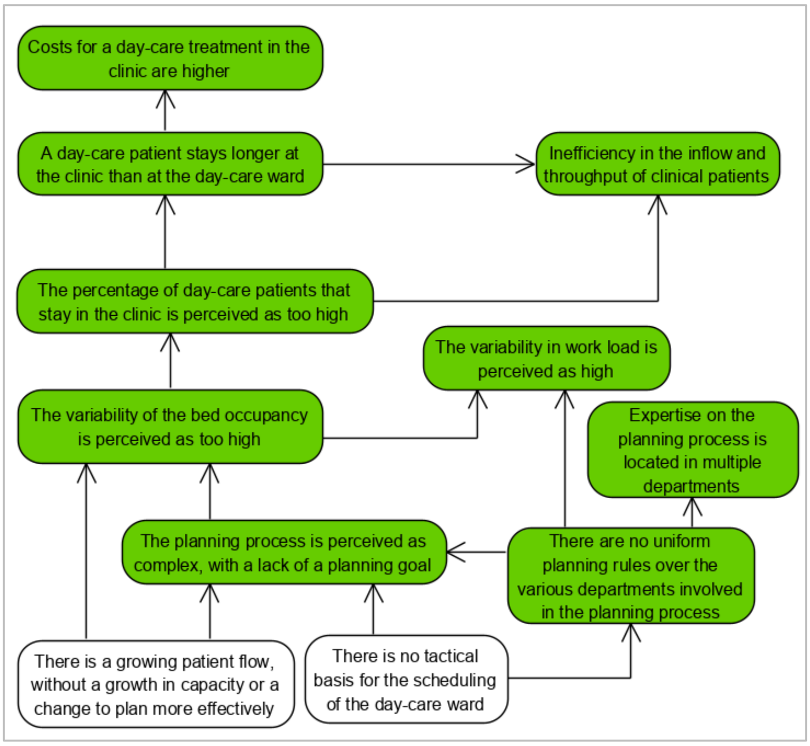

Figure 1.2: Problem cluster (shortened)

The term tactical, in the context of a tactical basis, comes from the framework for healthcare planning and control (Hans, van Houdenhoven, & Hulshof, 2012). They make a distinction between a strategic, tactical and operational level. Firstly, planning on a strategic level addresses structural decision-making. Decisions on a strategic level involve defining the organization's mission and translating this mission into the design, dimensioning and development of the healthcare delivery process. It has a long planning horizon. Secondly, planning on an operational level involves short-term decision-making that is related to the execution of the healthcare delivery process. Operational decisions, such as patient scheduling, are taken within a limit of a few weeks. Third, planning on a tactical level addresses the organization of this execution of the healthcare delivery process. Decisions are made on a longer planning horizon than on the operational level, but shorter than on a strategic level. Decisions involve, for example, block planning and scheduling rules.

Planning on a tactical level gives the organization guidelines and rules, which guide them in making planning decisions. If there is no clear tactical basis, as is the case in the day-care ward, the planners do not have a planning goal or guidelines, which causes them to plan without knowing the effects of their decisions. The day-care ward already had some initiatives on an operational level. However, without a good tactical basis, one can only fix problems when they come up, without being ahead of them before they arise. A tactical basis is therefore important in the planning of the day-care ward.

Besides the importance of a tactical basis, the core problem is one of the causes of the other problems and solving this core problem is achievable in the time frame. Looking at the other core problems, seen in the detailed problem cluster in Appendix A, they are not chosen for multiple reasons. They either cannot be influenced, will not make a significant change to the current situation or require considerable changes to the day-care ward and/or ZGV that might also not be achievable in the time frame. Therefore, the core problem *"There is no tactical basis for the scheduling of the day-care ward"* is chosen as the main problem that this research will focus on.

This core problem is perceived as an action problem. An action problem is a discrepancy between the norm and the reality as perceived by the problem owner (Heerkens & van Winden, 2017). The research question, which aims to solve the action problem, is formulated as follows:

What is a tactical basis for the appointment scheduling of the monitoring patients of the day-care ward, that also improves the performance?

The performance of the day-care ward will be valued by four key performance indicators (KPIs): bed ratio, ward occupancy, percentage of patients transferred to another ward, and the percentages of patients scheduled on another ward. The aim with improved performance is that among these four KPIs none show significant worsening and at least one shows significant improvement.

1.3 Research questions

To solve the action problem, the following research questions will be answered.

1. ***What is the current situation of the day-care ward and what is its performance?***

This first question focuses on the third phase of the MPSM, the problem analysis phase. This question is answered in Chapter 2. The current situation is analysed by the following sub-questions:

a. What is the current planning process?

The current planning process will be analysed and an overview of this process will be made. The aim is to understand the current planning process and to gain insights into where changes could be made. The research strategy for this question is to do a stakeholder analysis, gather data with a communication approach, and use qualitative processing to process the information gathered.

b. What is the range of treatments of monitoring patients?

The range of treatments gives insights into which treatments are offered, and how the day-care ward monitoring patients are distributed across these treatments. The research strategy for this question is to analyse patient data from the years 2018 and 2019.

c. What are the resources of the day-care ward?

These resources include at minimum personnel, beds available, rooms available, medical equipment and medical supplies. These resources give insights into what is available to the day-care ward, and thus what restrictions there are in resources. The research strategy for this question is to gather data with a communication approach and to use qualitative data processing to process the information gathered.

d. What is the performance of the day-care ward?

The performance is measured by the KPIs: bed ratio, ward occupancy, percentage of patients transferred to another ward and the percentage of patients scheduled at another ward. The research strategy for this question is to analyse the patient data from 2018 and 2019 to give these variables their value.

2. What are possible planning models and methods and how do they impact the performance of the day-care ward?

The second question focuses on the fourth and fifth phases of the MPSM, the solution generation and solution choice respectively. This question is answered using the following sub-questions:

a. What are possible planning models and methods for the day-care ward?

There are a lot of different planning models and methods known in the literature. For this question, we search the literature for models and methods relevant to the day-care ward, and it covers the fourth phase of the MPSM. The research strategy for this question is to perform a literature search. First, the preparation of the literature search is performed. Second, literature, based on the preparation, is searched and gathered. Third, the found literature is evaluated. Last, the data gathered from the literature is summarized. This question is answered in Chapter 3.

b. How do the different planning models and methods perform?

The relevant planning models and methods are tested by a discrete-event simulation to see how they compare to each other and the norm. This question is in line with the fifth phase of the MPSM. The gathered data will be processed and analysed to answer this research question. This question is answered in Chapter 5.

3. Which planning model(s) and/or method(s) give the best performance and how can this intervention be implemented in the day-care ward?

This question is both in the fifth and sixth phases of the MPSM. The first part of the question is the fifth phase, solution choice, as it is about choosing the best performing planning model(s) and/or method(s). The second part of the question is the sixth phase, solution implementation, as it asks how the best performing planning model(s) and/or method(s) can be implemented. Even though these topics are from two different phases, they must be considered together. There is a possibility that the best-performing option might be hard to implement. If such a situation comes to be, it is wise to take a look at other options that might be easier to implement, but taking into account that they do not perform as well. Combining these two questions allows that trade-off. The research strategy for this question is to first gather data from question 2b and data from the current patient scheduling system. Second, the trade-off is made. Third, when a solution is chosen, the implementation is further analysed. This question is answered in Chapter 6.

1.4 Deliverables and scope

The main deliverable of the research is a tactical basis for the scheduling of the day-care ward that can be implemented and which also improves the performance of the day-care ward. As stated in Section 1.2, a solution must be both improving the performance and smoothly implementable. Therefore, another deliverable is to provide advice on how to implement that tactical basis.

The scope of this research is defined by three aspects. Firstly, this research will only focus on improving the planning process on a tactical level. Secondly, this research focuses on the scheduling of monitoring patients only. There is another project in progress in the program Integral Capacity Management that aims to improve surgical room scheduling. As surgical room planners not only plan day-care surgeries but all surgeries, this is not within the scope of this research. Lastly, the seventh phase, solution evaluation, is be included in this research as it does not fit in the timeframe.

Chapter 2: Current Situation Analysis

This chapter describes the current situation of the day-care ward. This includes four topics, with each their own section: the planning process, treatments, resources and performance. These topics represent the research questions 1a, 1b, 1c and 1d respectively, and therefore this chapter answers the first research question.

2.1 Patient planning process

The patient planning process for the day-care ward is divided over multiple departments. This makes mapping the patient planning process complex, as multiple factors have to be taken into account when planning a patient. A general overview of this process can be seen in Figure 2.1.

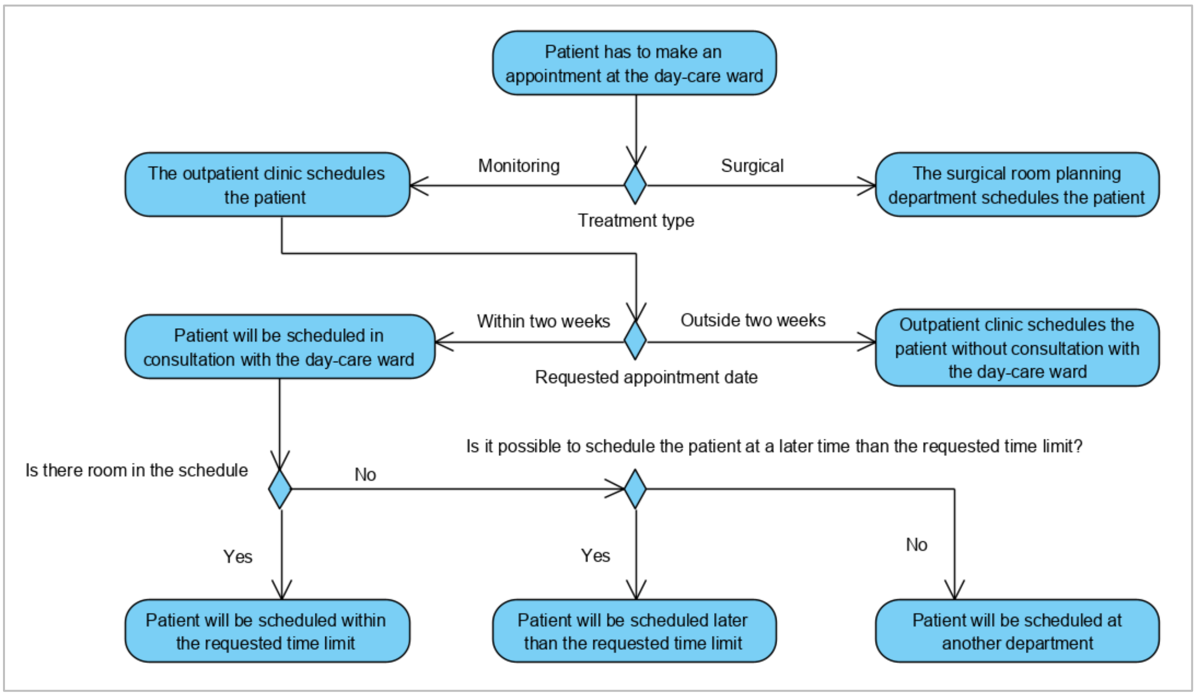

Figure 2.1: Planning process day-care ward

The type of treatment that the patient will receive determines who plans the patient on the day-care ward. If the patient will receive surgical treatment, the surgical room planning department schedules the patient at the day-care ward. If the patient will receive a monitoring treatment, the outpatient clinic, where the patient receives diagnosis and treatment, schedules the patient at the day-care ward. As this thesis focuses on monitoring patients, the planning process for monitoring patients is described in detail and the planning process for surgical patients is described more generally.

Monitoring patient planning process

As mentioned above, the respective outpatient clinic schedules the patient at the day-care ward. There are 12 outpatient clinics in the years 2018 and 2019 that schedule monitoring patients at the day-care ward, and each outpatient clinic has a (slightly) different planning process. This is due to the decentralized planning process for monitoring patients. There is a guideline available for the outpatient clinics when they schedule a patient at the day-care ward, created by staff from the day-care ward. For the outpatient clinics that schedule the most monitoring patients, more guidelines can apply. For example, the MDL (gastroenterology) outpatient clinic has an agreement with the day-care ward to not schedule more than 5 monitoring patients per day without consultation with the day-care ward.

The guideline document gives an overview of how many patients can be scheduled at what timeslots and any restrictions the time slots or treatments have. The guideline has ten timeslots and each time slot has a maximum number of patients that can be scheduled on that slot. For example, the time slot 08:00 can have a maximum of two patients planned. Three of the timeslots have a restriction where one of the patient slots available is reserved for a specific treatment. The 08:00 time slot also has one of its two patient slots reserved for a coronary catheterization (CAG). The guideline gives a maximum of 15 patients per day. However, when the number of patients for each slot is added up, the total number is 18.

The guideline also gives a rule when it comes to the time frame that a patient has to be scheduled. When a patient has to be scheduled within two weeks, or when a particular day has reached its maximum number of patients, the outpatient clinic has to call the day-care ward to consult with them. The outpatient clinic is therefore not allowed to plan a patient on their own in these two cases. The day-care coordinator looks at the schedule and tells the outpatient clinic if there is enough room on the requested day or time limit. To check if there is space in the schedule, they look at the limit of patients per nurse, which is five patients per nurse present. There is no space left in the schedule if the addition of the patient exceeds those five patients per nurse. In the case that there are multiple days possible to schedule, the day-care coordinator will choose the day with the least amount of patients scheduled.

If there is no room, the patient will either have to be scheduled on another day, which might be outside the time limit, or be scheduled on another ward. The second option is not ideal, as the day-care ward is specialized in the treatments given there, whereas the other wards are specialized in other treatments. However, if a patient has to receive treatment within a specific time limit and the day-care ward is full, treatment at another ward is a necessary choice.

Furthermore, the following two scheduling characteristics apply when scheduling a patient. First, some patients have to get regular treatments. In that case, the outpatient clinic will plan multiple appointments for this patient. Second, the patient's preference is taken into account but is not leading when scheduling the patient.

Surgical patient planning process

Compared to the planning process of monitoring patients, the planning process of surgical patients is quite different. To start, the general basis of the planning process is different. Where the planning process for monitoring patients has the basis of a patient needing an appointment, the planning process for surgical patients has the basis of filling the schedule of the operating rooms.

The outpatient clinic puts the patient on a waiting list for treatment. The surgical room planning department is responsible for the scheduling of the operating rooms. They continuously schedule the operating rooms. Their objective is to fill the schedule of the operating room as best as possible. They look for openings in the schedule and look at patients on the waiting lists and emergency patients to determine which patients can fit in a certain opening. There are multiple factors that they have to take into account, such as: which surgical specialisation has that time assigned, which doctor is assigned to do surgeries, how long the opening is, which patients are on top of the waiting list for this specialisation, if the necessary equipment is available, if there is a bed available for the patient, and more. Based on all these factors, they schedule the patients.

2.2 Treatments

The data used for the analysis of treatments was from the years 2018 and 2019. Data from 2020 is not chosen because of the COVID-19 impact on the day-care ward. The data set used contains the full treatment for a patient per data point. The steps for obtaining a representative data set can be found in Appendix B.

In the final data set, treatment groups with over 50 data points are seen as individual treatment groups. There are 36 treatment groups that have data points ranging from 47 to one and account for 7% of all the treatments. These treatments are given less than once per two weeks to once per two years. As these treatments do not occur often enough, they are grouped together and are called Rest.

The duration of treatment in the Rest group ranges from less than an hour to several days. To have an indication of the duration of treatment, this group is divided into multiple groups based on the duration of treatment using the five-number summary of a boxplot. The first quartile, median and third quartile are close or equal to three, five and seven hours respectively, see Table 2.1.

Number	Value
Minimum	38
First Quartile	182
Median	299
Third Quartile	420
Maximum	24740

Table 2.1: Five-number summary of Rest group

To give the possible users of these treatment groups a clear indication, the following four groups are created:

- Rest < 3h
- Rest 3h-5h
- Rest 5h-7h
- Rest > 7h

The treatment groups that are included in these Rest groups can be found in Appendix B.

With the Rest groups, the total number of treatment groups is 24. The treatment groups and their number of data points can be seen in Table 2.2. The treatment group for intravenous (IV/infuus) drip is divided into a group for inflectra IV and IVs that are not inflectra. The inflectra IV was 67% of the IV group and because of it being the majority, the inflectra IV is separated and is its own treatment group.

Table 2.2: Overview of monitoring patients' treatment groups

Treatment group	Count
Infuus (Inflectra)	2015
Cathkamer	1119
Bloedtransfusie	991
Infuus (Niet inflectra)	988
Ferinject	685
Magnesium i.v.	557
Methylprednisolonkuur	380
CT-scan	350
Immunotherapie	265
Photo dynamische therapie	253
CT cor	221
CT geleide punctie	160
CT-scan met prehydratie	147
Lumbaalpunctie	143
Bronchoscopie	105
Echogeleide leverpunctie	89
Synacthentest	84
Aclasta	76
Blaasspoeling	54
Echo geleide punctie	52
Rest <3h	164
Rest 3h-5h	169
Rest 5h-7h	165
Rest >7h	167

To visualize the level of complexity for scheduling this case mix, which are the treatments involved in the day-care ward, a classification proposed by Leeftink & Hans (2018) based on the duration of treatment and the coefficient of variation is made. Both these parameters are an indication of the complexity of scheduling. The coefficient of variation (s/m) indicates the variability of the system. A high coefficient of variation for a treatment group indicates high variability in the duration of treatment, which affects the performance of the schedule. The average duration of treatment (m) is divided by the capacity of the day-care ward (c), which is the time in minutes that the day-care ward is open, to indicate the scheduling flexibility. The higher m/c is, the longer the duration compared to the capacity of the day-care ward, and thus the flexibility of scheduling this treatment group is lower.

This classification is visualized twice: the first is based on the treatment groups from Table 2.2 and the second is based on the outpatient clinics that schedule monitoring patients at the day-care ward. The two graphs are visible in Figures 2.2 and 2.3 respectively. In the analysis of the case mix, the data reviewed is altered. Even though the unaltered data represents the real data, it gives a lopsided view of the average duration of treatment, as the extreme values can become as high as 10000 minutes and in some cases even higher. The graphs for the unaltered data and information on how the data is altered can be found in Appendix C, as well as the data for each point in the graphs.

When looking at the case mix for the treatment groups, Figure 2.2, it is visible the coefficient of variation is between 0 and 0.5. The lower the value, the less variable the treatment group is. The m/c is between 0.1 and 0.7, with most of it located between 0.1 and 0.5. Because this data is in the lower-left quadrant, it means that the treatment groups are, theoretically, easy to schedule effectively. With an m/c generally lower than 0.5, most treatments can be scheduled together. This means that, with a duration of treatment lower than half the opening hours, at least two patients can be scheduled on the same bed. A s/m lower than 0.5 indicates general lower variability, which means that the variability of the treatments does not exceed half the mean treatment time.

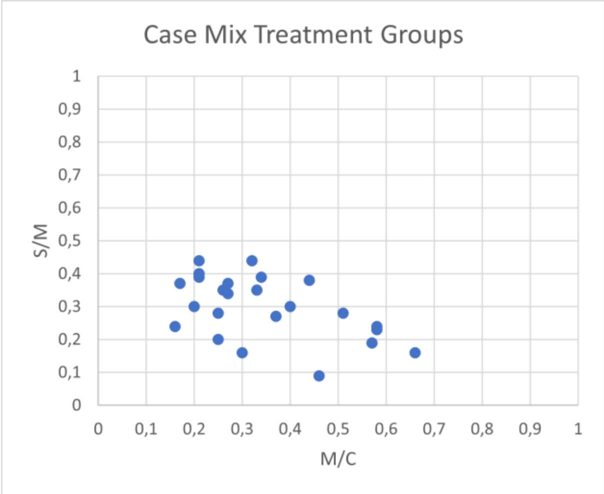

Figure 2.2: Case mix of treatment groups

When looking at the case mix for the outpatient clinic, Figure 2.3, it is visible that with altered data, the coefficient of variation is between 0.1 and 0.7, with most between 0.3 and 0.7. Compared to the treatment groups, the coefficient of variation is higher. However, this has an explanation. As each outpatient clinic plans multiple treatment groups, the range of duration of treatment is larger, and thus the standard deviation is higher. The m/c is between 0.2 and 0.55. This is a closer range compared to the treatment groups. Each outpatient clinic gives an average of their treatment groups, and thus a smaller range is visible, which is within the m/c range of the treatment groups.

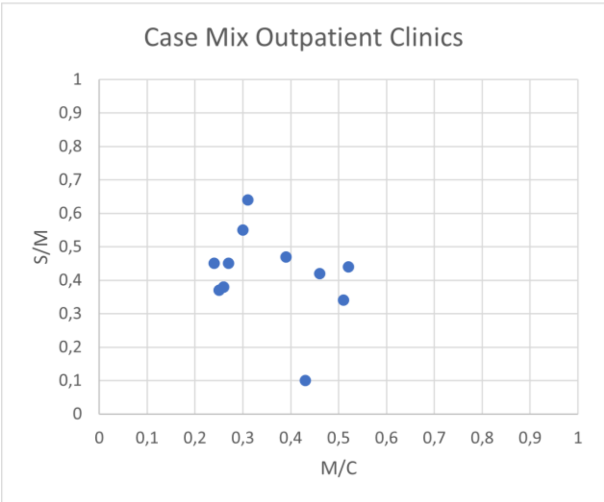

Figure 2.3: Case mix of outpatient clinics

In Figure 2.3, there is one low value of 0.1. This is of the KNO department (Throat, Nose and Ears/Keel, Neus en Oor). This department only has one day-care treatment that does not require surgery, and thus is a monitoring treatment. This treatment is one of the treatments combined in the Rest groups and is therefore not individually visible in Figure 2.2. This treatment group has a low variability compared to its mean treatment time and has therefore a low s/m. As the KNO department has no other monitoring treatments in 2018 and 2019, their coefficient of variability is only based on this one treatment and is, therefore, lower than the other outpatient clinics.

2.3 Resources

The resources are what the day-care ward needs to treat its patients. These resources fall into multiple categories: beds, staff, materials and other departments. Each of the following paragraphs describes each of these categories.

Beds

The day-care ward has a total of 46 beds in the ward, divided over 22 rooms. However, not all of these beds and rooms are available for the day-care ward patients. Room 37, with 1 bed, is used for dialysis and therefore no patients can be scheduled there. Room 30, with six beds, is used as a waiting room, so there are no beds available there. Lastly, rooms 26 and 27, with two and one bed, are used for another project within ZGV and can therefore also not be used to schedule day-care ward patients. This leaves 36 beds available, divided over 18 rooms.

Staff

During the day, there are 9 nurses, a secretary and a day-coordinator present in the day-care ward. The nurses can each take care of a maximum of 5 patients at a time. The day-coordinator oversees the day-care ward and thus does not take care of any patients. The different shifts that are used can be seen in Table 2.3. The skills per nurse can differ slightly, but there are always nurses available that do have the skill that another nurse might not have.

Table 2.3: Shifts of nurses at the day-care ward

Personnel	Shift
Day-coordinator	08:30-17:00
2 nurses	07:00-15:30
2 nurses	07:30-16:00
2 nurses	09:00-17:30
3 nurses	12:00-19:30

Materials

When giving treatment to patients, materials, medical equipment and medicine present at the day-care ward are used. The day-care ward staff experiences that there is almost never a lack of materials while giving treatment to patients. In the case that there is a lack of any of those, they can easily gain access to them via other departments.

Other departments

Part of the treatments given at the day-care ward are not solely given at the day-care ward itself. All surgical treatments are performed in an operating room, and some of the monitoring treatments are performed in another department. For example, a patient has to get a CT scan with pre-hydration. The pre-hydration is done at the day-care ward and the patient will then be guided to the department where the CT scan is done. Afterwards, the patient returns to the day-care ward and is discharged when his treatment is done. Treatments like these are dependent on other departments. Other treatments, which are mostly IVs, are given without dependence on other departments. Of all the treatments from the main treatment groups (excluding the Rest groups), approximately one-third are dependent on other departments.

2.4 Performance

The data used for the analysis of treatments was from 2018 and 2019. Data starting from 2020 was not chosen because of the COVID-19 impact on the day-care ward. Two different data sets are used in this analysis. The first data set used contained the full treatment for a patient per data point. This is the same data set used in Chapter 2.2. The second data set used contained the stay per location. If a patient is not moved to another location during his/her treatment, there is only one data point. If a patient is moved to another location (other bed or department), another data point is created.

To obtain a representative data set, the data is filtered. For each variable to be calculated, the data is filtered in a different way. For calculating the ward occupancy and bed ratio, a realistic representation of the day-care ward patients of the years 2018 and 2019 is needed. However, for calculating the number of patients that are admitted to other wards, only the treatments that are not normally given at the day-care ward should not be included. The steps to get these representative data sets can be found in Appendix B:

The analysis of the variables is done with these altered data sets. First, the ward occupancy and bed ratio per day will be discussed. Second, the ward occupancy per hour of the day will be discussed. Third, the variability of the ward occupancy per hour will be discussed. Last, the patients that are admitted to other wards will be discussed.

Ward occupancy and bed ratio per day

The ward occupancy and bed ratio per day are calculated similarly. The formulas are:

$$Ward\ occupancy = \frac{Total\ treatment\ time\ of\ all\ patients\ on\ a\ day\ in\ minutes}{Average\ number\ of\ nurses\ * Patients\ per\ nurse * Total\ time\ the\ ward\ is\ open\ in\ minutes}$$

$$Bed\ ratio = \frac{Total\ number\ of\ patients\ on\ a\ day}{Average\ number\ of\ nurses * Patients\ per\ nurse}$$

When the ward occupancy is 1, the full capacity of the day-care ward is used. When the bed ratio is 1, there was one patient per bed in the day-care ward on that day. Both formulas calculate the total capacity with the average number of nurses instead of beds. There are different methods to define the total capacity and there were three methods considered. Each method is discussed in the following paragraphs

The first method takes all the physical beds present in the day-care ward into account. This has changed through the years 2018 and 2019, and those changes are also included. This method does, however, include beds in the calculation that are not used on those days, as not all beds are used every day. This results in lower values for both the ward occupancy and the bed ratio, which gives an unrealistic view.

The second method only takes the number of beds used per day. For every day, the total number of beds used is calculated and is used for that particular day. This results in a different number of beds for each day. However, it is not uncommon at the day-care ward to use empty beds when there is an overlay of patients. An example of this is when a patient has a small delay in treatment, and the next patient scheduled on that bed has already arrived. The day-care ward can choose to put the new patient on another bed than scheduled. The two patients have a small overlay in their hospitalisation, but two beds are used in this scenario. If the extra bed is not available, it would be a choice to have the second patient wait a little longer. This gives a skewed view of the number of beds used on a day, but it is more accurate than the first method.

The third method is based on the number of nurses present in the day-care ward, where the capacity is calculated by taking the maximum number of beds a nurse can attend to. At ZGV, each day-care nurse present has a maximum capacity of five patients. Depending on the time of the day, the number of nurses changes due to the shifts (see Section 2.3). This method also has some flaws. First, it is not retraceable to see how many nurses were present during a day. This also includes any changes in the schedule, and thus a generalisation will be made. Second, the number of nurses present changes, so an average number of nurses present will be used to calculate the total number of beds.

These three methods are all valid methods, however, the most accurate and representable method is chosen. The second method is already more accurate than the first method, so the choice is between the second and third methods. The third method is more suitable because determining the number of beds based on the number of nurses can give a more representable view of the performance of the day-care ward. Even though it generalises the number of beds compared to the first and second methods, it eliminates the chance of including beds that were either not used or were only used because of convenience. Thus, the total number of beds is calculated using the third method, based on the average number of nurses.

The ward occupancy can be seen in Figure 2.4. The green line represents the ward occupancy per day of the year 2018 and the blue line represents the ward occupancy per day of the year 2019. The x-axis is defined in weeks, so each week has five values of both the green and blue lines. The red line represents the weekly average of the same week from both 2018 and 2019. The ward occupancy normally fluctuates between 0.5 and 0.6, with exception of a few declines, which are explained in the next paragraph. This means the ward operates with 50 to 60 per-cent of its capacity used. The average ward occupancy is 54.3% over both 2018 and 2019. The average ward occupancy in 2018 was 53.2% and 55.4% in 2019.

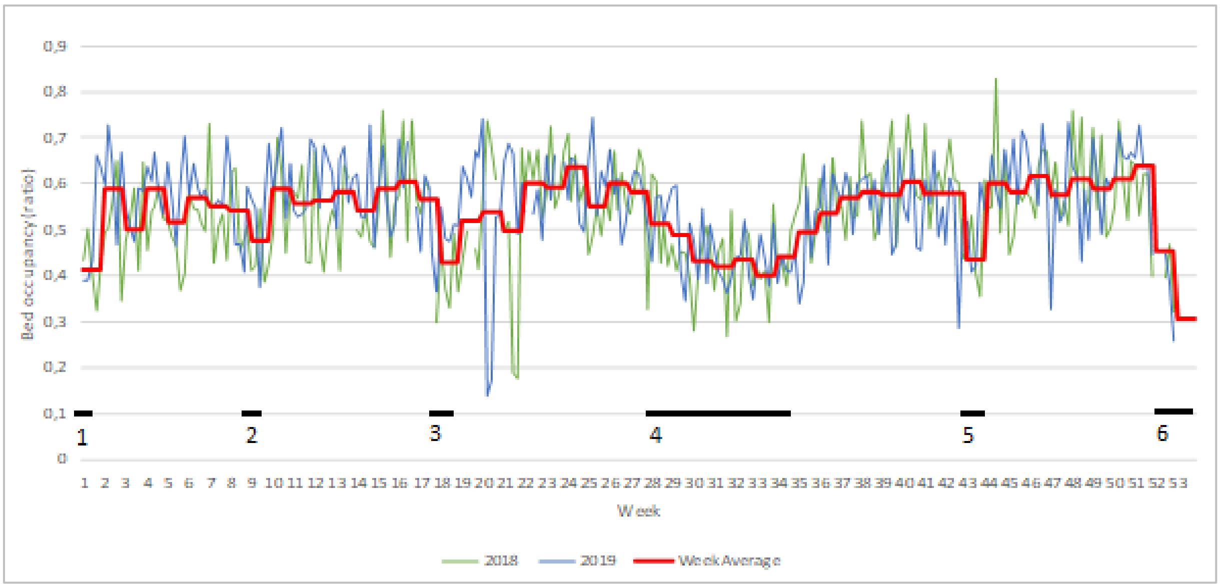

Figure 2.4: Ward occupancy over a year

There are a few black lines visible on the graph, and these represent the data above them. These six parts of the graph require further explanation, as these are holidays. All of them are school holidays for the middle part of the Netherlands, where ZGV is located, and working adults often take these weeks off as well. This results in a lower number of patients in those weeks, which results in lower ward occupancy. These lower values are also visible at the same weeks in the bed ratio, Figure 2.6, but these are not highlighted there. The six parts are the following:

1. Week 1 is the remaining week after New Year's Eve and part of the Christmas holiday.
2. Week 9 is the spring holiday.
3. Week 18 is the May holiday.
4. The weeks 28 till 34 are the summer holiday. Also, the construction industry also holds its summer holiday mostly in that period.
5. Week 43 is the autumn holiday.
6. Week 52 and 53 are part of the Christmas holiday.

The bed ratio can be seen in Figure 2.5. The blue line represents the bed ratio per day of the year 2018 and the orange line represents the bed ratio per day of the year 2019. The x-axis is defined in weeks, so each week has five values of both the blue and orange lines. The red line represents the weekly average of the same week from both 2018 and 2019. The average bed ratio is 1.24 for the combined 2018 and 2019. Separately, the average bed ratio is 1.22 for 2018 and 1.27 for 2019. A bed ratio of 1.24 means that a bed is, on average, occupied by 1.24 people per day. A bed ratio higher than 1 is preferable, as this increases the efficient use of the beds available. The lower values that are visible in the graph are, similar to the cause of pattern changes in Figure 2.4 of the ward occupancy, due to school holidays.

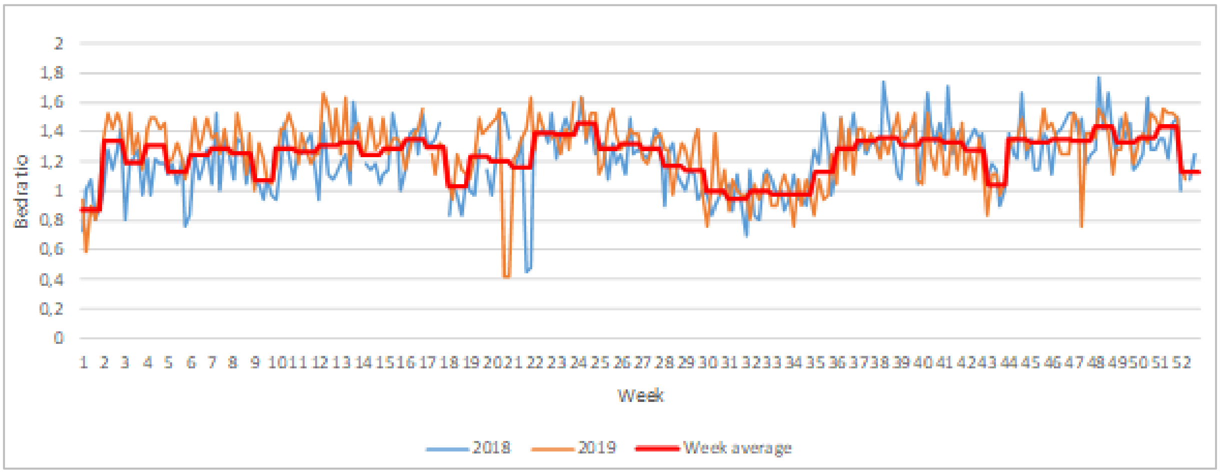

Figure 2.5: Bed ratio over a year

Ward occupancy per hour of the day

The ward occupancy per hour of the day shows the number of patients present per hour of the day. This is determined for each individual working day of the week. Figure 2.6 shows the ward occupancy per hour of the day for these working days. Each column per hour is the average number of patients present for that working day, which is an average for both 2018 and 2019. Each working day is represented by a different colour. The hour on the x-axis is the starting time of the interval. For example, 10:00 refers to every patient that is present between 10:00 and 10:59. Patients that are admitted in that timeframe are included, but patients that are discharged in that timeframe are excluded.

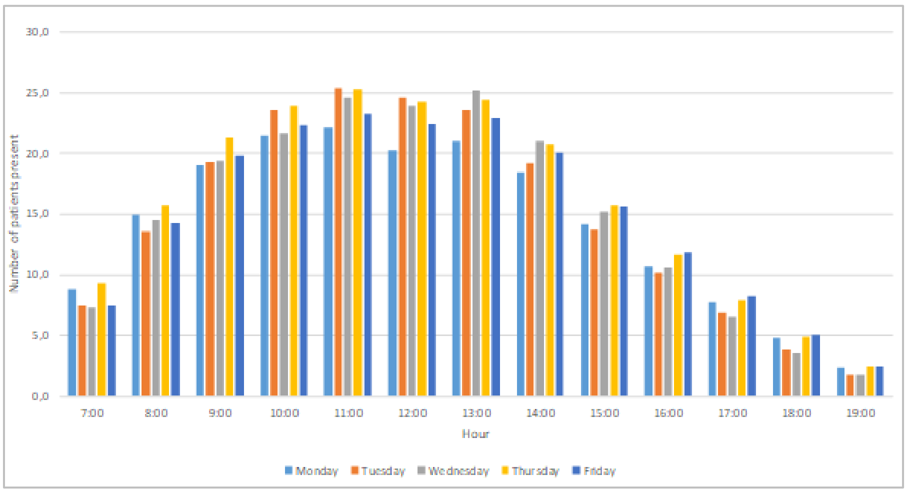

Figure 2.6: Ward occupancy per hour

There are a few things notable in Figure 2.6.

First, for every working day except Wednesday (grey) in Figure 2.6, the hour with the highest number of patients is 11:00. For Wednesday, this peak is at 13:00. When looking at the average distribution of the admission and discharge of patients per hour in Figure 2.7, there is a peak of average admitted patients at 11:00, which does not happen on any of the other working days. When this is not compensated with a high number of discharged patients, as high numbers of discharges start after 13:00, the high peak at 13:00 in Figure 2.6 is understandable.

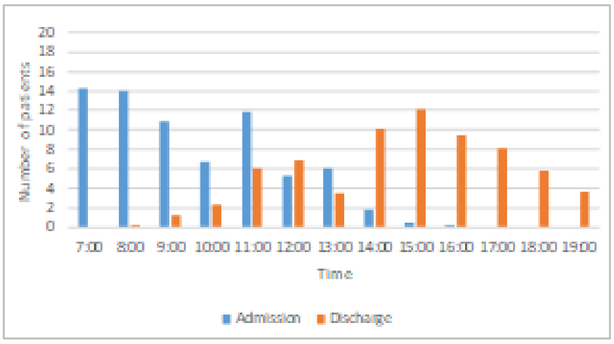

Figure 2.7: Admission and discharge of patients on Wednesday

Second, the curve that the column of Monday (light-blue) in Figure 2.6 makes is different from the other working days. The curve starts higher and has a lower peak compared to the other working days. This indicates that the patients are more evenly distributed than on the other working days. As seen in Figure 2.8, Monday starts with a high number of admitted patients compared to the other working days. Monday is mostly similar to Thursday (yellow) when it comes to the average distribution of the admission and discharge of patients per hour, but has a lower number of patients on average, and thus has a lower peak around the middle of the day compared to Thursday.

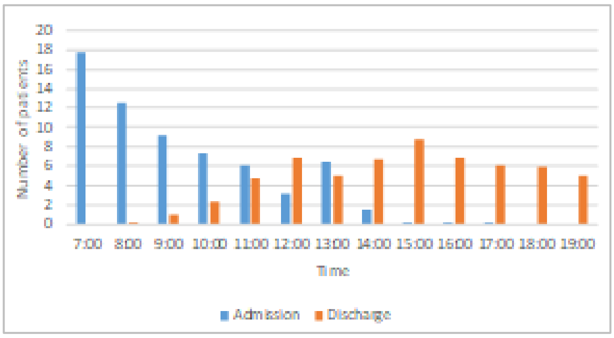

Figure 2.8: Admission and discharge of patients on Monday

Third, every working day has a lower number of patients present at 12:00 compared to 11:00 and 13:00, except for Tuesday (orange). This lower number of patients is due to the lunch break for the nurses. The difference with Tuesday is because one of the monitoring treatments is only performed on Tuesday, resulting in more patients on that day.

Additional graphs on the ward occupancy per hour and the admission and discharge distribution per hour on average and per day can be found in Appendix D, as well as the distribution of the number of patients per quarter and per month.

Variability in ward occupancy per hour

The variability in ward occupancy throughout the day is visualized in Figure 2.9. A boxplot is made for each hour that the day-care ward is open, showing the number of patients in that hour during 2018 and 2019. The hour on the x-axis is the starting time of the interval. For example, 10:00 refers to every patient that is present between 10:00 and 10:59. Patients that are admitted in that timeframe are included, but patients that are discharged in that timeframe are excluded. The lunch break around 12:00 and 13:00 is not taken into account. The legend for Figure 2.9 can be seen in Figure 2.10

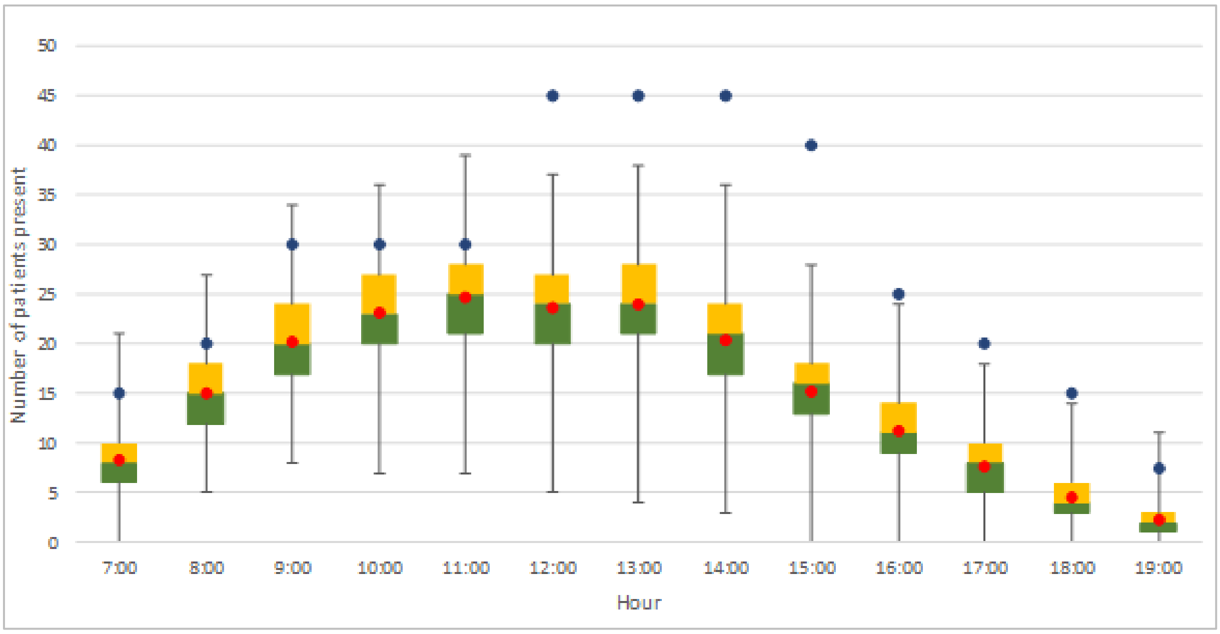

Figure 2.9: Distribution of ward occupancy per hour

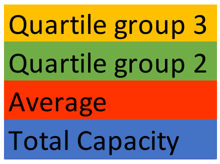

Figure 2.10: Legend for Figure 2.9

There are a few things notable in Figure 2.9.

First, the range of the boxplots in the middle of the day is notably bigger than the boxplots at the beginning and end of the day. This means that the variability is higher in the middle of the day compared to the beginning and end of the day. As admissions end around 15:00 and discharges start from 10:00, the number of patients can vary often, which can cause this high variability.

Second, the median and the mean are considerably close at every hour of the day. This tells that the distribution of patients in an hour is not skewed and it is thus symmetrical.

Third, the capacity compared to the boxplots is different at the beginning, middle and end of the day. Until 11:00, the capacity is in the fourth quartile, indicating that on at least 75 per-cent of the days, the capacity is larger than the number of patients. However, from 12:00 until 15:00, the capacity is higher than the maximum number of patients present in the day-care ward. This means that the capacity is always bigger than the number of patients present in the day-care ward. This leads to constant unused capacity in these hours. At the end of the day, from 16:00 until 18:00, the capacity is approximately equal to the maximum number of patients. This also means that the capacity is always larger than or equal to the number of patients present in the day-care ward. The ideal position of capacity, for example either above the maximum or within the fourth quadrant, is dependent on the goal that is set for the day-care ward. The nurses of the day-care ward experience high variability in workload, and Figure 2.9 suggests that their workload in the morning is regularly higher than their workload in the afternoon and evening.

Patients that are admitted to other wards

There are two types of day-care patients that are admitted to other wards: (1) day-care patients that get transferred from the day-care ward while receiving treatment and (2) day-care patients that have their treatment scheduled at another ward. To refer to these two types, the first type will be called transferred patients and the second type will be called scheduled patients in this section.

In 2018, the average percentage of patients that has their treatment at the day-care ward and completed it there was 86.4%. In 2019, this percentage was 88.9%. In 2018, the average percentage of transferred patients is 4.3%, which was 3.9% in 2019. The average percentage of scheduled patients is 9.5% in 2018 and 7.3% in 2019. This shows that the number of patients admitted to other wards was already lowering in 2019 compared to 2018.

Of the group of transferred patients, the most frequent monitoring treatment group is the Cathkamer (cathroom), which has 9.1% of the total number of transferred patients. For the surgical treatment groups, the most frequent monitoring treatment group is the group G01 Maag/galwegen (stomach and bile ducts), which has 10.2% of the total number of transferred patients. These two treatment groups are also the top two of the treatment groups that have transferred patients.

Of the group of scheduled patients, the most frequent monitoring treatment group is the Bloedtransfusie (blood transfusion), which has 11.6% of the scheduled patients. For the surgical treatment groups, the most frequent monitoring treatment group is the group G01 Maag/galwegen (stomach and bile ducts), which has 6.6% of the total number of scheduled patients. There are two monitoring treatment groups that are between these two, which are the Cathkamer (cathroom, 6.8%) and Methylprednisolonkuur (methylprednisolone IV, 6.8%).

Both transferred patients and scheduled patients do not have a monthly trend when comparing 2018 and 2019. Also, there is no visible trend when looking at days of the week for both transferred patients and scheduled patients when comparing 2018 and 2019. The graphs that show this can be found in Appendix E for the transferred patients and in Appendix F for the scheduled patients.

2.5 Conclusion

This chapter answers the first research question: what is the current situation of the day-care ward and what is its performance? Each section helped to answer this question.

Sections 2.1, 2.2 and 2.3 describes the current situation by analysing the appointment planning process, the different treatments given and the resources available. This gives an overview of how the day-care ward operates, which treatments are given, and what its capacity is. This information is gained by having conversations with employees and by analysing data.

Section 2.4 analyses the performance of the day-care ward by looking at multiple KPIs. This section gives insights into the performance of the day-care ward, which is going to be used to compare the performance of various situations modelled in the simulation.

These results of both the current situation and the performance are presented to multiple stakeholders and they validate the findings, also recognizing the performance and the insights gained from the performance.

To conclude, an appropriate picture of the day-care ward is obtained in this chapter. Several insights are reached in this chapter, and this chapter gives a basis for both Chapters 3 and 4, concerning the literature study and the simulation study. With a good picture of the day-care ward, the literature study can be focused more on the characteristics of the day-care ward. Also, the current situation gives a basis for the simulation study, and the KPIs established in Section 2.4 can be used to determine the performance of various situations modelled in the simulation.

Chapter 3: Intervention Selection

This chapter discusses the literature research which provides interventions to be tested in the simulation. Section 3.1 describes the characteristics of the day-care ward and compares them to the other departments. Then, in Section 3.2, the method of the literature search is explained, with the restrictions regarding the characteristics. Next, in Section 3.3, the findings are presented and lastly, Section 3.4 gives a conclusion and an overview of the interventions that are used in Chapters 4 and 5.

3.1 Characteristics of the day-care ward

The characteristics of the day-care ward are unique but have partial similarities with other departments in the hospital, such as the outpatient clinic, operation room department (OR) and the inpatient wards. Each department is discussed in the following paragraphs. Both the similarities and the differences and how this affects the use of the results of their appointment scheduling literature are discussed. The characteristics of the day-care ward that are discussed are the scheduling system, appointment length, opening hours and improvement target. We discuss these characteristics in the remainder of this section in order of importance

Opening hours

The day-care ward is only open during weekdays and the opening hours are from 07:00 till 20:00. This means that any patients present at 20:00 is transferred to an inpatient ward, and thus from 20:00 till 07:00, the day-care ward is closed and empty. The inpatient wards are open every day, at every hour. The OR is open at every hour of the day, but the scheduled surgeries generally take place on weekdays and during working hours. The outpatient clinic is only open on weekdays and during working hours. The outpatient clinic is thus most similar to the day-care ward when it comes to the opening hours.

Scheduling system

Scheduling systems usually vary between two types: an offline or online system. Offline and online scheduling are terms used in mathematical programming (Phavorin, et al., 2018). Here, offline scheduling is defined as making scheduling decisions with complete knowledge of all the jobs issued and all their parameters. Translated to appointment scheduling in healthcare, it means that a scheduler knows all the patients that have to be planned. Online scheduling is defined as making scheduling decisions when only knowing the current state, meaning not all jobs are known. Translated to appointment scheduling in healthcare, it means that every patient is scheduled immediately, and the scheduler only has the knowledge of all the patients already scheduled and does not know which patients will still have to be planned. This is sometimes also referred to as real-time scheduling.

The day-care ward uses an online system for its monitoring patients, while the surgical patients are scheduled by the surgical room planning department, which uses the offline system. For the outpatient clinics and inpatient wards, both offline and online systems can be used.

Appointment length and stochasticity

The appointment length and variation are also characteristics of the day-care ward. Each treatment has its own mean treatment duration ranging from an average of two hours to eight hours. In the case of the OR, the treatment times are quite similar to those of the day-care ward, also including the variations in treatment duration. The outpatient clinic is very different from the day-care ward when it comes to appointment length and the variation in appointment length, as the appointments are generally shorter and there is little variation. The inpatient ward has a similarity, but also significant differences. The length of stay is substantially longer, as patients often stay longer than a day, but there is more variation in the length of stay. However, as there is no limit on the duration of stay at the inpatient ward, this variation is in most cases higher than that of the day-care ward.

Improvement target

The goal for improving the schedule can be very different between departments. The goal of the day-care ward at ZGV is to optimize the appointment scheduling by decreasing ward occupancy, increasing bed ratio and minimizing the number of patients that are transferred to or scheduled on another ward because of scheduling. The outpatient clinic generally focuses on patient waiting time and server idle time, by which the server is the doctor in this case. The OR generally focuses on server idle time and overtime, by which the server is the OR. The inpatient ward generally focuses on ward occupancy and bed ratio.

Both the OR and inpatient ward have some similarities with the day-care ward. The OR focuses on overtime, which is similar to the number of patients that are transferred to another ward in the day-care ward. The inpatient ward focuses on ward occupancy and bed ratio, which is also a focus of the day-care ward. However, they do not focus on overtime, as the inpatient ward is open day and night.

3.2 Literature search

The literature search methods used to execute the literature review are the backward reference search and the forward reference search. Backward reference searching looks at the references in the article and forward reference searching looks at which articles have cited the article. To have an initial number of articles to apply these methods to, the article by Hulshof et al. (2012) is analysed, which provides a classification of different planning decisions in health care. Papers that might fit the day-care ward are chosen and reviewed. The backward and forward reference search strategies are applied to these papers, and papers resulting from that search are also reviewed on their fit for the day-care ward.

Before stating the findings of this literature search, there are few notes on the literature that came up during the search. These are all connected to the characteristics of the day-care ward.

First, the appointment scheduling for the departments like the OR, outpatient clinic and inpatient wards are widely analysed and represented in literature, whereas the day-care ward is not a concept represented in literature. Therefore, possible planning models and methods have to come from literature that analyses other departments and is altered to fit the day-care ward.

Second, methods from literature analysing the inpatient ward are not considered. The characteristic of the opening hours contradict the day-care ward highly and, therefore, it will be hard to alter the methods to fit the day-care ward.

Third, heuristics for offline scheduling cannot be applied. Heuristics are defined by Foulds (1983) as “a method which, on the basis of experience or judgement, seems likely to yield a good solution to a problem but which cannot be guaranteed to produce an optimum”. In appointment scheduling, the solution to a problem means an improved schedule compared to the initial schedule. Offline heuristics can be applied when using offline scheduling, as this allows the scheduler to alter the schedule before notifying the patients of their appointment. The day-care ward uses online scheduling for monitoring patients, as stated in Chapter 3.1, and therefore any method that uses offline heuristics cannot be applied. However, heuristics such as sequencing rules and appointment rules can be used, as they can be applied to online systems as well.

Last, most of the literature focuses on lowering patient waiting time and server idle time. This is not the goal of improving the schedule for the day-care ward, as mentioned in Section 3.1. However, it is unknown if the same methods can improve the KPIs for the day-care ward. Nonetheless, the best-performing methods for lowering patient waiting time and server idle time are expected to also increase ward occupancy and decrease the number of patients that receive treatment in a different ward.

3.3 Results

The results of the literature search cover four different decision factors. There is a difference between two of those decision factors, sequencing rules and appointment rules, that needs to be addressed first. Sequencing rules refer to determining the order in which the patients are assigned appointments based on the patient's classification (Cayirli, Veral, & Rosen, 2006). Appointment rules refer to determining the number of patients in an appointment slot and the length of that appointment slot. These two terms are used in this chapter. Some articles refer to appointment rules which are defined as sequencing rules by Cayirli et al. (2006). In those cases, the rules will be referred to as sequencing rules.

Under the following headers, the following topics about appointment scheduling for the day-care ward are discussed and the findings presented: appointment rules, sequencing rules, scheduling slack, and days to use rule.

Appointment rules

Appointment rules mostly refer to block scheduling. Block scheduling is often used when scheduling appointments for the outpatient clinic, as this scheduling method was found in articles regarding outpatient clinic scheduling. Block scheduling is an appointment scheduling rule based on the patients arriving in a time block. There is a variety of block scheduling, based on appointment interval, block size and initial block (Wijewickrama, 2006). A block system called single-block was used by most hospitals in the past. This single-block system would schedule all patients to arrive at the beginning of a clinic session. The patient would not have a specific appointment time, and thus this system would create long waiting times for patients, but shortened idle time for personnel.

Another variant of block scheduling is the individual-block system (Wijewickrama, 2006). This block system gives each patient a unique appointment slot and these slots are evenly divided over the clinic sessions. The Bailey-Welch rule is a variant of the individual-block system. The Bailey-Welch rule states that two patients are scheduled on the first appointment slot and the rest of the appointment slots are filled with one patient each (Bailey, 1954).

Sickinger and Kolisch (2009) formulated their version of the Bailey-Welch, the generalised Bailey-Welch rule. This rule states that, as per the Bailey-Welch rule, two patients are scheduled on the first appointment slot and the rest of the appointment slots are filled with one patient each. However, if more patients need to be scheduled that day, they state that patients are scheduled from the second slot on, scheduling one additional patient per slot. If there are still patients that need to be scheduled after all slots have two patients scheduled, the same procedure starts again, but at the first slot. This procedure repeats until all patients for that day are scheduled.

In addition, there is the individual-block system with variable intervals (Wijewickrama, 2006). This rule calls for patients individually with unequal appointment intervals. This means that the appointment time is altered to the treatment time of the patient.

Another variant of block scheduling is the multiple-block system (Wijewickrama, 2006). This system schedules two patients at a time with an interval of twice the treatment time. Another version of this includes the initial block as described in the Bailey-Welch rule, where the initial block has more patients scheduled.

Lastly, another variant of block scheduling is the variable blocks system with fixed intervals (Baril, Gascon, & Cartier, 2014). This rule consists of planning appointment periods of varied sizes with keeping fixed intervals. This means that a block with a fixed interval could consist of various amounts of patients.

To conclude, there are different types of block scheduling. The current type used by the day-care ward is the individual-block system with variable intervals. However, the other types of block scheduling methods cannot be applied to the day-care ward. This is, first, because of the variation in treatment time for each of the treatment groups. Most of the block scheduling methods use fixed intervals, and the day-care ward has different intervals for different treatments. Second, a part of the treatments are dependent on other departments, such as the CT scan. If a patient getting a CT scan has a delay, it also impacts the department where the CT scan is performed, as their schedule will also experience a delay because of it. Therefore, methods like the Bailey-Welch rule, cannot be applied, as this schedules two patients in an individual block, meaning one patient will have a delay, as will the patients in the block after that. Thirdly, the current bed ratio is an average of 1.24, which means that, on average, 1.24 patients lay on a single bed (or server) during one day. Block scheduling generally is applied when scheduling multiple patients on one server. This is not the case for the day-care ward, because of the variable intervals and therefore other kinds of block scheduling rules that do not include variable intervals cannot be applied.

Sequencing rules

Multiple articles discuss sequencing rules and there are multiple rules tested in these articles.

Klassen and Rohleder (2004) use the patient classification based on the variability of the appointment duration. They make two groups, patients with high variability and with low variability, where half of the patients are put in the high variability group, and the other half in the low variability group. With these groups, they test four different sequencing and appointment rules:

1. FCFA: First Come, First Appointment
2. LVBEG: Low variance at the beginning of the day
3. B2: Schedule two patients in the first slot of the day (Bailey-Welch rule)
4. B2+LVBEG: Low variance at the beginning of the day and schedule two patients in the first slot of the day

The B2 and B2+LVBEG rules are not all applicable to the day-care ward, as the appointment slots are not of the same length and the appointment duration differs. Klassen and Rohleder (2004) focus on the outpatient clinic, where these characteristics can be found. Therefore, the B2 and B2+LVBEG rules are hard to apply to the day-care ward. The day-care ward already schedules multiple patients at the same time and is dependent on other departments, and therefore cannot always have a patient be delayed.

They conclude that when looking at patient waiting time and server idle time, the LVBEG rule always performed best, regardless of other factors. However, for server-oriented performance indicators, such as server idle time, server utilization and day end time, B2 performs best, with B2+LVBEG performing almost as good. B2 is set up to reduce server idle time. They also test if there was a significant difference between the rules tested, based on client waiting time and server idle time. In all cases, the LVBEG rule performs statistically better than the other rules.

In an earlier article from Klassen and Rohleder (1996), they also confirm that the LVBEG rule was the best among the set of rules. This is, again, focused on the outpatient ward, and thus not all rules can be applied in the day-care ward. The rules tested were the following:

1. FCFA: First Come, First Appointment
2. 2ATBEG: Two patients in the first slot, identical to B2
3. 4ATBEG: Four patients in the first slot
4. OFFSET: First 5 patients arrive earlier than their given appointment time, the rest arrives later than their given appointment time
5. ALTI-1: Alternate low variance and high variance patients
6. ALTI-5: Alternate low variance and high variance patients, in groups of 5 patients
7. HVBEG: High variance at the beginning of the day
8. HVBND: High variance at the beginning and end of the day
9. LVBEG: Low variance at the beginning of the day
10. LVBND: Low variance at the beginning and end of the day

Cayirli et al. (2006) use the patient classification based on if a patient is a new patient or a returning patient, arguing that new patients generally have a higher mean service time compared to returning patients. With this classification, they test six rules:

1. FCFA: First Come, First Appointment
2. ALTER: Alternate between new and return patients
3. NWBG: Schedule new patients at the beginning of the day, and return patients in the remaining time
4. RTBG: Schedule return patients at the beginning of the day, and new patients in the remaining time
5. NWBND: Schedule new patients at the beginning and end of the day, and return patients in between
6. RTBND: Schedule return patients at the beginning and end of the day, and new patients in between

The results of testing these rules yield that the rules NWBG, ALTER and RTBG generally perform the best among the sequencing rules.

To conclude, the LVBEG is the best performing rule when considering a patient's variance. However, when considering the patient's mean service time, the ALTER, NWBG (high mean service time at the beginning of the day) and RTBG (low mean service time at the beginning of the day) rule all perform well.

Scheduling slack

Hahn-Goldberg et al. (2012) describe adding slack into the schedule as one of the techniques for solving scheduling problems with uncertainty. The method of adding slack into the schedule is mostly used in OR scheduling and is mainly focused on lowering overtime (Hans, Wullink, van Houdenhoven, & Kazemier, 2008). Overtime in the day-care ward is not appliable, as the day-care ward closes at 20:00, but the remaining patients are transferred to other wards, which is, as described in Section 1.2, not desirable.

Hans et al. (2008) discuss the use of scheduling slack in their article about robust surgery loading. Their goal of scheduling slack is to make the surgery schedule more robust against overtime. The slack is based on the variability of the treatment. In the article, they set the amount of slack in such a way that the probability of overtime is approximately 30%, with the assumption that the treatments are normally distributed. The amount of slack is calculated by taking 0.5 times the standard deviation of the total treatment time.

Days to use rule

While following scheduling rules can improve the performance of the day-care ward, it is also important to know when to deviate from those rules. For example, a day would be divided into low variance patients in the morning and high variance patients in the afternoon. If only patients with high variance want an appointment on that day, there would be a high amount of idle time in the morning, and the performance would be poor. In this case, it may be a better choice to fill the schedule with the other patient group than to leave it empty (Klassen & Rohleder, 2004).

Klassen and Rohleder (2004) define the days to use rule (DtoR) as the number of days to use the scheduling rule before filling up the remaining days. They say that, in their case, the DtoR could range anywhere from 0 to 10 days. In this definition, if a patient wants an appointment with a DtoR of 1 day, all of the appointment slots would be open after one day, regardless of the patient's classification.

This definition of the concept will not work for the day-care ward, as each patient and treatment has a different urgency period. However, another definition could fit the day-care ward: days until the use of rule (DuoR). In this regard, a specific number of days is chosen which is the number of days before the specific appointment day that the rules are followed. Once that number of days leading up to the appointment is reached, the rules are not followed for that specific appointment day. For example, if the number of days is three, up until three days before a specific appointment day, the rules are followed. If a patient requests an appointment on that day only three days or less before, the rules are not followed and the patient is scheduled if there is room anywhere in the schedule. With this alteration of the DtoR rule, the DuoR can be applied to the day-care ward.

3.4 Intervention selection and conclusion

The findings of the literature search are used as interventions for the simulation. However, as explained in Section 3.3, not all methods found in literature can be applied to the day-care ward, and therefore some cannot be used. The following methods are analysed for the day-care ward in the remainder of this study:

Sequencing rules:

1. FCFA: First Come First Appointment
2. LVBEG: Low variance at the beginning of the day
3. HVBEG: High variance at the beginning of the day

For sequencing rules, three different rules are chosen. The FCFA rule is the current method of planning and is therefore used for comparison. The other two rules are new rules that originate from the literature and look at the variability of the treatment as an indicator to schedule them at the beginning of the day or not. These rules will have to be altered even more for the day-care ward, as, for example, some of the treatments have an average treatment time of 8 hours and are therefore less flexible to schedule on a day. Therefore, not all treatments will follow the LVBEG and the HVBEG rule.

Slack rules

1. Amount of slack
    a. 0% of the standard deviation
    b. 25% of the standard deviation
    c. 50% of the standard deviation
    d. 75% of the standard deviation
2. Where the slack will be planned:
    a. Directly after the appointment
    b. At the end of the day

For the slack rules, there are two choices to be made: the amount of slack and where the slack will be planned. For the first one, Hans et al. (2008) used 50% of the standard deviation. To gain insights on the impact of the amount of slack, 25% and 75% of the standard deviation are also included. The day-care ward does not schedule any slack currently, so that is the scenario to compare to. Second, where the slack is planned might have an impact on the performance of the day-care ward. Therefore, two options are determined, which are either scheduling the slack directly after the appointment or scheduling the slack at the end of the day.

DuoR

1. 0 days
2. 3 days
3. 1 week

For the DuoR, three options are chosen. First, 0 days, which means that only emergency appointments that arrive the same day do not have to adhere to the sequencing rule and slack rules. Second, 3 days, which means that a maximum of 83% of the capacity is already scheduled. Third, 1 week, which means that a maximum of 76.5% of the capacity is already scheduled. Currently, as no sequencing rule and slack are applied, the days until the use of rule is not applied.

Conclusion

To conclude, three different types of methods result from the analysed literature that can be applicable to the day-care ward, with each having different scenarios. In Chapter 5, these are elaborated on further when discussing the experiment design of the simulation. The alterations to fit the day-care ward, as mentioned for the sequencing rules, are discussed and executed, after which these rules are implemented in the simulation to compare their performance.

Chapter 4: Simulation Design

This chapter discusses the simulation study that is performed to determine the outcome of using the proposed planning models and methods. In Section 4.1, the conceptual model is presented. Then, in Section 4.2, the computer model is explained. Lastly, in Section 4.3, the experiments are clarified.

4.1 Conceptual model

This section discusses the theory of conceptual modelling (Section 4.1.1) and gives the conceptual model for this simulation study (Sections 4.1.2 and 4.1.3)

4.1.1 Theory of conceptual modelling

Part of a simulation study is to create a conceptual model. According to Robinson (2014), a conceptual model is "the abstraction of a simulation model from the part of the real world it is representing". The formal definition is the following :

> "A non-software specific description of the computer simulation model (that will be, is or has been developed), describing the objectives, inputs, outputs, content, assumptions and simplifications of the model" (Robinson, 2008a)

As the definition explains, the conceptual model is non-software specific and also does not involve any coding. Figure 4.1 shows the problem domain of a simulation study. It shows the parts that are involved in conceptual modelling and what comes after. Chapter 2 represents the System description seen in Figure 4.1. By model abstraction can the conceptual model be established from the system description.

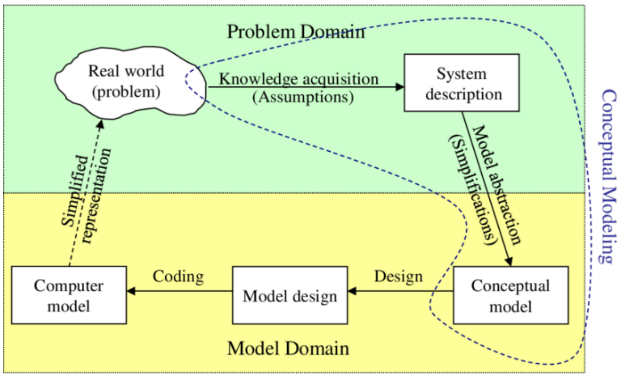

Figure 4.1: Artefacts of conceptual modelling (Robinson, 2011)

To create a conceptual model, Robinson (2008b) created a framework, as shown in Figure 4.2, with five key activities. The first activity is to understand the problem situation. From the problem situation, the modelling and general project objectives are determined, which is the second activity. With these objectives, the experimental factors of the model are determined, which are also called the inputs of the model. Given the inputs, the model content is established. This includes the scope and the level of detail of the model. Next to describing the scope and level of detail, there are more ways of representing the content of the conceptual model. Robinson (2014) explains the five most popular methods of representation as surveyed by Wang and Brooks (2007). From these five popular methods, we choose one method to extend the description of the content: a list of assumptions and simplifications. Lastly, the response of the model is determined. This is what the model gives as output, thus what the model produces.

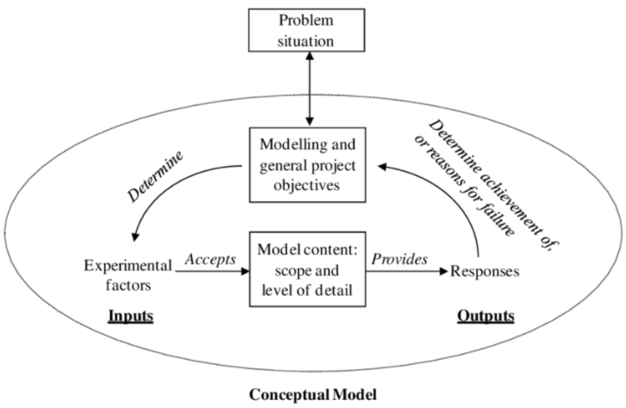

Figure 4.2: A framework for conceptual modelling (Robinson, 2008b)

When creating this conceptual model, Robinson (2014) suggests several requirements for this conceptual model.

He first discusses the four main requirements of a conceptual model. First, a model should be valid, meaning it should produce sufficiently accurate results for the objective of the study. Second, a model should be credible, which entails that the clients, for whom the study is performed, should believe in the model. Third, the model should be feasible, which means it should be feasible to build within the set time and with the given data. Last, the model should have utility. The model should be easy to use, quick to run, flexible and visual.

Another requirement that Robinson discusses is to build the simplest model that meets the objectives of the study. This lowers the complexity of the simulation study to a point that the model is still accurate. Figure 4.3 shows the relationship between complexity and accuracy. Robinson considers point *x* to be the best trade-off between accuracy and complexity. He argues that it has a sufficient level of accuracy for the limited level of detail. If *x* would follow the line to the left, the complexity would be reduced, but it would jeopardize the accuracy. If *x* would follow the line to the right, it would give a limited advance in complexity in comparison to the increase of complexity. The goal is to create a model that a model that has sufficient accuracy, but with the lowest possible complexity. Robinson points out that finding the point *x* is difficult, and one should strive for a sufficient model instead of the best model.

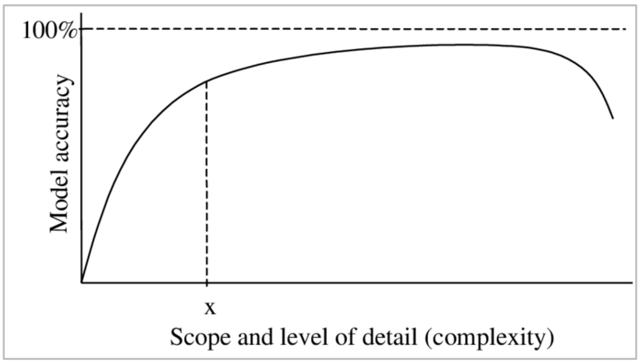

Figure 4.3: Simulation model complexity and accuracy (Robinson, 2008a)

The conceptual model is described in Sections 4.1.2 and 4.1.3. The model validation, based among others on the five requirements mentioned above, is discussed in Section 4.2.

4.1.2 Objective, inputs and outputs

This section describes the objective, inputs and outputs in that respective order.

The objective is the first part that is described in the conceptual model. The research question of this thesis is: What is a tactical basis for the appointment scheduling of the monitoring patients of the day-care ward, that also improves the performance? In Chapter 3, possible interventions are found in the literature that could serve as a tactical basis. The **objective** of the simulation study therefore is:

> *To test which of the interventions gives an improved performance on the four given KPIs compared to the simulated current situation*.

Second, the inputs are the experimental factors. These factors are altered in the simulation to test multiple possibilities. There are four experimental factors in this simulation study, and these are equal to the interventions presented in Section 3.4:

- Sequencing Rule
- Slack Amount
- Slack Location
- DuoR (Day until the use of Rule)

Last, the outputs are the response of the simulation. As Robinson (2014) states, these are the statistics that inform whether the objective is achieved, or if not, why it is not achieved. The outputs in this simulation are the KPIs that measure the performance according to the research question. These are:

- Bed ratio
- Ward occupancy
- Percentage of patients transferred to another ward
- Percentage of patients scheduled at other wards

4.1.3 Scope

The scope of the conceptual model describes what is to be modelled and what is not. As shown in Figure 4.3 in Section 4.1.1, a bigger scope and level of detail does not always generate a significantly higher model accuracy and also is not always an effective way of modelling. To describe the scope, we will go into three sections: component, assumptions and simplifications list.

Component list

Table 4.1 shows the components of the day-care ward and if they are included or excluded in the model. These components are divided into four categories: entity, operations, queues and resources. Surgical patients and related entities are outside the scope of this study and are therefore also not included in the component list and the simulation as a whole. Each of the categories is addressed in the following paragraphs.

Table 4.1: Component List

Component	Included or Excluded
Entity	
Monitoring patients	Included
Surgical patients	Excluded
Nurses	Excluded
Specialists/Doctors	Excluded
Day coordinator	Excluded
Operations	
Arrival time for appointment	Included
Arrival time at the day-care ward	Excluded
Treatment/bedtime at day-care ward	Included
Treatment partially at another department	Excluded
Multiple treatments	Included
Queues	
Waiting at home	Included
Waiting room day-care ward	Included
Waiting to get treatment at another department	Excluded
Resources	
Beds	Included
Materials	Excluded

First, from the entities, only the monitoring patients are included in the simulation. Most noticeable, the nurses are excluded. The interaction between nurses and the treatment of the patient is not described in the data. However, the capacity of the day-care ward is based on the nurses' capacity instead of the number of beds.

Second, from the operations, the arrival time of patients and the treatment part at another department are excluded. The arrival of patients at the day-care ward is not included as there is insufficient data on the arrival rate of patients. The treatment partially at another department is also not included, as the data set given did not have sufficient data to simulate this. Also, given the timeframe, there was not enough time to identify the characteristics of all the other departments where treatments or procedures are performed.

Third, from queues, only the waiting to get treatment at another department is excluded. As stated in the previous paragraph, treatment and procedures at other departments are excluded, and therefore also is the waiting time between departments.

Last, from resources, materials are excluded and beds are included. As mentioned in Section 2.3, most of the time there are enough materials, and in the case there are not, the nurses can easily get access to the materials. Thus, the materials are excluded.

Assumptions and Simplifications

The assumptions and simplifications show how the model is different from the real world. Assumptions fill in gaps in the knowledge of the real world, where simplifications simplify components of the model to make for quick model development and easy use (Robinson, 2008a). This model has three assumptions and nine simplifications (of which we discuss the two most important ones below). An overview of all simplifications is presented in Table 4.2.

Assumption 1: How far the scheduler looks into the future in order to schedule the patient. Each patient has an urgency period assigned, but there is not always enough capacity left on the requested day. However, there are no general rules on how far the scheduler will look in the future, starting from the urgency period. Therefore, we assume that the scheduler will look until twice the urgency period, with the exception of 0 and 1, which are searched until 0 and 3 days respectively. If there is no capacity left, it will then look into the days before the urgency period, if possible, before scheduling the patient at another ward.

Assumption 2: How much capacity can be scheduled in advance. There are no guidelines or rules for how much capacity can be scheduled ahead of time. To have an approximation, the capacity scheduled in advance is calculated for each different urgency period and is based on the average amount of patients scheduled in the patient data from 2018 and 2019.

Assumption 3: How much capacity of the day-care ward is used in the simulation. The total capacity of the day-care ward is shared among the monitoring and surgical patients and is not easily separated. As this research focuses only on the scheduling of the monitoring patients, this poses a difficulty. The scheduling of both types of patients influences each other. There are two options considered: integrating the current surgical patient schedule or estimating the capacity solely for the monitoring patients and only operating on that capacity. The first option was not feasible because of the interaction it has with the schedule of the monitoring patients when it was made, which means that the options to schedule patients in a different matter are limited. Therefore, option two is chosen and the capacity for monitoring patients is estimated at 38% of the total capacity.

Simplification 1: The number of beds used in the simulation is infinite. This is influenced by the third assumption and the scope of this research and is addressed by discussing the advantages and disadvantages of limited beds. An advantage of limited beds is the interaction between the patients and the beds in the simulation, meaning that when beds are full, the patient will have to wait. This also leads to a more realistic percentage of patients transferred at the end of the day. However, limited beds gives their disadvantages as well. The interaction with the surgical patients is not included and the capacity is separated. As the capacity is already separated, the interaction between the beds and the patients does not give the same impact as when the surgical patients are also included in the simulation. Including surgical patients is outside of the scope of the research and, therefore, the decision is made to have infinite beds in the simulation

Simplification 2: How the simulation determines the appointment time and day. The model will not be a smart scheduler. In the real world, multiple limitations and possibilities are considered when scheduling a patient, such as scheduling a certain treatment only on one specific day and choosing a day with the least patient scheduled. The simulation will not consider these limitations and possibilities and will look at the first possible day onwards and will start from the first available timeslot. This makes the model close to reality, but not the same, as modelling all the limitations and possibilities accurately was not possible in the time frame and it would increase the time to run the simulation.

Table 4.2: Simplifications

Simplification	Explanation
Infinite beds	There is no limitation on the number of beds with the aim to decrease model complexity and given the time constraint, as only the monitoring patients are included and the beds are shared among monitoring and surgical patients.
Scheduling choices	When using the FCFA rule, the simulation looks at the next available slot. Any additional limitations that the day-care ward has are not included, as not all are known and lowers the complexity of the model
Material	The material is not simulated, as it rarely impacts the patient's treatment time and is not part of the aim of this research.
Waiting room day-care ward	As there are infinite beds, the patient does not have to wait in the waiting room. However, for recording the patient's information, the waiting room is included in the simulation
Waiting time scheduling	When scheduling a patient, the patient will immediately get an appointment and will not be put on a waiting list and/or scheduled at a later time.
Urgency period	The urgency period is randomized for each appointment. These are based on the distribution of urgency periods for each treatment. When a patient has multiple appointments, these can have the same or very different urgency periods.
No-shows and cancellations	Patient no-shows and cancellations are not included in the simulation.
External influences	External influences, such as machine malfunction, shift changes, traffic jams, and more, are not included as a factor in the simulation.
Patient arrival time at the day-care ward	All patients arrive on time for their appointment.

4.2 Computer model realization

The simulation is created in Plant Simulation, version 14.0. This section describes the dashboard and input data.

4.2.1 Plant Simulation model

Figures 4.4 and 4.5 show the simulation model in Plant Simulation. The computer model is divided into six parts, which are elaborated on individually.

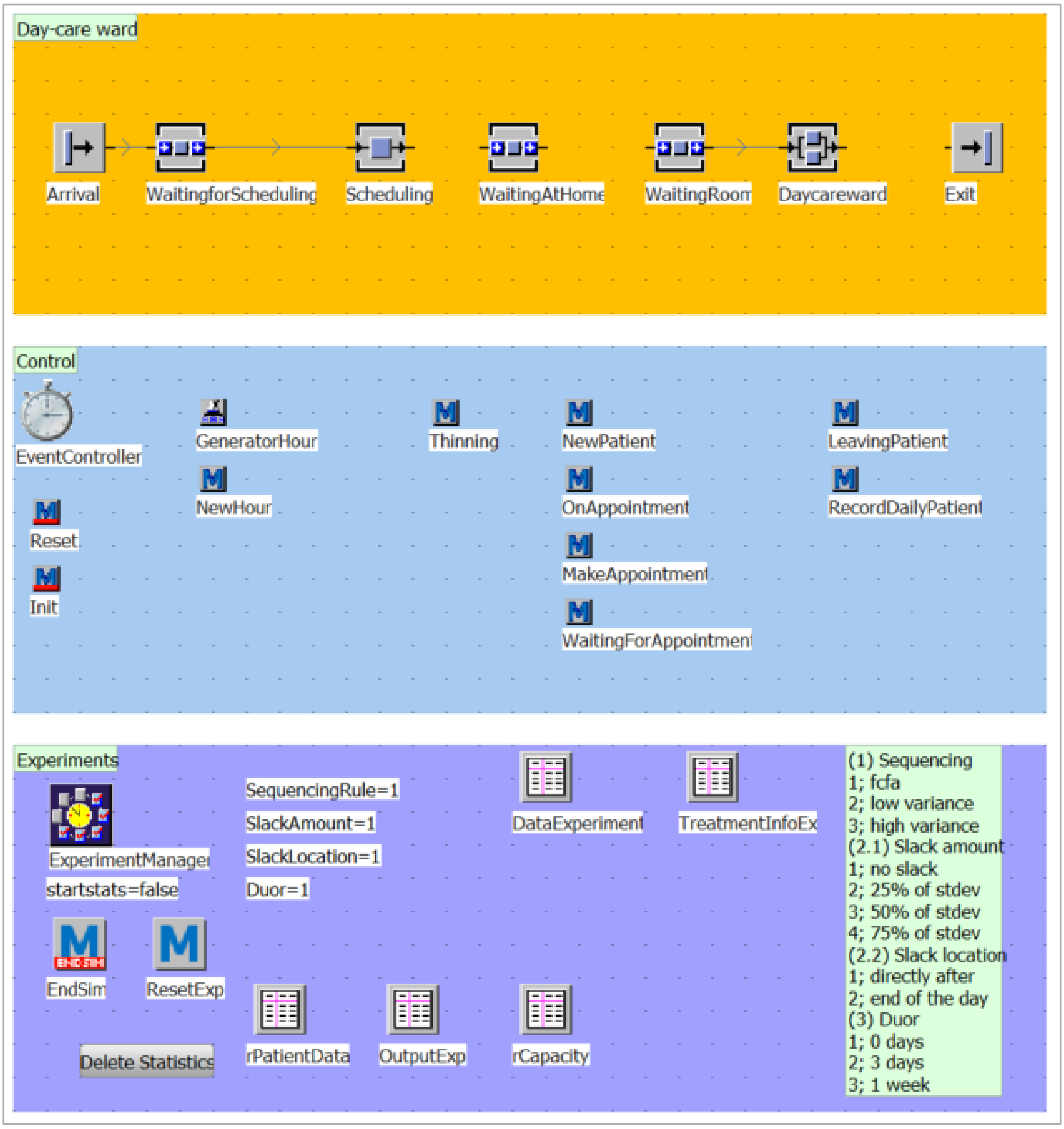

Figure 4.4: Day-care ward in simulation, left side

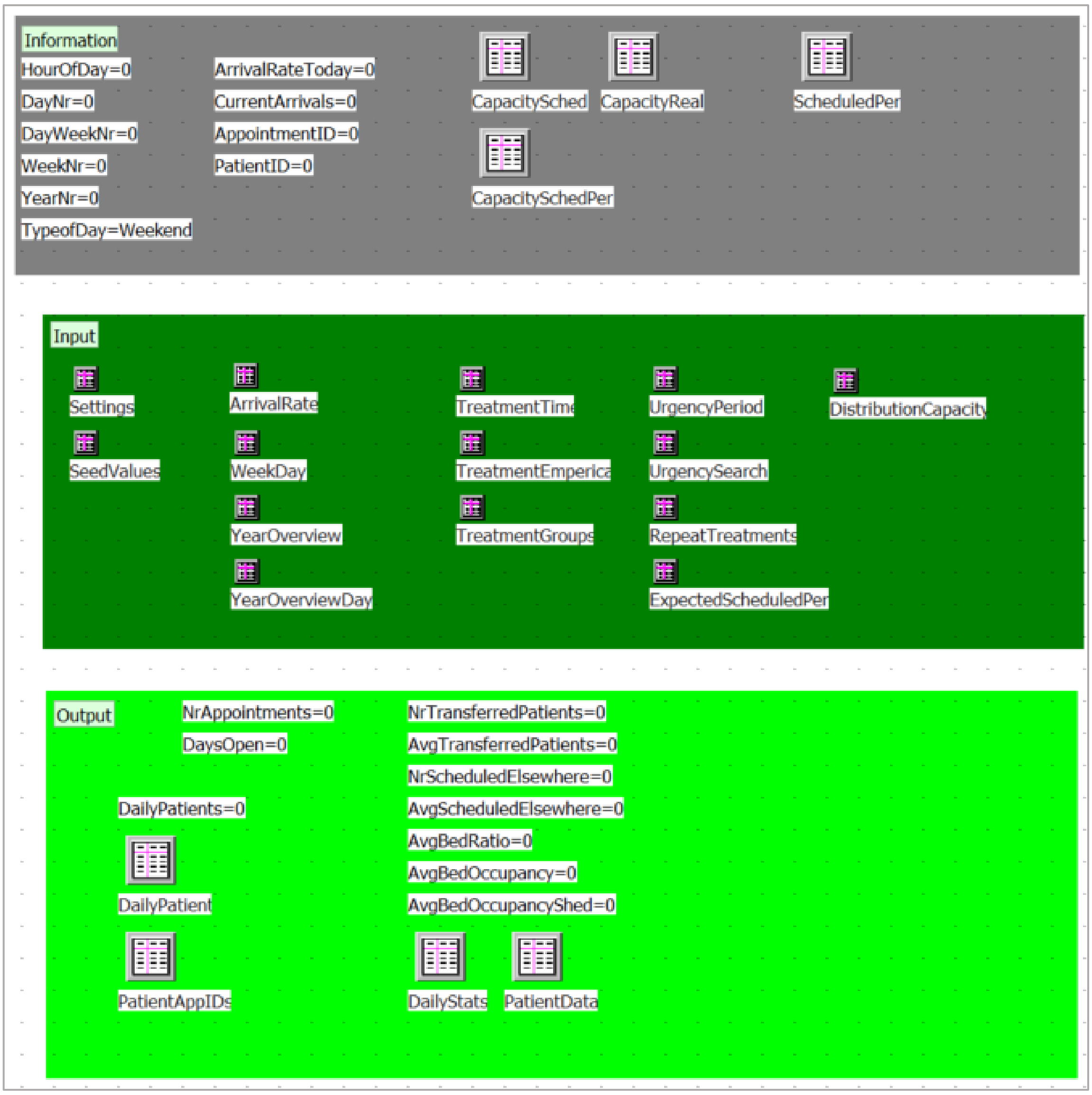

Figure 4.5: Day-care ward in simulation, right side

Day-care ward

This part is the visual part of the simulation. The patients enter the system here and stay until all of their appointments have happened, as visible in Figure 4.4. They immediately schedule all of their requested appointments when they enter the system. If they do not have an appointment the same day as entering the system, they go to the WaitingAtHome queue, which they will leave when they go to their next appointment. They go through the WaitingRoom queue, which records their details, and receive their treatment at the Daycarward. Once their treatment is done, they either leave the system through Exit or go back to WaitingAtHome, depending on if they have other appointments left or not.

Information

This part holds information about the simulation that is neither input or output data, as visible in Figure 4.5. This part keeps track of the hour, day, week and year, and also tracks which type of day it is, what the arrival rate is today, but also how many patientIDs and appointmentIDs have been given out. Next to that, this part tracks the capacity per day in the four tables.

Control

In the Control part of the simulation are all the methods that make control the simulation and determine the schedule, as visible in Figure 4.6. It also involves the method NewHour, which changes the hour every hour in the simulation, and performs tasks at specific hours, e.g. closing the day-care ward at 20:00. The longest method is the method MakeAppointment, which checks the schedule and schedules all the appointments for the patients. Also included in Control is the EventController, the Reset method and the initializing method Init.

Input

The Input part holds all the input information the simulation needs to run, as visible in Figure 4.7. The information is all divided into different tables. More in-depth information about how this data was retrieved and what each table holds can be read in Section 4.2.2.

Output

The Output part has all the output data of a run, as visible in Figure 4.8. Most of the output KPIs are in this part, as well as a few tables that record data from the run, such as PatientData, which holds all the information of the patients that have entered the system since the run started.

Experiment

The Experiment part holds all input and output information for the experiments to run, as visible in Figure 4.9. This includes four variables that determine what experiment is running: SequencingRule, SlackAmount, SlackLocation and Duor. It also includes methods that copy data from the output to the tables in this part to save the data, as the output part resets after each run. Extra information that the simulation needs regarding the sequencing rule and slack amount can be found in table TreatmentInfoEx.

4.2.2 Input data

This subsection gives a more detailed overview of what the input is and how it was retrieved and calculated.

Arrival Rate

The arrival rate to the day-care ward to schedule an appointment is based on empirical data. This was retrieved by adding the number of appointments made at the day-care ward on a day in the year. Those days were then divided into four different day types: Normal, Weekend, Holiday and Reduction. Based on the type of day, which can be Normal, Weekend, Holiday or Reduction, the simulation can randomly choose one of the arrival rates which is related to that day type.

Treatment Time

The treatment times are determined using empirical data from the patient data. Where possible, a statistical distribution is fit on the empirical data. To determine if a statistical distribution fits the empirical data, the following steps, as explained in Robinson (2014), are followed:

1. Select a statistical distribution
2. Determine the parameters of this distribution
3. Test the goodness-of-fit

If no statistical distribution passes the goodness-of-fit test, we use an empirical distribution. Further information on these three steps can be found in Appendix G. The distribution for each of the treatment groups can be seen in Table 4.3. It also shows which treatments from the data set were not included when determining the parameters. The number of low treatment times not included can be seen under “Min deduction” and the number of high treatment times not included can be seen under “Max deduction”.

Table 4.3: Distributions of treatment groups

Treatment group	Number of patients	Distribution	Min deduction	Max deduction
Infuus (inflectra)	2015	Empirical (199;70)	/	1
Infuus (niet inflectra)	988	2-Lognormal (5.09;0.32^2)	93	4
Cathkamer	1119	Empirical (455;103)	/	54
Bloedtransfusie	991	3-Lognormal (5.85;0.30^2;91)	14	9
Ferinject	685	Empirical (160;70)	/	3
Magnesium	557	Empirical (268;104)	/	/
Methylprednisolon	380	3-Lognormal (4.83;0.45^2;26)	/	3
Ct-scan	350	Empirical (253;112)	/	1
Immunotherapie	265	3-Lognormal (5.19;0.51^2;59)	/	1
Phototherapie	253	2-Lognormal (5.26;0.30^2)	/	9
Ct-scan cor	221	2-Lognormal (5.26;0.17^2)	/	3
Ct-scan punctie	160	2-Lognormal (5.71;0.28^2)	/	6
Ct-scan hydratie	147	Empirical (444;86)	/	2
Lumbaalpunctie	143	3-Lognormal (4.87;0.45^2;65)	/	/
Bronchoscopie	105	3-Lognormal (5.15;0.39^2;105)	1	/
Echo leverpunctie	89	Empirical (347;132)	/	/
Synachten	84	3-Lognormal (4.39;0.63^2;63)	/	/
Aclasta	76	3-Lognormal (4.74;0.28^2;6)	/	2
Blaasspoeling	54	3-Lognormal (4.85;0.43^2;57)	/	/
Echo punctie	52	Normal (328;99^2)	/	4
Rest < 3h	164	Empirical	/	/
Rest 3h-5h	169	Empirical	/	/
Rest 5h-7h	165	Empirical	/	/
Rest > 7h	167	Empirical	/	16

Urgency Period

For each treatment, the urgency period distribution is determined by using the patient data. The urgency period listed there is according to the nurses and the schedulers at the outpatient clinics not reliable, so the actual difference between scheduling and appointment was taken as the urgency period. In the simulation, the table shows cumulative percentages for each urgency period per treatment.

Repeat Treatments

For each treatment, the number of repeat treatments that are scheduled at the same time is determined using the patient data. Each treatment has a set of empirical data that contains how many repeat appointments are scheduled per patient. The table containing this data also has a percentage that notes how many of the patients are actually scheduled and who is thinned out of the system. The arrival rate is based on the number of appointments scheduled, and if repeat treatments are scheduled, some of those patients need to be thinned in order to have an accurate arrival rate.

Expected Scheduled

When scheduling patients in the future, there needs to be space in the schedule in the case that patients with a shorter urgency come in. Therefore, the percentage of the capacity that can be scheduled before a certain time is also included in the simulation. For example, when the simulation is looking to schedule an appointment more than 100 days in advance, they can only schedule a total of 17.1% of the capacity. These percentages are based on the patient data by looking at how much of the capacity was scheduled a certain number of days in advance, using the actual treatment time instead of the scheduled time. All the percentages can be found in Table 4.4

Table 4.4: Capacity expected to schedule

Days in advance	Percentage
0	100%
1	97.5%
2	89%
3	83.2%
4	79.4%
7	76.4%
14	65.9%
21	54.1%
28	43.7%
35	37.5%
42	29.8%
49	26.4%
56	23.5%
63	20.8%
70	18.8%
100	17.1%

Distribution Capacity

To test whether there is space in a timeslot, there is a table in the simulation with the distribution of capacity. As the capacity is not bound to the number of beds but the number of nurses, it can change every timeslot. Based on the nurses' schedule and the assumed 38% of the capacity available for monitoring patients, the maximum capacity for each timeslot is determined. There is also a different capacity distribution for normal and reduction days because there are fewer nurses available on a reduction day. In both cases, the maximum capacity is rounded to a whole number.

4.3 Model verification and validation

This section discusses model verification and validation. The aim of model verification and validation is to make sure that the model is sufficiently accurate (Robinson, 2014). Robinson also states that a model that is 100% accurate is unachievable and that a model is not meant to be completely accurate, but a simplified version of the real world that is used for comprehending and exploring reality. Clarification on the theory of model verification and validation as well as the difficulties of model verification and validation can be found in Appendix H. Subsection 4.3.1 discusses conceptual model validation, Subsection 4.3.2 discusses data validation and, lastly, Subsection 4.3.3 discusses verification and white-box validation

4.3.1 Conceptual model validation

Conceptual model validation is a form of model validation that determines if the proposed conceptual model is sufficiently accurate, given the objective. As Robinson (2014) states, there is no formal method to validate a conceptual model. Conceptual model validation is about having confidence that an assumption about the real system is correct. It also focuses on the impact it has if an assumption is incorrect. The assumptions can be assessed as high, medium and low. The assessment of the three assumptions can be seen in Table 4.5.

Assumption	Confidence	Impact
(1) Number of days to schedule in the future	Medium	Medium
(2) Capacity to schedule in the future	High	Low
(3) Capacity of the day-care ward	Medium	High

Table 4.5: Assumptions

The first assumption has medium confidence with medium impact. If the number of days to schedule in the future is too low, it can lead to a high percentage of patients that are scheduled elsewhere. However, having the number be too high can lead to a long run time of the simulation. With the shorter urgency periods, it was advised to look at the maximum twice the time in the future, so that is applied to all the urgency periods, to take the initial urgency period into account when determining the maximum. The confidence is medium, as it falls somewhat on the shorter side. However, the objective of the simulation is to compare the interventions to the simulated current situation, so therefore the impact is medium, as it does give a skewed view, but it applies to all the situations.

The second assumption is the capacity to schedule in the future. As this is based on real world data, the confidence in this assumption is high. The impact it can have is similar to the previous assumption. If the distribution is either too restrictive or too unrestrictive, it impacts the percentage of patients that are scheduled elsewhere. If it is too restrictive, patients with longer urgency periods will be scheduled elsewhere more often. If it is too unrestrictive, patients with shorter urgency periods will be scheduled elsewhere more often. This will presumably have a less drastic impact on the KPIs than the previous assumption, so therefore the impact is put on low.

The third assumption is the capacity of the day-care ward. The issue with setting the capacity, together with the number of beds used in the simulation, has already been discussed in detail in Section 4.1.3. As it is not fully accurate to the real world but does obligate to the objective of this simulation, the confidence is put at medium. However, the impact is high, as it influences almost all KPIs. However, this risk is well thought out and chosen because the alternatives did not decrease this risk or were not possible within the scope or time frame of this research.

4.3.2 Data validation

This form of model validation determines if the data used and analysed in all stages of the simulation study are sufficiently accurate, given the objective. The data should be reliable to be used in the simulation study, and the modeller should make as much effort as possible to ensure that the data is as accurate as possible.

The data used in the simulation model is patient data from the day-care ward from the years 2018 and 2019. These years were chosen to give an accurate representation of the day-care ward, as data from 2020 included the patient data from the COVID-19 pandemic, where fewer patients than normal were in the day-care ward. This period is not a good representation of the day-care ward and was therefore not included in the data.

The raw data is retrieved from the administrative system that the day-care ward and outpatient clinics use. As mentioned in Chapter 2, the data has to be filtered for its different uses, to make sure that irrelevant data points are not included. What data points are filtered depends on what needs to be analysed. For example, when analysing the overall performance of the day-care ward, the surgical patients need to be included, but when the treatment groups of monitoring patients are analysed, these surgical patients need to be excluded.

While working with the data, some parts stood out that had problems and inconsistencies. This was mainly during the filtering of the data, as the data points were evaluated. In a perfect world, these problems would not arise. The exact cause of these inconsistencies and problems is unknown in this research, however, there are possible causes. Human error can be one of the causes, and the amount of human error can be reduced, but can never be totally eliminated. Another possible cause can be poor communication between the departments. As stated in Chapter 1, there are no uniform planning rules for the various departments involved in the planning process. In conversations with outpatient clinic assistants and by looking at the data, it became apparent that different departments schedule differently, such as the use of specific treatment indicators or what to include in the comment, if at all. This can cause irregularities in the data.

A few examples of problems and inconsistencies in the data:

First, when establishing the treatment groups, some of the treatment indicators, on which the groups are based, are generic and do not indicate what kind of treatment is given, such as “Algemeen” (general) and “Overig” (other/rest). In the system, the person making the appointment can add comments to the treatment, and these are visible in the data as well. Some of the data points have another treatment indicator in the comments, so these data points have their treatment indicator changed from a generic one to the one that matches the comment. Others either have no comment or a generic comment. In consultation with the capacity managers of ZGV, these data points are deleted, given that they have no indication of treatment type.

Second, not all of the treatments in the data are performed at the day-care ward. The location of patient admission is recorded in the data, and sometimes this includes treatments at different locations in the hospital. Some of these can be explained by day-care patients forced to be transferred to another ward and can therefore not be deleted before checking. To check which of the treatment indicators are day-care treatments and which are not performed at the day-care ward, one of the nurses at the day-care ward checked the list of treatment indicators that had zero or close to zero treatments at the day-care ward. Two treatment indicators on that list are performed at the day-care ward, but the others are not. The other treatment indicators are deleted from the data.

Third, some treatment indicators appeared more than once but were written differently. Again, these were checked with one of the day-care ward nurses, who informed us which were actually the same and which were actually different. The treatment indicators that described the same treatments were merged into one indicator. For example “blaasspoelen” and “blaasspoeling” were merged.

Last, some monitoring patients have surgery dates. The distinction between surgical patients and monitoring patients is made by if a patient had a surgery date or not. While discussing the treatment indicators with one of the nurses from the day-care ward, she noted that some of the surgical treatment indicators still existed in the list of patients without a surgery date. With help of the nurse, the surgical treatment indicators are deleted from the data only containing monitoring patients’ data points.

All these instances are solved by either consulting staff of the day-care ward or making a well-considered choice on what to do together with capacity management consultants at ZGV. All these choices are to improve the quality of the data set. This sometimes means leaving some questionable data points out of the final set. Appendix A gives some further insights into these choices made.

4.3.3 Verification and white-box validation

Verification and white-box validation are different from each other but are put together in this section as both are performed constantly during model coding (Robinson, 2014). White-box validation is a form of model validation that determines if individual parts of the computer model represent the real world with sufficient accuracy, while verification determines if the computer model is true to the conceptual model.

However, the methods of verification and white-box validation are similar. According to Robinson (2014), there are three different methods of verification and white-box validation: checking code, visual checks and inspecting output reports. Two of these three methods are discussed and how they were applied in this simulation study.

Visual checks

As well as checking the code for data and logic, visual checks are also used for verification and validation. This is performed by running the model and visually inspecting how it performs and what outputs it gives.

The approach for the visual checks is to perform these every time an additional part of the computer model is added. For example, in an earlier version of the model, the option that multiple appointments are added at once was not included. Once this part, or any other part, is added to the computer model, visual checks are performed. In this study, two main visual checks are performed.

First, after the initial coding, a patient is followed through the model step by step, to see if it works correctly. If that is not the case, the code is altered accordingly and the same check is performed again. If the first patient goes through the process smoothly, the process is run for multiple patients. If an error occurs, that patient's situation is examined and the code is altered accordingly. This process repeats itself until no errors occur with any patient.

Second, conditions are set up to force specific events to happen. The aim is to test the code by forcing events to happen and checking if it gives the expected outcome. If these events do not happen as expected, the code is checked step by step and the source of the problem is found. The type of event that is forced will differ between each part of the coding that is tested.

Inspecting output reports

Lastly, the output that the simulation model produces is evaluated. Running a model without any errors does not immediately mean that the model produces the expected results. Therefore comparing actual and expected results is important. Here, expected results are not the desired results, but what you expect the system will produce.

Some of the output reports in the simulation are used to gather data from the simulation, but some output reports are created to test the code. If the actual results are not as expected, the cause will be investigated and the incorrect code will be corrected. Then the results are checked again until it gives the expected results.

4.4 Conclusion

This chapter establishes the simulation design by describing the conceptual model, computer model, and model validation and verification.

The conceptual model serves as a basis for the simulation. It states the objective, which is to test which of the interventions gives an improved performance on the four given KPIs compared to the simulated current situation. Furthermore, the input and output of the model are described, and the scope of the model is clarified.

The computer model is made in Plant Simulation, version 14.0. The model is divided into six parts: day-care ward, information, control, input, output, and experiments. The different input data are also discussed. This model is used to test the experiments in a safe environment, which is covered in Chapter 5.

Last, the model accuracy is discussed by discussing three types of model validation and verification: conceptual model validation, data validation, and verification and white-box validation. These showed that the model is sufficiently accurate for its objective.

Chapter 5: Experiment Design and Results

This chapter covers the design of the experiments and the results from the simulation. Section 5.1, Experiment Design, discusses the different experiments, how these are set up in the simulation and how the experimental design is validated. Section 5.2, the results, covers the results from each experiment for each KPI and will look into more detailed results of the experiments that show improvement according to the objective of the simulation and the research question of this thesis.

5.1 Experiment design

This section goes into the experimental design of this research. It covers the different experiments that are going to be performed, the set up of the simulation and the experiment validation.

5.1.1 Experiments in the simulation

As stated in Chapter 3.4, the interventions can be categorized into three sections: sequencing rules, slack and days until the use of rule (DuoR). Because slack has two different interventions, there are a total of four different types of interventions that are tested in the simulation. They are tested individually, but also together, to see if the interaction between different interventions gives different results.

Sequencing Rule

In this category, there are three different scenarios: first come first appointment (FCFA), low variability at the beginning of the day (LVBEG) and high variability at the beginning of the day (HVBEG).

The FCFA sequencing rule looks at the first possible spot, taking into account the urgency period. It starts on the day the urgency period gives and will look up until twice the urgency period. On a specific day, it starts looking from the beginning of the day and taking the first available spot. If no spot is available, it goes to the next available day.

The LVBEG and HVBEG sequencing rules work similar in the simulation. There is a group of treatments that on average take less than half the opening time of the day-care ward. These are then categorized in high and low variability according to their standard deviation, also taking into account the average number of treatments in a year.

When the simulation wants to schedule an appointment with LVBEG or HVBEG as a sequencing rule, the start time is either before or after 12:00. It otherwise performs the same way as the FCFA rule. There are two reasons for choosing 12:00 and not 13:30 (halfway during the day) as the middle point. First, it is only the start of the appointment and the rest of the appointment can still cross over the 12:00 point. Second, a new shift of nurses starts at 12:00.

Slack Amount and Location

The slack amount can range from 0% to 75% of the standard deviation. In the case that the slack location is after the appointment, the slack is added to the treatment time. In the case that the slack location is at the end of the day, the simulation looks at the first available slot, counting back from the end of the day, that still has capacity left. It then looks if it can schedule the slack between that slot and the time the appointment ends. If it does not fit, it goes to the next available day.

Days until the use of Rule

When an appointment is scheduled with an urgency that is lower than the DuoR, the sequencing rule is FCFA and no slack is scheduled. Every time the possible appointment day is changed, the method checks if it is within the DuoR or not and acts accordingly.

Experiments

To name each of the experiments with a recognizable name, we name each intervention by a letter or number. The identifiers for each intervention can be found in Table 5.1. The current situation of the day-care ward, which is FCFA, no slack and 0 days DuoR, is named F00A0.

Table 5.1 Identifiers Experiments

Intervention	Scenarios	Identifier
Sequencing Rule	First come, first appointment (FCFA)	F
	Low variability at the beginning of the day	L
	High variability at the beginning of the day	H
Slack Amount	0% of the std.dev.	00
	25% of the std.dev.	25
	50% of the std.dev.	50
	75% of the std.dev.	75
Slack Location	After the appointment	A
	At the end of the day	E
DuoR	0 days	0
	3 days	3
	1 week	7

The number of possible combinations is 72. However, only 61 experiments are included in the simulation, as a few will yield the same results. This is due to two interactions between the interventions. First, when scheduling no slack, the location of the slack is irrelevant. In these cases, the slack location identifier A is chosen to label the experiment. Second, DuoR when the sequencing rule is F and the slack amount is 0 is also irrelevant. DuoR sets the sequencing rule back to FCFA and schedules no slack, so when that is already the case, the different DuoR will not impact the simulation. In these cases, the DuoR identifier 0 is chosen.

5.1.2 Experiments set up

To set up the experiments in the simulation, several variables need to be determined. This includes the warm-up period, run length and the number of replications per experiment. Also, the data from each run needs to be recorded. This section goes into how the value of these variables is determined, and both how and what data is used and recorded.

Warm-up period

At the start of the simulation, no appointments are scheduled and scheduling new appointments is quite easy. The system does not have a steady state yet. The data from 2018 and 2019 does not have this initialisation bias, as the day-care ward was already operating before 2018. The simulation, however, does not. That is why the removal of the initialisation bias is important in this simulation.

Robinson (2014) defines the warm-up period as "running the model until it reaches a realistic condition and only collecting results from the model after this point". There are multiple methods for determining the warm-up period. Hoad et al. (2010) found 42 methods and categorised them into 5 main types: Graphical, Heuristic, Statistical, Initialisation bias tests and Hybrid. Hoad et al. recommend one of the heuristic methods called the Marginal Standard Error Test (MSER), created by White (1997).

Using the MSER method, the warm-up period is determined for two different experiments to test if they have a difference. The warm-up period for the first is 67 work days and for the second it is 77 work days. To be safe, a warm-up period of 90 work days is chosen, which is 129 days including the weekends and holidays. The bed ratio is chosen as KPI for this calculation.

Run length

The run length of a simulation is the amount of time the simulation will run on top of the warm-up period. Robinson (2014) argues that there are limited resources for determining the run length. Banks et al. (2009) recommend a rule of thumb when determining the run length, which is to have a run lent of at least ten times the warm-up period. However, Robinson argues that there is no sufficient justification for this ratio and that in the case of a long warm-up period, the run length could be excessive. We choose this rule of thumb as the warm-up period is not too long. This puts the run length at 900 working days, which is 1420 simulation days.

Number of replications

An experiment should be executed multiple times to ensure that the data generated from the simulation is sufficiently accurate when estimating the mean performance (Robinson, 2014). This is performed by changing the seed values in the simulation with each replication. Robinson (2014) discusses three approaches to determine the number of replications: a rule of thumb, a graphical method and a confidence interval method. We chose to use the confidence interval method with a 95% confidence interval. This resulted in the outcome to have three replications per experiment.

Table 5.2 Treatments with a variability label of either High or Low

Treatment	Variability
Aclasta	Low
Blaasspoeling	Low
Capsaicine	Low
Ceftriaxonkuur	Low
CTcontrast	Low
CTcor	Low
Drainwissel	Low
Infuus	Low
Infuus-Inflectra	Low
Mamma	Low
Methylprednisolon	Low
Obstipatie	Low
Rosevin	Low
Scopie	Low
StressMRI	Low
Synacthen	Low
Zolendronine	Low
APD	High
Bronchoscopie	High
Catheterwissel	High
CTpunctie	High
CTscan	High
Ferinject	High
Immunotherapie	High
Lumbaal	High
Magnesium	High
PDT	High
Solumedrol	High
Trombocyten	High

Data used in the experiments

Two sets of data are used to let the simulation run the experiments. Both can be found in a table in the Experiment part of the dashboard. The first data is regarding the sequencing rule. The LVBEG and HVBEG rule both distinguish between high and low variability. Only treatments lasting less than half the opening time of the day-care ward are used in these sequencing rules, so each treatment first had to get a boolean value, true if they were included in these sequencing rules and false if not.

After that, each treatment lasting less than half the opening time of the day-care ward is labelled either high or low variability, as can be seen in Table 5.2. This distinction is made by sorting these treatments on the standard deviation of their treatment time and dividing them according in a way that approximately half of the treatments, taking into account the number of treatments per treatment type, fall under high and low variability.

The second data is regarding the slack amount. The slack amount is a percentage of the standard deviation. As the treatment is scheduled in timeslots of 15 minutes, the slack amount has been divided by 15 and rounded up to make sure the right amount of timeslots is scheduled for the amount of slack.

5.1.3 Experiment validation

As stated in Section 4.3, this form of model validation determines if the experimental procedures used are giving results that are sufficiently accurate, given the objective. Robinson (2014) states that the validation of the accuracy of simulation experiments asks for attention to detail when determining the warm-up period, run length and the number of replications. The simulation is visually inspected when running the experiments by first testing a few and checking if the results are sufficiently accurate.

5.2 Results

This section shows the results of the simulation study. The objective of the simulation study is to test which of the interventions gives an improved performance on the four given KPIs compared to the simulated current situation. There are two things to note before the results are shown.

First, the objective states that the interventions are compared to the simulated current situation. This means that output values do not have to reflect real world effects. With the simplifications and assumptions, the simulated current situation is not the same as the real world current situation and the results of the simulation are therefore not exactly as they would be in the real world. The implications and limitations of this are further discussed in Chapter 6.

Second, an improved performance means, which is also stated in the research question in Section 1.2, that among the four KPIs none show significant worsening and at least one shows significant improvement. Therefore, the only experiments with results that show no significant worsening and at least one improvement are described in more detail. Of the other experiments, which either show no significant improvement or show significant worsening, only the KPI results are shown.

To show results from an experiment are significantly different, the p-value from hypothesis testing is used (Wilkerson, 2008). The most commonly used confidence interval is 95%, which is also applied here. The null hypothesis (H_0) is that data from two different experiments are not significantly different, and the alternative hypothesis (H_a) is that they are significantly different. If the p-value between those two experiments is equal to or lower than 0.05, H_0 is rejected and the H_a is accepted with 95% confidence. If the p-value between those two experiments is higher than 0.05, H_0 is not rejected.

A total of 61 experiments are run, of which the KPI results are shown in Table 5.3. As the legend (Figure 5.1) shows, the darker green cells show the best value of a KPI and the darker red cells show the worst value of a KPI. The lighter shades of both show the values of the KPI that are not significantly different, where the light green shows values that are not significantly different from the best value and the light red shows values that are not significantly different from the worst values.

The current situation, F00A0, has the best performance when it comes to bed ratio and the percentage of patients scheduled at another ward. However, it has the worst performance when it comes to the percentage of patients transferred to another ward. There is only one experiment that shows improved performance, which is H00A7. It has the best performance in ward occupancy and is not significantly different in bed ratio and the percentage of patients scheduled elsewhere. However, it performs significantly better in the percentage of patients transferred.

In the remainder of this section, we discuss the correlation between KPIs, followed by an exploration of each of the KPIs for the best and worst value, as well as compare the experiments F00A0 and H00A7.

Table 5.3: KPI output per experiment

Experiment	Bed Ratio	Ward occupancy	Patients Scheduled Elsewhere	Patients Transferred
F00A0	2.547	78.9%	29.4%	4.6%
F25A0	2.332	72.9%	34.7%	3.8%
F25A3	2.358	73.5%	34.1%	4.2%
F25A7	2.367	73.8%	33.8%	4.3%
F25E0	2.441	73.4%	32.1%	2.1%
F25E3	2.465	74.2%	31.5%	2.1%
F25E7	2.480	74.7%	31.2%	2.2%
F50A0	2.203	68.6%	38.0%	3.3%
F50A3	2.243	69.7%	37.0%	3.8%
F50A7	2.261	70.3%	36.6%	3.9%
F50E0	2.315	67.4%	35.2%	1.5%
F50E3	2.356	68.7%	34.2%	1.6%
F50E7	2.398	70.2%	33.3%	1.6%
F75A0	2.113	65.1%	40.2%	2.5%
F75A3	2.175	67.0%	38.8%	3.3%
F75A7	2.208	68.0%	37.9%	3.5%
F75E0	2.231	64.1%	37.2%	1.2%
F75E3	2.286	65.6%	35.9%	1.2%
F75E7	2.338	67.7%	34.7%	1.3%
L00A0	2.456	77.9%	31.6%	4.1%
L00A3	2.516	79.1%	30.1%	4.1%
L00A7	2.525	79.2%	29.9%	4.1%
L25A0	2.266	72.2%	36.3%	3.8%
L25A3	2.327	73.5%	34.8%	4.1%
L25A7	2.338	73.9%	34.6%	4.0%
L25E0	2.412	74.3%	32.7%	2.6%
L25E3	2.469	75.9%	31.3%	2.6%
L25E7	2.498	76.7%	30.6%	2.6%
L50A0	2.157	68.4%	39.1%	3.4%
L50A3	2.216	69.9%	37.7%	3.7%
L50A7	2.230	70.4%	37.4%	3.7%
L50E0	2.287	67.2%	35.8%	1.8%
L50E3	2.368	69.9%	33.8%	1.8%
L50E7	2.440	72.8%	32.1%	2.0%
L75A0	2.044	64.2%	42.0%	2.6%
L75A3	2.118	66.5%	40.1%	2.8%
L75A7	2.149	67.5%	39.4%	2.9%
L75E0	2.143	60.4%	39.4%	1.4%
L75E3	2.270	64.8%	36.3%	1.5%
L75E7	2.369	68.7%	34.0%	1.6%
H00A0	2.398	76.4%	33.1%	2.2%
H00A3	2.511	78.7%	30.4%	3.3%
H00A7	2.539	79.5%	29.7%	3.6%
H25A0	2.149	70.2%	39.3%	2.5%
H25A3	2.300	73.5%	35.6%	3.1%
H25A7	2.344	74.7%	34.5%	3.2%
H25E0	2.208	71.6%	37.8%	1.6%
H25E3	2.274	73.1%	36.2%	1.6%
H25E7	2.318	74.0%	35.1%	1.7%
H50A0	2.037	66.0%	42.2%	2.3%
H50A3	2.180	69.3%	38.6%	2.9%
H50A7	2.230	70.7%	37.4%	3.0%
H50E0	2.153	70.2%	39.2%	1.5%
H50E3	2.188	70.9%	38.3%	1.6%
H50E7	2.221	71.5%	37.5%	1.5%
H75A0	1.867	60.5%	46.4%	1.9%
H75A3	2.048	64.4%	41.9%	2.7%
H75A7	2.125	66.5%	40.1%	3.0%
H75E0	2.117	69.2%	40.2%	1.5%
H75E3	2.147	69.9%	39.4%	1.5%
H75E7	2.175	70.3%	38.6%	1.5%

Worst value	P>0,05 of the worst value
Best value	P>0,05 of the best value

Figure 5.1: Legend for Table 5.3

5.2.1 Correlations between KPIs

Correlations are often used to determine if there is an association between two variables, but they also indicate how strong it is (Taylor, 1990). The association between two variables and the strength of the correlation is expressed in the correlation coefficient, R. The value of R is between -1 and 1. A negative R indicates that an increase in one variable gives a decrease in the other variable. A positive R indicates that an increase in one variable gives an increase in the other variable. An R of zero indicates that there is no correlation between the two variables.

The absolute value of R expresses the strength of the correlation. There is a labelling system where the absolute value of R is represented by four labels, which are low if $R \leq 0.35$, moderate if $0.35 < R \leq 0.67$, high if $0.67 < R < 0.9$ and very high if $R \geq 0.9$ (Mason, Lind, & Marchal, 1983). The correlations discussed in this chapter are only those that are high or very high.

Among the KPIs, there are two correlations that are high and one that is very high.

First, the correlation between bed ratio and the patients scheduled elsewhere is very high and almost 1. Figure 5.2 shows the scatter graph of this relation and the trendline that corresponds with it. The R-value of -0.9998 indicates that if the bed ratio is higher, the percentage of patients scheduled elsewhere is lower. This is clear, as fewer patients are scheduled outside of the day-care ward, more patients are scheduled at the day-care ward, and as the time frame is the same for every experiment, this does indicate an increase in bed ratio.

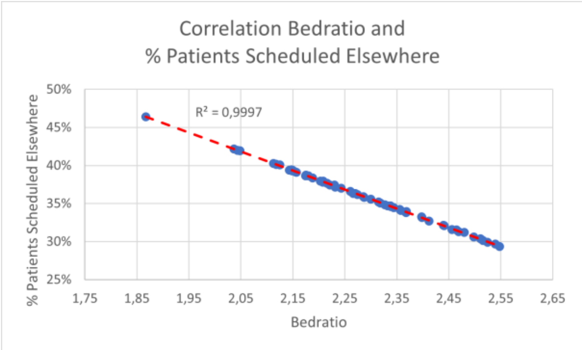

Figure 5.2: Correlation Bed Ratio and Percentage of Patients Scheduled Elsewhere

Second, the correlation between ward occupancy and the percentage of patients scheduled elsewhere is high. Figure 5.3 shows the scatter graph of this relation and the trendline that corresponds with it. The R-value of -0.8267 indicates that if the ward occupancy is higher, the percentage of patients scheduled elsewhere is lower.

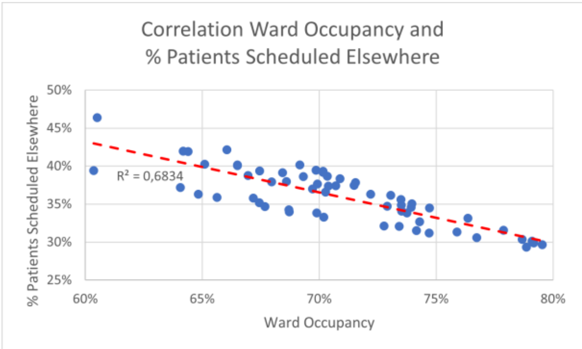

Figure 5.3: Correlation Ward occupancy and % Patients Scheduled Elsewhere

Last, the correlation between bed ratio and ward occupancy is high, with an R-value of 0.8257. The R-value is a positive value, which is expected as they are both higher when the percentage of patients scheduled elsewhere is lower. Figure 5.4 shows the scatter graph of this relation and the trendline that corresponds with it.

The R values between ward occupancy and both bed ratio and the percentage of patients scheduled are quite similar. As the bed ratio and the percentage of patients scheduled elsewhere have an R of almost 1 together, their correlation with ward occupancy being similar is logical.

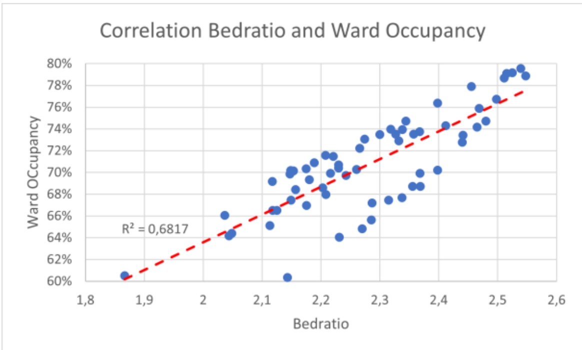

Figure 5.4: Correlation Bed Ratio and Ward occupancy

5.2.2 Bed ratio

The simulated current situation, F00A0, performs best with a bed ratio of 2.547, and H00A7 is second with a bed ratio of 2.539. The p-value between F00A0 and H00A7 is 0,265, which means that the null hypothesis is not rejected and we assume the output is not significantly different. No other experiments have a p-value lower than 0.05 with F00A0 The worst performing experiment is H75A0, with a bed ratio of 1.867, and no other experiments have a p-value with H75A0 which is equal to or lower than 0.05.

Bed ratio as a KPI has a high correlation with the slack amount, with an R of -0.7352, as shown in Figure 5.5. This indicates that an increase in slack amount gives a decrease in bed ratio. As slack is added to the schedule, fewer patients get scheduled on a specific day, which causes the bed ratio to go down.

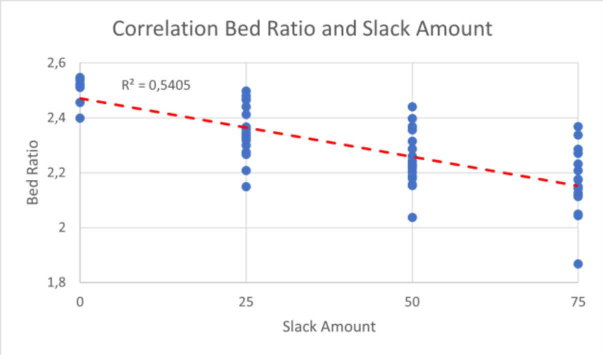

Figure 5.5: Correlation between Bed ratio and Slack Amount

Each different slack amount has a visible lowest value of bed ratio, which are H00A0, H25A0, H50A0 and H75A0. This shows us that the combination of HVBEG, putting the slack immediately after the appointment and 0 DuoR performs the worst on bed ratio within its value of slack amount.

5.2.3 Ward occupancy

The experiment with the best performing ward occupancy is H00A7 with a ward occupancy of 79.5%. Three other experiments have a p-value higher than 0.05 with H00A7, which are L00A7, L00A3 and F00A0 with p-values of 0.254, 0.195 and 0.084 respectively. This means that the null hypothesis is not rejected for all these experiments and we assume their output is not significantly different from H00A7. The worst performing experiment is L75E0 with a ward occupancy of 60.4%. The experiment H75A0 has a p-value of 0.559 with L75E0 and we, therefore, assume their output is not significantly different from L75E0.

To further examine the difference between H00A7 and F00A0, as their ward occupancy is not significantly different, the distribution during the day and admission and discharge during the day were visualized.

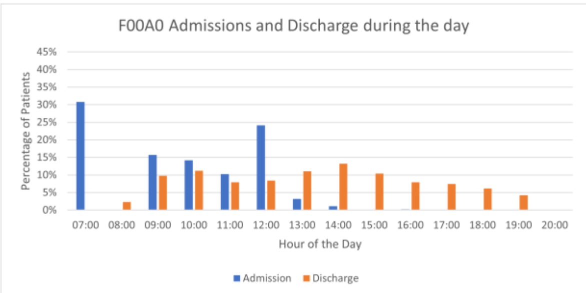

Figure 5.6: F00A0 Admission and Discharge

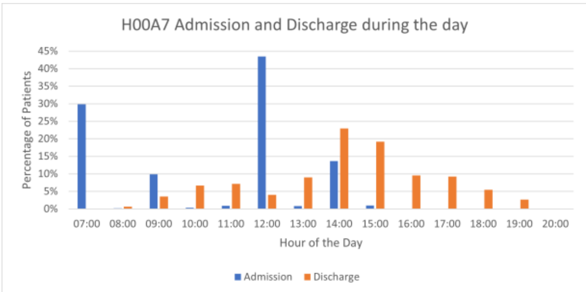

Figure 5.7: H00A7 Admission and Discharge

Figures 5.5 and 5.6 show the admission and discharge distribution of F00A0 and H00A7 respectively. Both have their two highest admissions at the same time, 07:00 and 12:00. However, F00A0's highest peak is at 07:00, while H00A7's highest peak is at 12:00. Also, we can see that the distribution of discharged patients is more widely distributed with F00A0 compared to H00A7, but both have their peak of discharged patients at 14:00.

One of the reasons why both have a peak at 12:00 is that a new shift of nurses starts at that time, which increases the capacity and more patients can be scheduled at that time. However, with H00A7, the sequencing rule determines that treatments labelled with low variability and that have an average treatment time of less than half a day can only be scheduled after 12:00. This causes more patients to be scheduled at 12:00.

As mentioned in the simplifications in Section 4.1.3, the simulation chooses the first available slot to schedule the patient. This results, as can be seen in Figures 5.6 and 5.7, that most patients are scheduled at the first available spot and the admission rates peak at those slots.

The effect of the admission and discharge distribution can be seen in Figures 5.8 and 5.9, which show the boxplot of the ward occupancy per hour for F00A0 and H00A7 respectively.

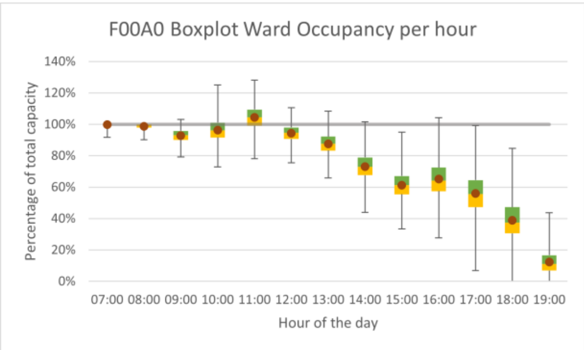

Figure 5.8: F00A0 Ward occupancy per

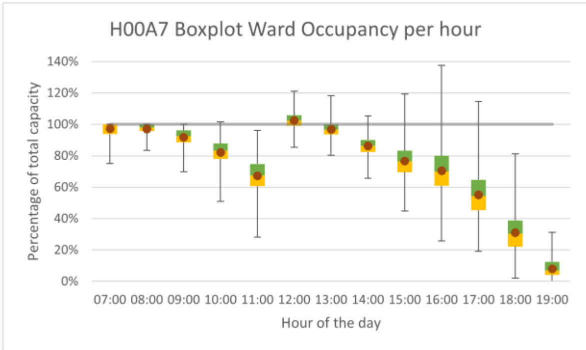

Figure 5.9: H00A7 Ward occupancy per

The 12:00 peak of H00A7 can also be seen in Figure 5.9, as well as a lower number of admissions between 08:00 and 11:00 compared to F00A0, which is closer to 100% average ward occupancy around those hours, while H00A7's average ward occupancy decreases.

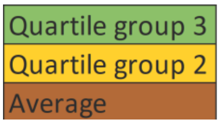

Figure 5.10: Legend for Figures 5.8 and 5.9

Ward occupancy as KPI has a high correlation with the slack amount, with an R of -0.8996, which is visible in Figure 5.11. This is expected, as ward occupancy and bed ratio are positively correlated and bed ratio also had a negative correlation with the slack amount. This negative correlation indicates that an increase in slack amount gives a decrease in bed ratio. As slack is added to the schedule, fewer patients get scheduled on a specific day. A possible explanation for this is that adding slack to the treatment time covers more of the patients' treatment time. This can increase the number of times a patient's treatment is shorter than the expected treatment time and the slack combined, which can lower the ward occupancy.

Each different slack amount has a visible lowest value, which are the same values as in Figure 5.5 in Section 5.2.2. This is likely due to the correlation between bed ratio and ward occupancy.

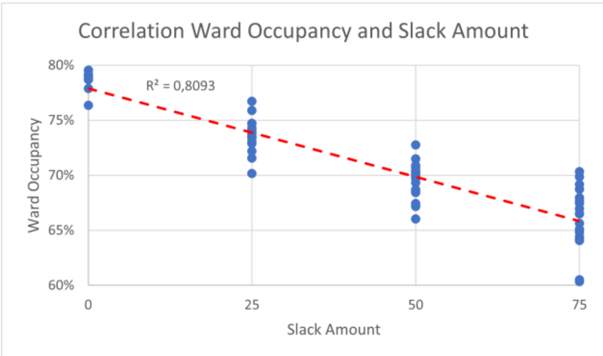

Figure 5.11: Correlation Ward occupancy and Slack Amount

5.2.4 Patients scheduled elsewhere

The experiment with the best performing percentage of patients scheduled elsewhere is F00A0. This is not unexpected, as F00A0 is the best performing in both bed ratio and percentage of patients scheduled elsewhere and those two are very highly correlated as shown in Section 5.2.1. There are nine other experiments with a p-value higher than 0,05 with F00A0: F25E3 (p=0.079), F25E7 (p=0.11), L00A0 (p=0.069), L00A3 (p=0.446), L00A7 (p=0.573), L25E3 (p=0.095), L25E7 (p=0.237), H00A3 (p=0.35), and H00A7 (p=0.758). This means that the null hypothesis is not rejected for all these experiments and we assume their output is not significantly different from F00A0. The worst performing experiment is H75A0, which is also not unexpected, as it also performed the worst for bed ratio. No other experiments have a p-value that is equal to or lower than 0.05 with H75A0.

The results for F00A0 and H00A7 for the percentage of patients scheduled elsewhere are not significantly different. However, this does not have to mean that other aspects are different. Two aspects of appointments are compared for F00A0 and H00A7 in regards to the percentage of patients scheduled elsewhere: urgency period and treatment type. Both can influence if a patient can be scheduled within the urgency period or not.

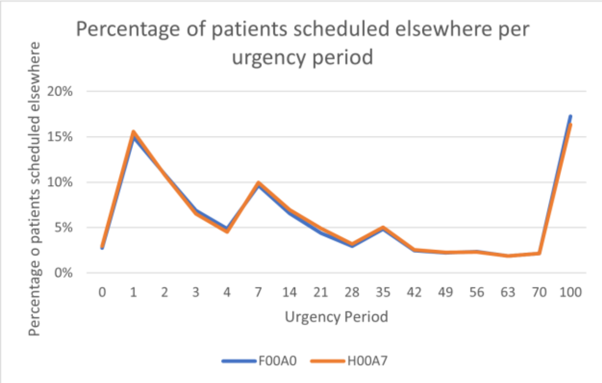

Figure 5.12: Percentage of patients scheduled elsewhere per urgency period

Figure 5.12 depicts the comparison of the percentage of patients scheduled elsewhere per urgency period for both F00A0 and H00A7. The two distributions follow almost the same trend. The correlation coefficient between the two lines is 0.997, which indicates that they are very highly correlated.

Figure 5.13 shows what percentage of the patients scheduled elsewhere had which treatment type for both F00A0 and H00A7. This graph shows only the treatments that had more than 1% for either experiment, as 42 of the 56 treatment types were lower than 1%. The two are quite similarly distributed, which is reflected in the correlation coefficient, which is 0.9902. This indicates that they are very highly correlated.

For both F00A0 and H00A7, the Bloedtransfusie is the treatment with the highest percentage. Bloedtransfusie has three aspects that could explain why the percentage of patients scheduled is the highest for this treatment. First, its average treatment time is 455 minutes, which is around 7.5 hours (see Section 2.2). Second, it is the third largest treatment group (see Section 2.2). Third, approximately 59% of its urgency periods are two days or lower. The combination of these three aspects makes this treatment hard to schedule and that can explain the high percentage for both F00A0 and H00A7.

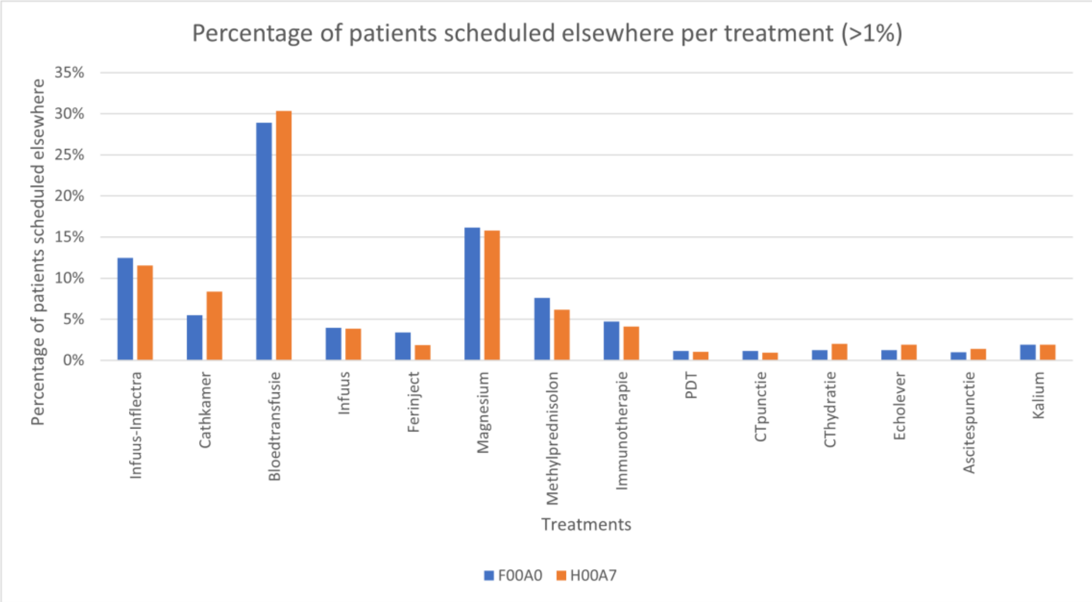

Figure 5.13: Percentage of patients scheduled elsewhere per treatment (>1%)

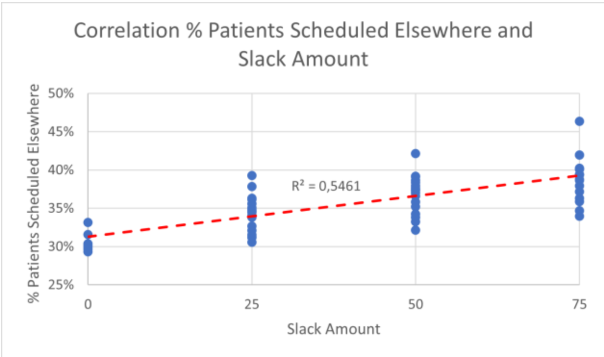

Figure 5.14: Correlation % Patients Scheduled Elsewhere and Slack Amount

Percentage of patients scheduled elsewhere as KPI has a high correlation with the slack amount, with an R of 0.7390, and is shown in Figure 5.14. This is expected, as the percentage of patients scheduled elsewhere and bed ratio is very highly and negatively correlated and bed ratio also has a correlation with the slack amount. This negative correlation also explains why the bed ratio has a negative correlation, but the percentage of patients scheduled elsewhere has a positive correlation with the slack amount. The correlation as depicted in Figure 5.14 indicates that an increase in slack amount gives an increase in the percentage of patients scheduled elsewhere. As a probable cause for this correlation, the more slack is added to the schedule, the quicker schedule will be full with fewer patients scheduled, which can cause other patients to be scheduled at another ward if no day within their urgency is available.

Each different slack amount has a visible highest value, which are the same values as in Section 5.2.2 and 5.2.3. This is likely due to the correlation between the percentage of patients scheduled elsewhere, bed ratio and ward occupancy.

5.2.5 Patients transferred

The experiment with the best performing percentage of patients scheduled elsewhere is F75E0. There is another experiment with a p-value higher than 0.05 with F75E0, which is F75E3, with a p-value of 0.88. This means that the null hypothesis is not rejected for all these experiments and we assume their output is not significantly different. The worst performing experiment is F00A0, and F75E0 shows an almost 74% decrease in patients transferred compared to it. Another experiment shares a p-value higher than 0.05 with F00A0 and that is F25A7 with a p-value of 0,056. We, therefore, assume their output is not significantly different.

The results of H00A7 are significantly different from both F00A0 and F75E0, with p-values of 0,002 and 0 respectively. However, this means that H00A7 performs significantly better than F00A0, with a decrease of 21.7% in patients transferred. The difference between the two will be shown by looking into different treatment types of the appointments. Figure 5.15 shows what percentage of the transferred patients had which treatment type for both F00A0 and H00A7. This graph shows only the treatments that had more than 1% for either experiment, as 40 of the 56 treatment types were lower than 1%.

For both experiments, the Cathkamer treatment has the highest percentage. However, the percentage is considerably higher for F00A0 than H00A7, 57.57% compared to 24.32% respectively. There are a few properties the Cathkamer treatment has, that can make its percentage of transferred patients higher. First, its average treatment time is 455 minutes, which is around 7,5 hours (see Section 2.2). Second, it has a high number of high treatment times in its empirical distribution (see Section 4.2.2). Third, it is the second largest treatment group (see Section 2.2). The combination of these three aspects gives probable cause that the chances of getting transferred are higher. A possible explanation of why the F00A0 experiment has a higher percentage than H00A7 is the sequencing rule. Since part of the treatments are scheduled after 12:00, it is probable that the Cathkamer treatment has more possibilities to be scheduled starting in the morning and has, therefore, on average, additional slack before the closing of the day-care ward.

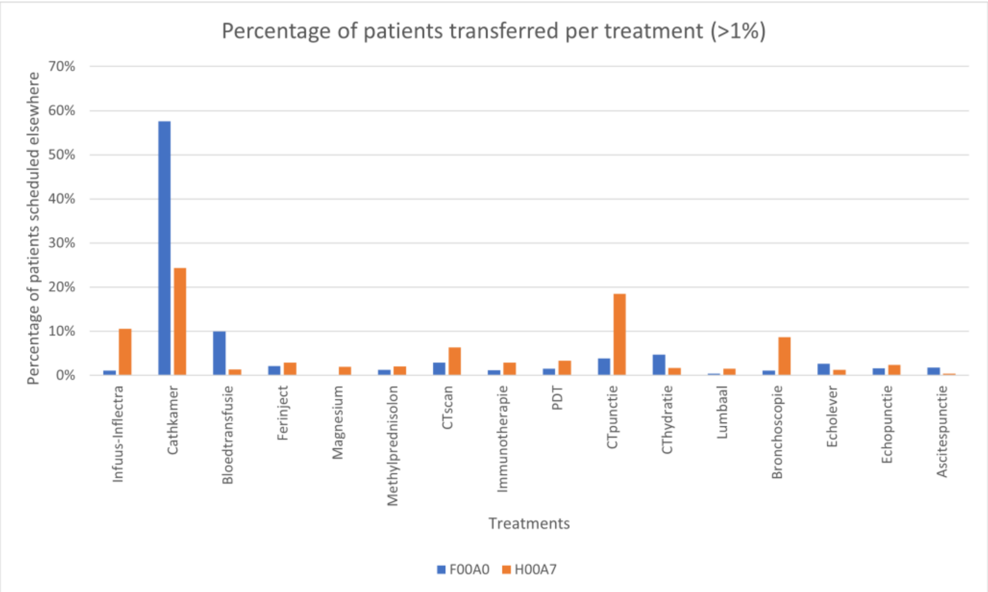

Figure 5.15: Percentage of patients scheduled elsewhere per treatment (>1%)

The percentage of patients transferred as KPI has a high correlation with the location of the slack, with an R of -0.8309, and is shown in Figure 5.16. The number 1 represents slack added immediately after the appointment and the number 2 represents slack added at the end of the day. The negative correlation shows that when the slack is scheduled at the end of the day, the percentage of patients transferred will be lower, and when the slack is scheduled immediately after the appointment, the percentage of patients transferred will be higher.

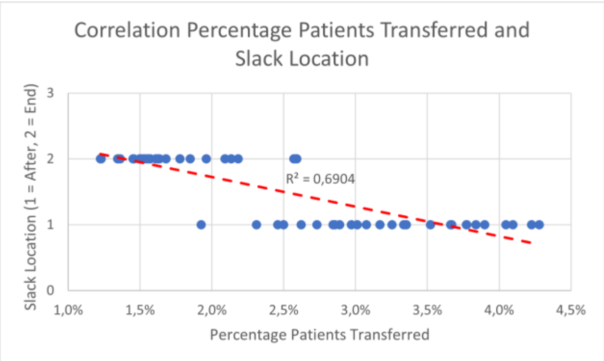

Figure 5.16 Correlation Percentage Patients Transferred and Slack Location

5.3 Conclusion

This chapter discusses the experimental design and the results of those experiments.

The simulation tests four different interventions: sequencing rules, slack amount, slack location and DuoR. Each has multiple scenarios, and a total of 61 experiments, including the current situation F00A0, are performed in the simulation. The simulation has a warm-up period of 129 days, a run length of 1420 days and uses 3 replications of each experiment.

Of all the experiments, H00A7 is the only experiment that shows overall improvement in the KPIs compared to F00A0. H00A7's performance of the KPIs bed ratio, ward occupancy and percentage of patients scheduled at another ward is not significantly different from F00A0. However, the percentage of patients transferred to another ward decreased by 21,7%.

We also observe some correlations between KPIs and interventions. The KPIs bed ratio, ward occupancy and percentage of patients scheduled at another ward are all highly correlated. These three also all highly correlated with the amount of slack scheduled. Furthermore, the percentage of patients transferred to another ward is highly correlated with the location of the slack.

These results are further concluded and discussed in Chapter 6, where the implications of these results are elaborated, as well as limitations of this research, implementation advice based on these results and suggestions for further research.

Chapter 6: Conclusion and Recommendation

This chapter concludes this research and gives recommendations to ZGV. It discusses the practical and theoretical implications, the limitations of this research and the possibilities for further research.

6.1 Conclusion

This thesis has as main research question: *What is a tactical basis for the appointment scheduling of the monitoring patients of the day-care ward, that also improves the performance?* To establish a tactical basis, three different methods were used: an analysis of the current situation, literature research for interventions, and a simulation study.

The data analysis served as the problem analysis phase of the MPSM and gave insights into the current planning process, the different types of treatments, the resources available, and the performance of the day-care ward. This gave an input basis for the simulation, but also provides some insights into how the day-care ward operates. Some of the results from the analysis confirm what the nurses already thought was the case, but were never confirmed, and some of the results gave new insights. It also provided a more precise list of treatment groups.

The literature research served as the solution generation phase of the MPSM and provided possible interventions to be applied to the day-care ward. The day-care ward is not a concept widely present and researched in the current literature, so possible scheduling methods and models were generated from other known parts of a hospital: the OR, outpatient clinic and inpatient ward. This resulted in three different scenarios to be tested: sequencing rules, slack (amount and location) and DuoR.

The simulation study served as the solution choice phase of the MPSM and tested the performance of the different scenarios generated from the literature review by simulating the day-care ward. Out of the 60 experiments, only one combination had a better overall performance than the simulated current situation, which was H00A7. This intervention used the HVBEG sequencing rule, which schedules only high variability treatments in the morning, and had a DuoR of 7 days, which means that the sequencing rule was not followed if the patient was scheduled within 7 days. H00A7 did not perform significantly better from the simulated current situation on bed ratio, ward occupancy and the percentage of patients scheduled elsewhere, however, it performed significantly better with the percentage of patients transferred, with a decrease of 21.7% patients transferred.

To conclude, a tactical basis for the scheduling of monitoring patients that improves performance is H00A7, which means applying the sequencing rule HVBEG and a DuoR of 7 to the day-care ward scheduling process.

Theoretical implications

Next to the practical implications, which are the results of this thesis which can be used by ZGV to change their planning process, this research also has theoretical implications. To start, the day-care ward is not prominent in the existing literature, despite its unique characteristics. These characteristics are the limited opening hours, the use of online scheduling, and the appointment length based on the treatment type. Furthermore, this research tested several known planning models and methods that work for the other departments, and the findings show how these influence the performance. Adding slack decreases the bed ratio, ward occupancy and the percentage of patients scheduled elsewhere, but when adding the slack at the end of the day, it decreases the percentage of patients transferred significantly. Also, the combination of a sequencing rule based on variability and time frame to not apply the rules (DuoR) improves the overall performance.

Limitations

This thesis has some limitations, most of which relate to the scope and the simulation.

The first limitation is regarding the scope. The surgical patients are excluded from this research, while they are connected with the monitoring patients in the day-care ward. Separating the two types of patients gives only a partial view of the day-care ward and the interaction between the scheduling of these patients is lost. There are multiple reasons for choosing to separate the two patient types, but the main reason is that the surgical patients are scheduled by the surgical room planners, who not only schedule day-care surgeries but all the surgeries. To analyse and research this planning process as well is valuable to this research, but does not fit within the time frame. This influences the creation of the simulation, as it does not reflect the day-care ward as accurately as it would with the surgical patients included.

Another limitation that relates to the simulation followed from excluding the surgical patients in this research. The capacity of the day-care ward is for all patients and this needed to be set to determine the capacity for the simulation. The day-care ward does not divide their capacity evenly every day, some days include more surgical patients while other days include more monitoring patients. The capacity of the nurses is estimated at 38%, but we made a decision to not include bed capacity in the simulation (see Section 4.1.3) and use infinite beds. This has the effect that patient waiting times were not included, as well as delays in treatment because of full capacity. However, to accurately include this capacity, the surgical patients need to be included in the simulation.

Lastly, another limitation is regarding the way the simulation searches for an appointment slot. It currently looks for the first available spot and does not use, for example, heuristics to find the best available spot. The day-care ward has a few limitations in place when it comes to scheduling patients, such as contacting the day-care ward when the appointment is within two weeks. These are not included in the simulation, as it would increase the complexity of the simulation, which could lead to a long run time. To have a more accurate simulation model, these operational level decisions could be included, but that does mean fewer experiments have to be performed to make sure the simulation does not take too long to run.

To conclude, the simulation model is a very simplified version of the day-care ward but served its purpose with the objective of the simulation study. However, for more accurate results that are comparable to the real world data, a bigger, more complex simulation is needed.

6.2 Implementation advice

To follow the conclusion of this research, we advise ZGV to implement a version of H00A7. As mentioned in Section 6.2, the simulation is a more simple representation of the day-care ward and the results should be carefully considered. However, H00A7 showed overall improved performance compared to the simulated current situation and can therefore be considered when implementing changes to the appointment scheduling on a tactical level.

First, the sequencing rule, HVBEG, can be implemented by labelling treatments that have an average treatment time under 6.5 hours (half the opening time of the day-care ward) either as high variability or low variability. When scheduling these treatments, they have a limited time frame where they can be scheduled. The simulation puts this switch at 12:00, but 13:30, which is exactly in the middle of the opening hours, or somewhere in between can also be considered. High variability patients can only have the start of their appointment before the given time and low variability patients can only have the start of their appointment after the given time.

Second, the DuoR of 7 days can be implemented in combination with the sequencing rule, as it applies to it. Currently, when an outpatient clinic is scheduling a patient within two weeks, they have to contact the day-care ward. In the same fashion, if the appointment is within one week, they would not have to adhere to the limited time frame. Another possibility is to also put the DuoR at two weeks for easy use and to avoid confusion, but the performance impact of that intervention is unknown and needs further research.

Third, H00A7 does not include scheduling any slack, as the performance of the KPIs bed ratio, ward occupancy and the percentage of patients scheduled elsewhere goes down. However, if there is a need to lower the number of transferred patients regardless of the other three KPIs, adding slack to the schedule can be useful, especially when the slack is scheduled at the end of the day. The effect slack will have on other performance indicators, such as patient waiting time and variability of ward occupancy during the day, is unknown in this research.

Besides the implementation of H00A7, we also suggest that this tactical basis is communicated to all the stakeholders. During this thesis, it became clear that not everyone is on the same page regarding scheduling patients at the day-care ward. The day-care ward already has made some effective steps to improving communication, and making sure that new implementations are communicated effectively will add to those efforts.

Also, we suggest that the treatment groups created in Chapter 2 are implemented. There were many inconsistencies in the treatment groups and how patient data was recorded in the patient data. To improve the data coming from the day-care ward, a clear method on how an appointment is registered might be helpful. This will also make future research at this department easier to perform.

6.3 Future research suggestions

The topics for future research can be categorized into two categories: based on the limitations of this research and based on opportunities to improve found by this research, but outside the scope.

The limitations of this research call for further research of the day-care ward. First, a more accurate simulation model would include the surgical patients and their scheduling process. In this model, the inclusion of the beds would be relevant and would make the results more accurate. Second, more operational level scheduling decisions could also be included and researched, as they affect the KPIs, as well as make a simulation model more accurate.

The following three opportunities for further research were found while doing this research, but were outside the scope:

First, in the current set up, including slack is found not beneficial. However, there are more possibilities with including slack, such as adding slack only to high variability treatments or the effect they have on KPIs that were not included in this research, such as patient waiting time and the effect of variability during the day on the nurses.

Second, not all scheduling methods are tested. Broader research on different types of interventions and their effect on the tactical level of appointment scheduling of the day-care ward could give more insights. An example is differentiating between new and returning patients (mentioned in Section 3.3).

Third, the current appointment scheduling for the day-care ward is decentralized, as the outpatient clinics schedule the monitoring patients themselves and the surgical room planning department schedules the surgical patients. As stated in Section 1.2 this decentralization causes some issues in the planning process. Research into a possible centralised planning process could be beneficial to the day-care ward.

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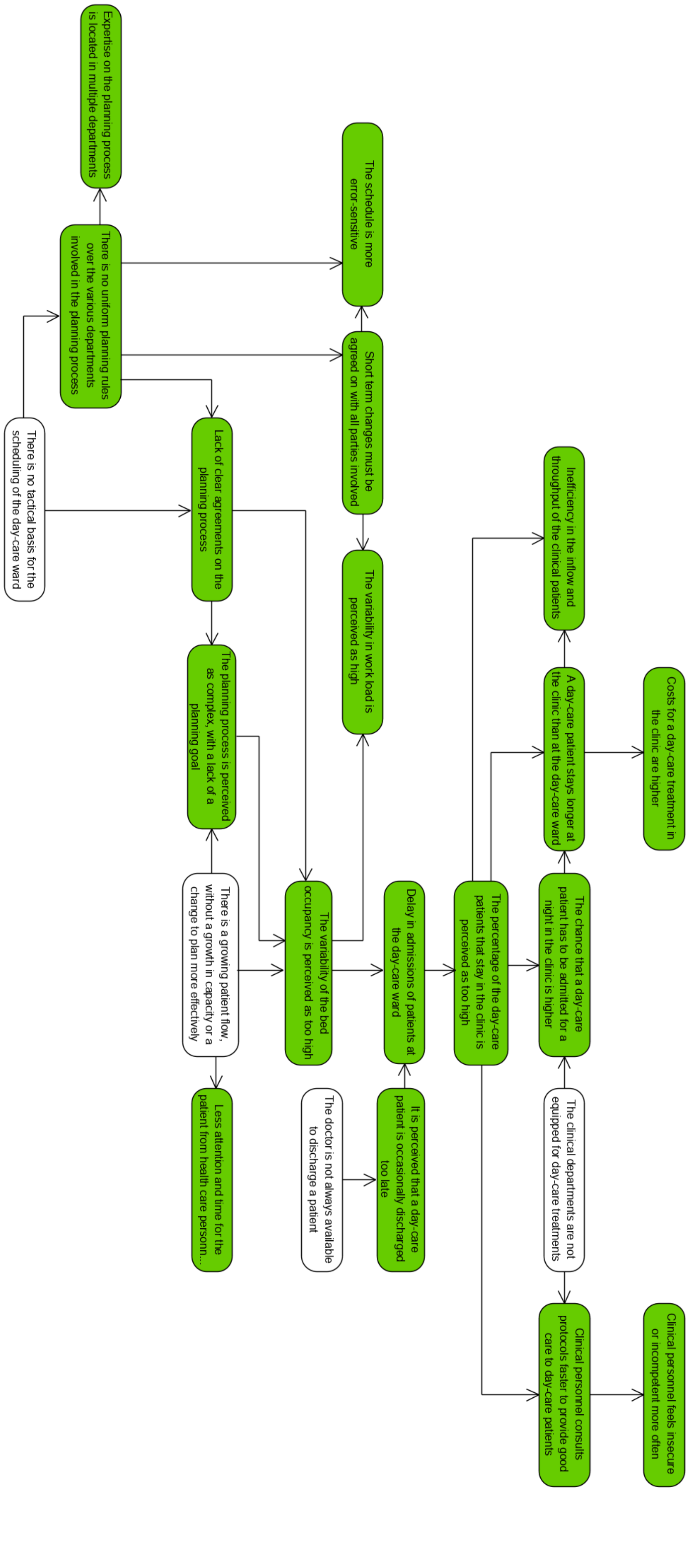
Appendix A: The Problem Cluster



The problems from the shortened problem cluster, explained in detail:

- *There is no tactical basis for the scheduling of the day-care ward.* Currently, there is no clear tactical basis is sufficiently used across the different departments involved in the planning process.
- *There are no uniform planning rules over the various departments involved in the planning process.* Surgical patients are planned by surgical room planners and monitoring patients are planned by their respective outpatient clinic. This means that a lot of different departments are simultaneously planning for the day-care ward, with no planning basis.
- *There is a growing patient flow, without a growth in capacity or a change to plan more effectively.* In 2018, the average number of patients per day at the day-care ward was 38 (Capacity Management Consultant, 2020). At the beginning of 2020, this number was 42. In that time, small to no changes were made in capacity or efficiency of planning related to this growing number of patients.
- *Expertise on the planning process is located in multiple departments.* As a result of the scheduling being done by different departments, the knowledge on their part of the planning process will stay at the particular department.
- *The planning process is perceived as complex, with a lack of a planning goal.* Multiple departments mentioned that the current planning process is complex to them. Also, because of the unclear basis, there is no common planning goal.
- *The variability in work load is perceived high.* The variability in bed occupancy causes the nurses to be very busy at certain times, and idle at others. Also, the fact that the schedule is made by different departments gives more pressure on the day-care ward staff, as they to convene with multiple departments when any changes occur.
- *The variability of the bed occupancy is too high.* The variability of bed occupancy is what causes other problems. This problem is noticed when the day-care staff is scheduling their nurses.
- *The percentage of day-care patients that stay in the clinic is perceived as too high.* The high variability in bed occupancy causes delays, which means a higher percentage of day-care patients are transferred to the clinic when the day-care closes. Also, more day-care patients are scheduled in the clinic than wanted.
- *A day-care patient stays longer at the clinic than at the day-care ward.* As seen in the detailed problem cluster, the clinic is not specialised to care for day-care patients, and thus treatment is perceived to take longer on average.
- *Inefficiency in the inflow and throughput of clinical patients.* Because more day-care patients are staying in the clinic, the normal schedule of the clinic can be interrupted. This causes inefficiency in both inflow and throughput of the clinics and their patients.
- *Costs for a day-care treatment in the clinic are higher.* This is especially the case for patients that are transferred from the day-care ward to the clinic. The unforeseen longer stay, and the fact that day-care treatment takes longer in a clinic cause for higher costs compared to such a treatment that is only done in the day-care ward.

Appendix B: Filtering Patient Data

The table below shows the steps that were taken to get the data set that contained only the monitoring treatments that day-care ward treatments.

	Task	Number of data points (and deleted)
1	Full treatment data set	21495
2	Eliminate all with a surgery day, as these are surgical patients	11519 (-9976)
3	Eliminate treatments not done at the day-care ward and surgical treatments that did not have a surgery day	10369 (-1150)
4	Move treatments from too general indicators to their respective treatment indicators according to the memo.	10365 (-4)
5	Delete treatments done in department A3-3	10359 (-6)
6	Delete treatments from indicators where all treatments were not done at A3-4.	9850 (-509)
7	Merge indicators that are appear more than once	9850 (0)
8	Relocate general treatments if the diagnosis only has one kind of treatment	9850 (0)
9	Delete treatments: - Under 30 min (all) - Under 60 min (i.v.) - Indicator specific	9550(-300)

To obtain a representative data set for Section 2.2, the data is filtered using the following criteria:

- Eliminate data that does not fit the required data set:
  - The treatments analysed are monitoring treatments, so only monitoring treatments will be in the data set. This is done by eliminating all the treatments that have a surgery date and time. Some surgical treatments did not have a surgery date and time and were eliminated in consultation with a day-coordinator.
  - The treatment, indicated by the treatment group, must be performed at the day-care ward. Any treatment group where all treatments were never performed at the day-care ward is eliminated from the data. This was done in consultation with a day-coordinator.
  - Eliminate patients that have been treated in the A3-3 department.
  - Eliminate patients that have a treatment time lower than 30 minutes. The assumption is that admitting and discharging a patient will take at least 30 minutes. Some indicators have a different minimum treatment time, as indicated by a day-coordinator.
- Relocate data in the correct treatment groups
  - Move treatments from too general treatment groups to their respective treatment groups according to the memo. Create treatment groups for specific treatments that appear often in these general treatment groups but do not have their own treatment group.
  - Merge treatment groups that appear more than once.
  - Relocate treatments from too general treatments groups (with also general memos) according to the patient's diagnosis, if that diagnosis only has one kind of treatment.

The data started with 21495 data points, and after eliminating data according to the criteria above, 9550 data points were left. The biggest part of the elimination of data was the elimination of surgical patients (9976 data points). A detailed overview of obtaining this data set and how many data points were eliminated can be found in Appendix B.

To obtain a representative data set for Section 2.4, the data is filtered using the following criteria:

- Ward occupancy and bed ratio
    1. All data points not at A3-4 (day-care ward) were eliminated.
    2. All data points that were either at the weekend or on a national holiday were eliminated. The national holidays used were determined by the collective labour agreement for hospitals by the FBZ (federation of healthcare professional organisations) (FBZ, 2019)
    3. All data points that surpass the opening hours of the day-care ward (such as overnight stays at A3-4) had the admission and/or discharge time and date changed. The assumption is that the patient started their treatment at the day-care ward and was moved to another ward at the end of the day. Thus, the admission time started on the registered admission day and was changed to 07:00 if it is registered earlier than that. The discharge day was changed to the admission day (if it is not equal) and the discharge time was changed to 20:00 if it surpassed 20:00
    4. In the case of ward occupancy, the dataset that contained the stay per location was used. In this data set, there were multiple data points that were repeated up to 4 times. When a data point was repeated in the set, the repeated datapoint was deleted, such that all data points are identical
- Patients that are admitted to other wards
    - The data points that are of treatment groups not done at the day-care ward are deleted. This is based on the same groups as in Chapter 2.2
    - The data is divided into three groups:
        1. The data points that had admission at the day-care ward and discharged at the day-care ward
        2. The data points that had admission at the day-care ward and discharged at another ward
        3. The data points that had admission at another ward and discharged at another ward

Treatment groups that were included in the Rest treatment groups can be seen in the table below.

Treatment group	Count
ascitespunctie	47
PEG sonde plaatsing / wissel	46
Kalium infuus	43
capsaicine protocol	41
ceftriaxonkuur	38
Trombocytenconcentraat	38
Solumedrolkuur	34
Catheterwissel	33
apd	33
CAD ontwennen	28
zoutbelastingtest	25
Scopie (slechte mobiliteit patient)	24
duodenoscopie	24
zolendroninezuur	23
Stress MRI cardio	22
ct contrast allergie	20
Nefrostomie plaatsine	20
iloprost infuus	18
Dubbel	17
rosevin kuur	14
wakeful maintenance test	13
Embolisatie	12
drainwissel	11
Observatie	8
Ilomedine	7
MDL Scopie	7
SPB prikken	5
sigmoidoscopie + klinische voorbereiding/laxeren	3
pleurapunctie	3
anemie	2
O05 Mamma	1
obstipatie	1
Adnex	1
Electrolyten, vocht toediening	1
tractus digestivus	1

Appendix C: Case Mix Analysis

Figures C1 and C2 have three colours included, because some of the data is altered based on extreme values (values above 1000). The blue values are unchanged, meaning that the data is not altered to exclude extreme values. The orange and grey values represent the same treatment groups, where the grey values represent the unaltered data and the orange values represent the altered data.

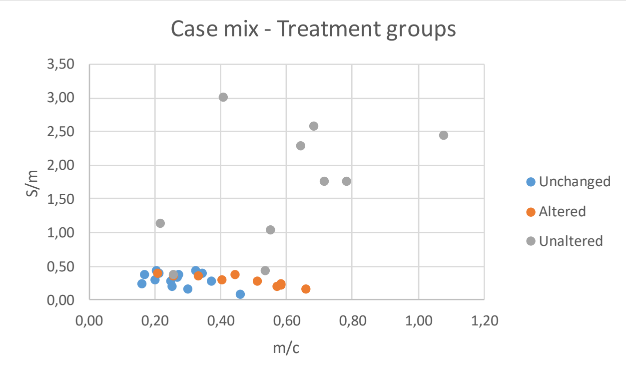


Figure C1: Case mix of the treatment groups, including the altered and unaltered data

Normally, this representation only has an x-axis and y-axis limit of one. This is especially the case for the x-axis, as this is the average duration of treatment divided by the capacity of the day-care ward. If this value is higher than 1, it means that the average duration of treatment is higher than the opening hours of the day-care ward, and this is generally not possible. In Figure C2, one such value does exist. This unaltered value is the value of the "Overig > 7h". This is an exception, as this includes only the treatments that do not occur often enough and which duration of treatment is higher than seven hours. This therefore also includes all the extreme values of the whole Overig group. This causes the average duration of treatment to be higher than the capacity of the day-care ward. Without these extreme values, the x-value comes below one.

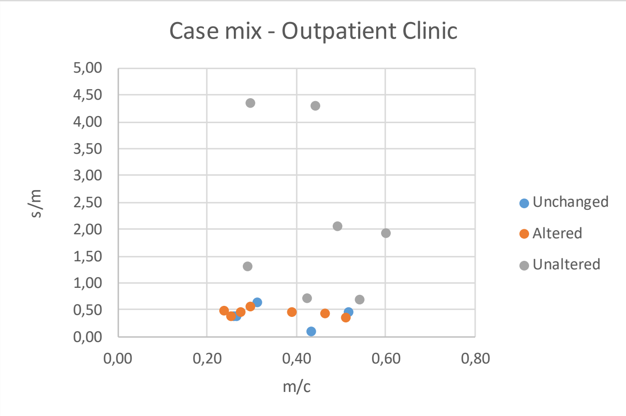
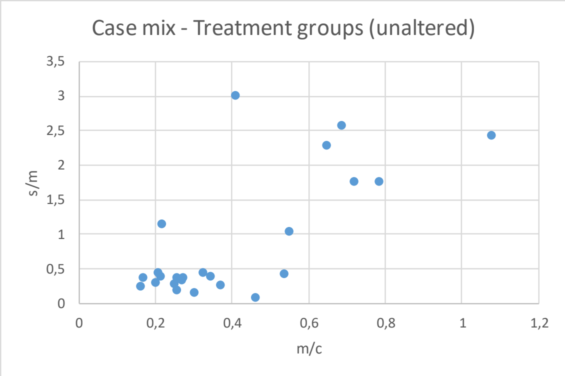


Figure C2: Case Mix of the Treatment groups, including the altered and unaltered data

A y-value higher than one is possible, but is means that the standard deviation is bigger than the average, which indicates very high variability in the duration of treatment. The high values that are visible on the graphs are caused by extreme values (above 1000 minutes), as it increases both the average duration of treatment as the standard deviation. Excluding these extreme values causes the y-values of the treatment groups with high variability to have their coefficient of variation below 1.

On the following two pages, the unaltered and altered data are in separate graphs, accompanied by their respective tables. On page 72 is the case mix of the treatment groups and on page 73 is the case mix of the outpatient clinics.



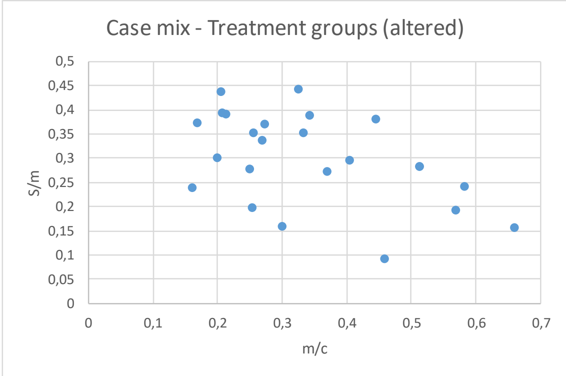
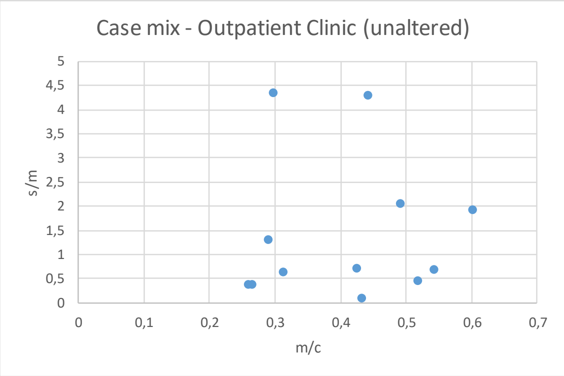


Table C1: Unaltered treatment groups data

Group	Mean	Variation	Coefficient of variance	Mean/Total capacity
I.Infuus	199	76	0,38	0,26
N.Infuus	168	192	1,14	0,22
Cathkamer	610	1072	1,76	0,78
Bloedtransfusie	534	1377	2,58	0,68
Ferinject	160	70	0,44	0,21
Magnesium	268	104	0,39	0,34
Methyl	166	65	0,39	0,21
Ct-scan	253	112	0,44	0,32
Immuno	319	958	3,00	0,41
Photo	213	79	0,37	0,27
Ct cor	198	39	0,20	0,25
Ct punctie	503	1148	2,28	0,64
Ct hyd	559	987	1,77	0,72
Lumbaal	210	70	0,33	0,27
Broncho	289	78	0,27	0,37
Echo lever	417	179	0,43	0,53
Synachten	156	46	0,29	0,20
Aclasta	131	49	0,37	0,17
Blaas	195	54	0,28	0,25
Echo punctie	429	449	1,05	0,55
O.1	125	30	0,24	0,16
O.2	234	37	0,16	0,30
O.3	358	33	0,09	0,46
O.4	840	2046	2,44	1,08

Table C2: Altered treatment groups data

Group	Mean	Variance	Coefficient of variance	Mean/Total capacity
I.Infuus	199	70	0,35	0,26
N.Infuus	162	64	0,40	0,21
Cathkamer	455	103	0,23	0,58
Bloedtransfusie	455	110	0,24	0,58
Ferinject	160	70	0,44	0,21
Magnesium	268	104	0,39	0,34
Methyl	166	65	0,39	0,21
Ct-scan	253	112	0,44	0,32
Immuno	260	92	0,35	0,33
Photo	213	79	0,37	0,27
Ct cor	198	39	0,20	0,25
Ct punctie	315	93	0,30	0,40
Ct hyd	444	86	0,19	0,57
Lumbaal	210	71	0,34	0,27
Broncho	289	79	0,27	0,37
Echo lever	400	113	0,28	0,51
Synachten	156	47	0,30	0,20
Aclasta	131	49	0,37	0,17
Blaas	195	54	0,28	0,25
Echo punctie	347	132	0,38	0,44
O.1	125	30	0,24	0,16
O.2	234	37	0,16	0,30
O.3	358	33	0,09	0,46
O.4	515	81	0,16	0,66



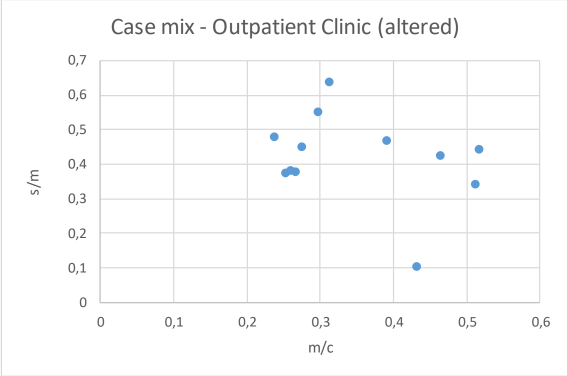


Table C4: Unaltered outpatient clinic data

Outpatient Clinic	Mean	Variation	Coefficient of variance	Mean/Total capacity
Maag-, Darm- En Leverziekten	225	294	1,31	0,29
Interne Geneeskunde	383	791	2,07	0,49
Cardiologie	468	904	1,93	0,60
Reumatologie	202	77	0,38	0,26
Neurologie	231	1007	4,35	0,30
Longgeneeskunde	344	1475	4,29	0,44
Urologie	331	234	0,71	0,42
Dermatologie	207	78	0,38	0,26
Chirurgie	422	290	0,69	0,54
Gynaecologie	243	155	0,64	0,31
Keel-, Neus- En Oorheelkunde	336	35	0,10	0,43
Geriatrie	403	179	0,44	0,52

Table C3: Altered outpatient clinic data

Outpatient Clinic	Mean	Variation	Coefficient of variance	Mean/Total capacity
Maag-, Darm- En Leverziekten	214	96	0,45	0,27
Interne Geneeskunde	197	74	0,37	0,25
Cardiologie	361	153	0,42	0,46
Reumatologie	202	77	0,38	0,26
Neurologie	185	89	0,48	0,24
Longgeneeskunde	231	128	0,55	0,30
Urologie	304	142	0,47	0,39
Dermatologie	207	78	0,38	0,26
Chirurgie	398	136	0,34	0,51
Gynaecologie	243	155	0,64	0,31
Keel-, Neus- En Oorheelkunde	336	35	0,10	0,43
Geriatrie	403	179	0,44	0,52

Appendix D: Ward occupancy Analysis

Ward occupancy per hour per day of the week

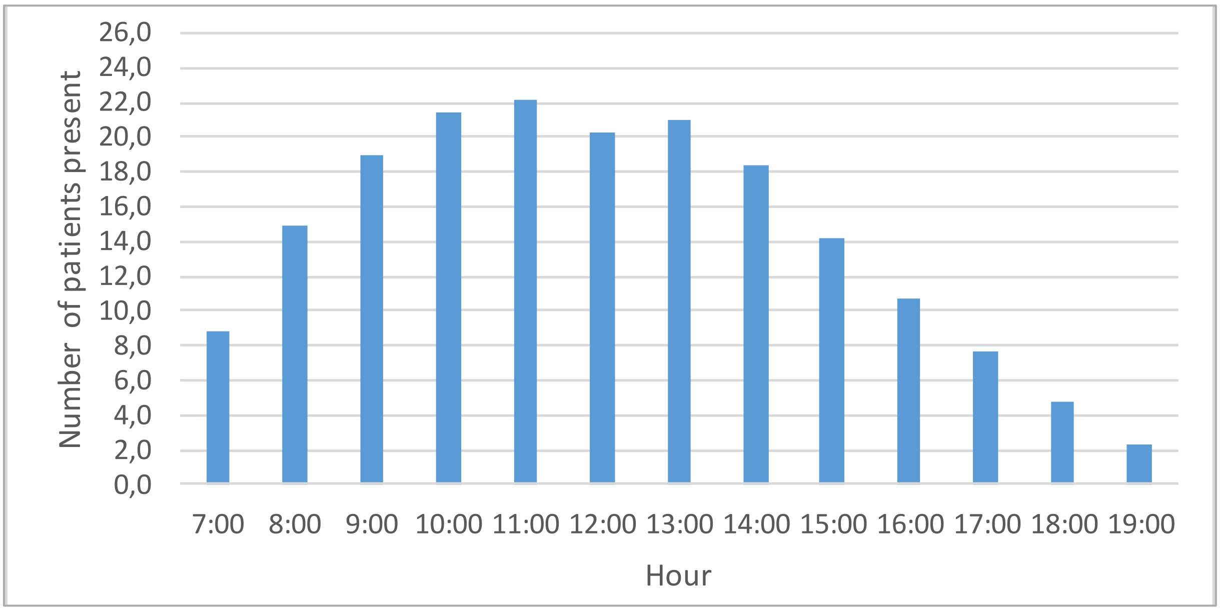


Figure D1: Ward Occupancy per hour - Monday

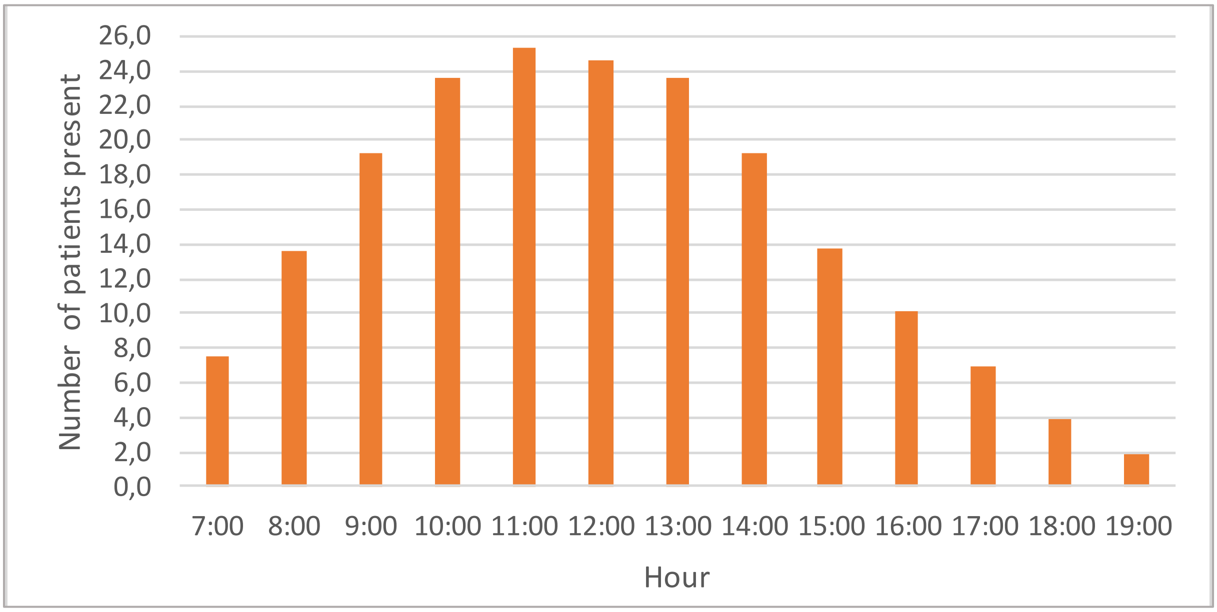


Figure D2: Ward Occupancy per hour - Tuesday

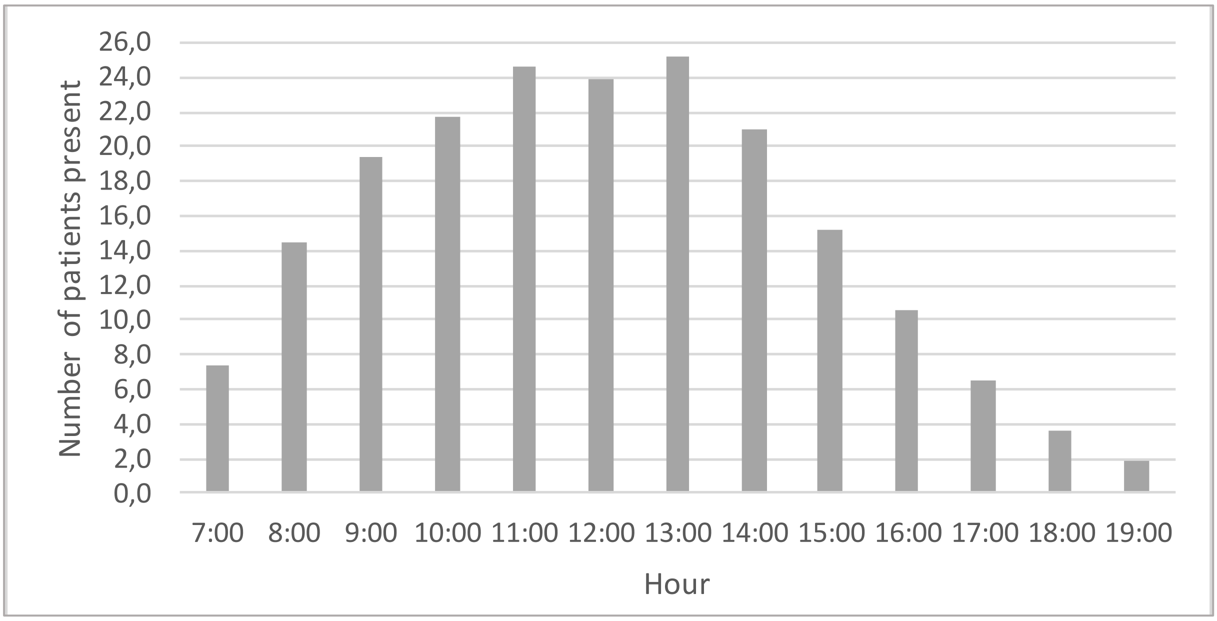


Figure D3: Ward Occupancy per hour - Wednesday

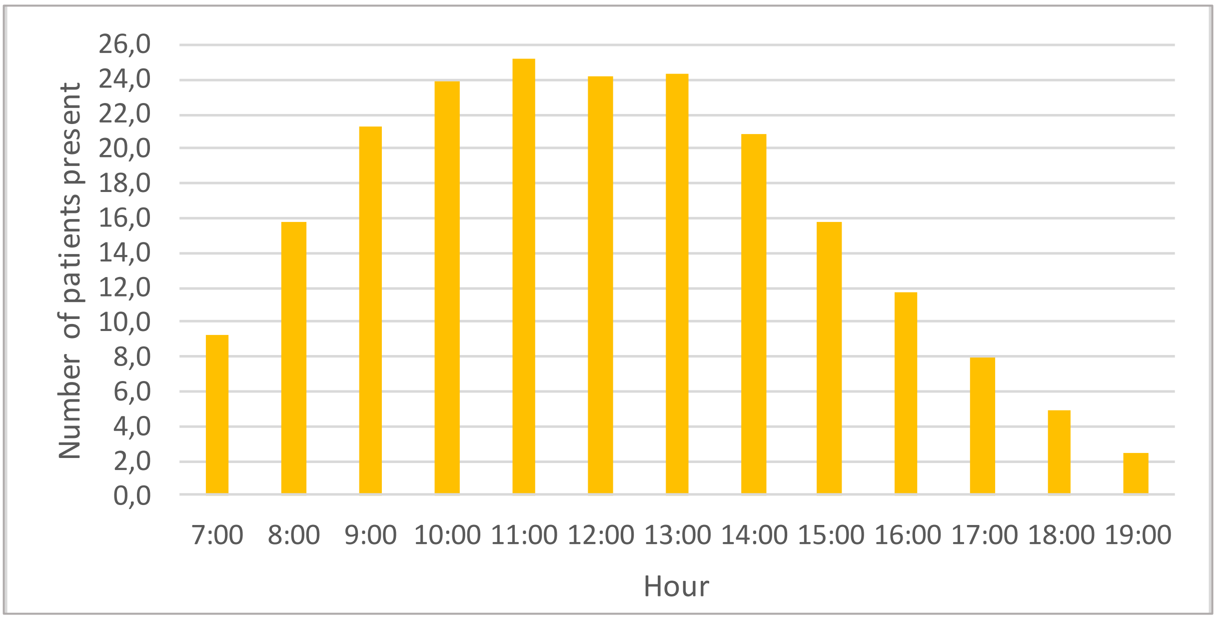


Figure D4: Ward Occupancy per hour – Thursday

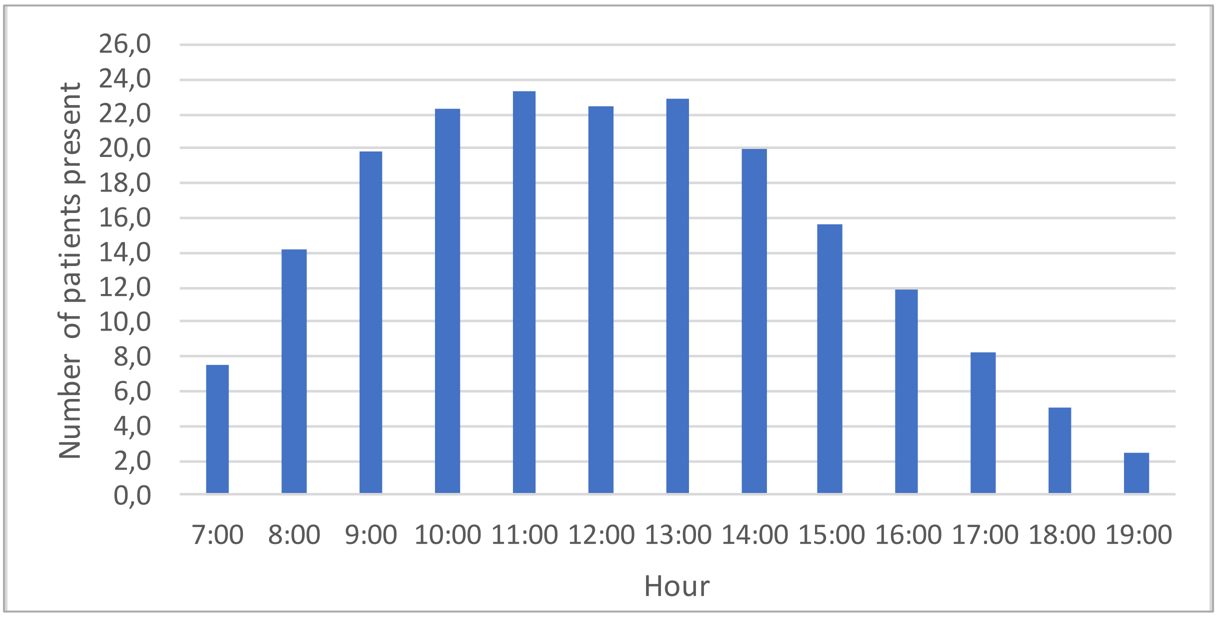
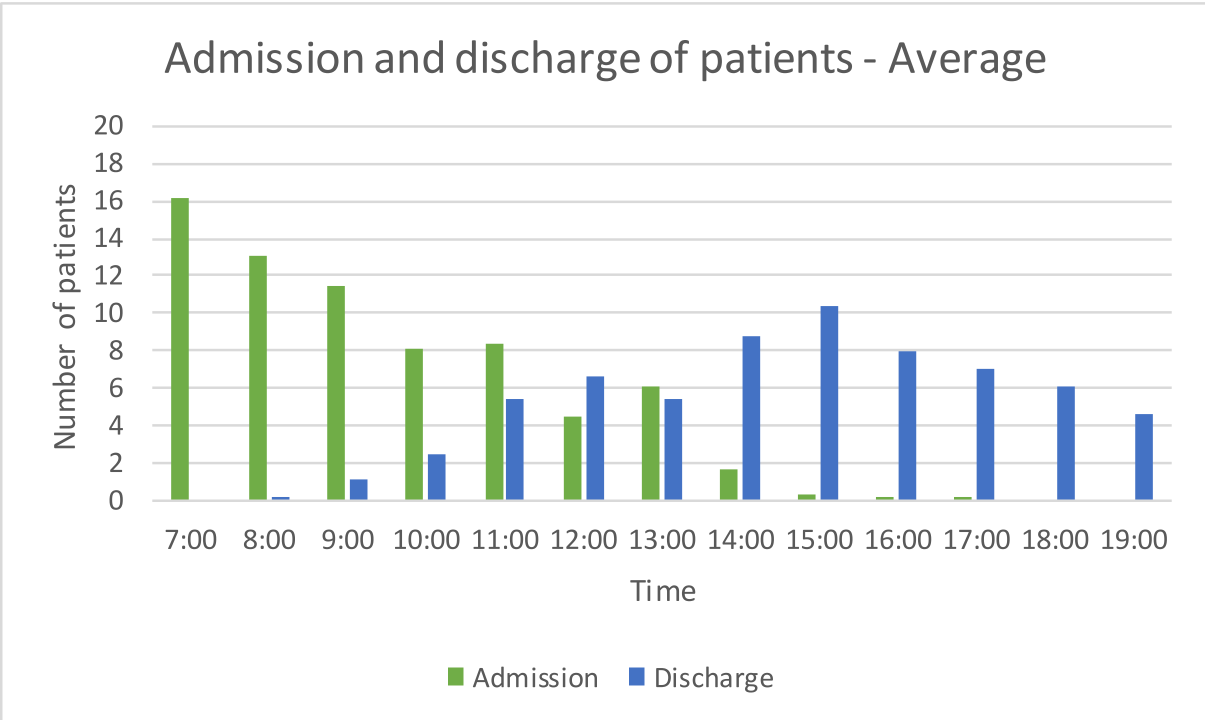
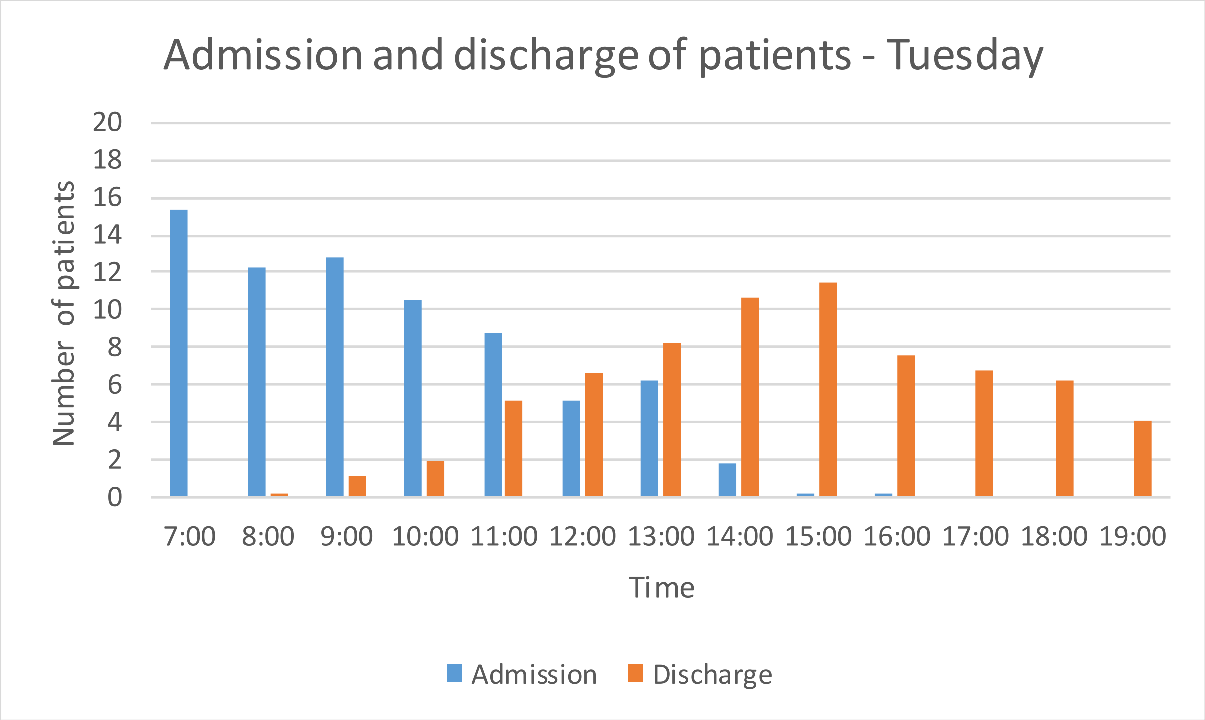
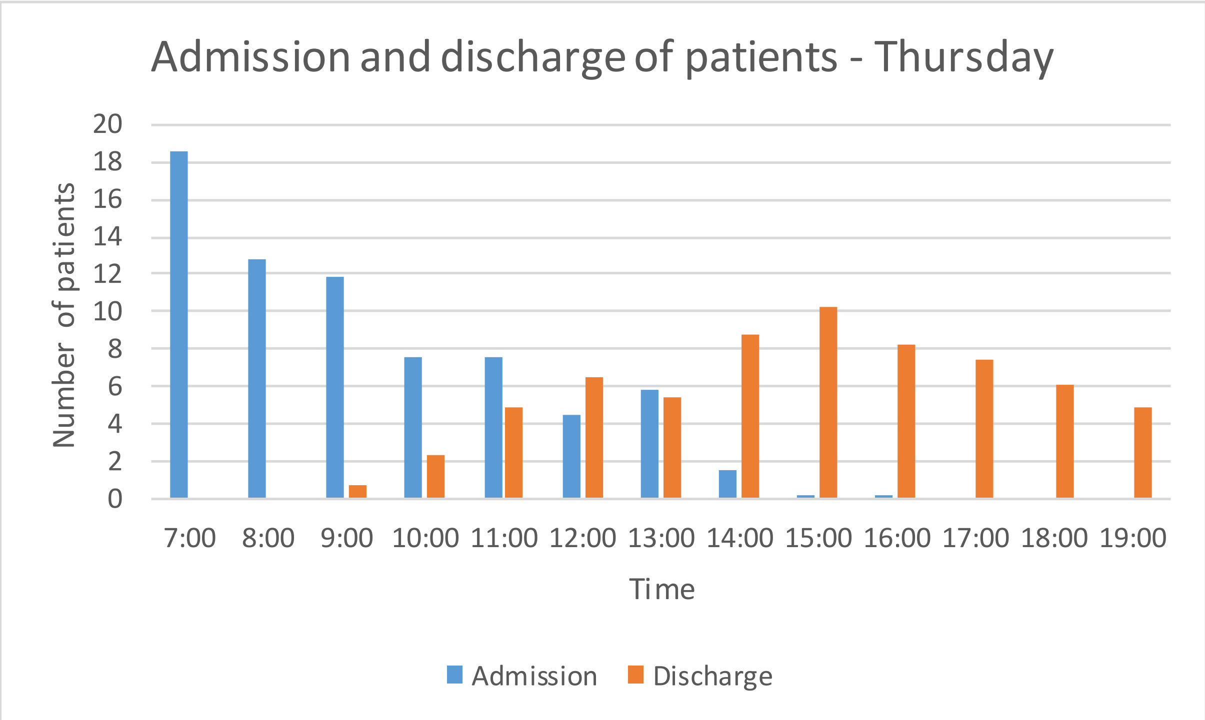


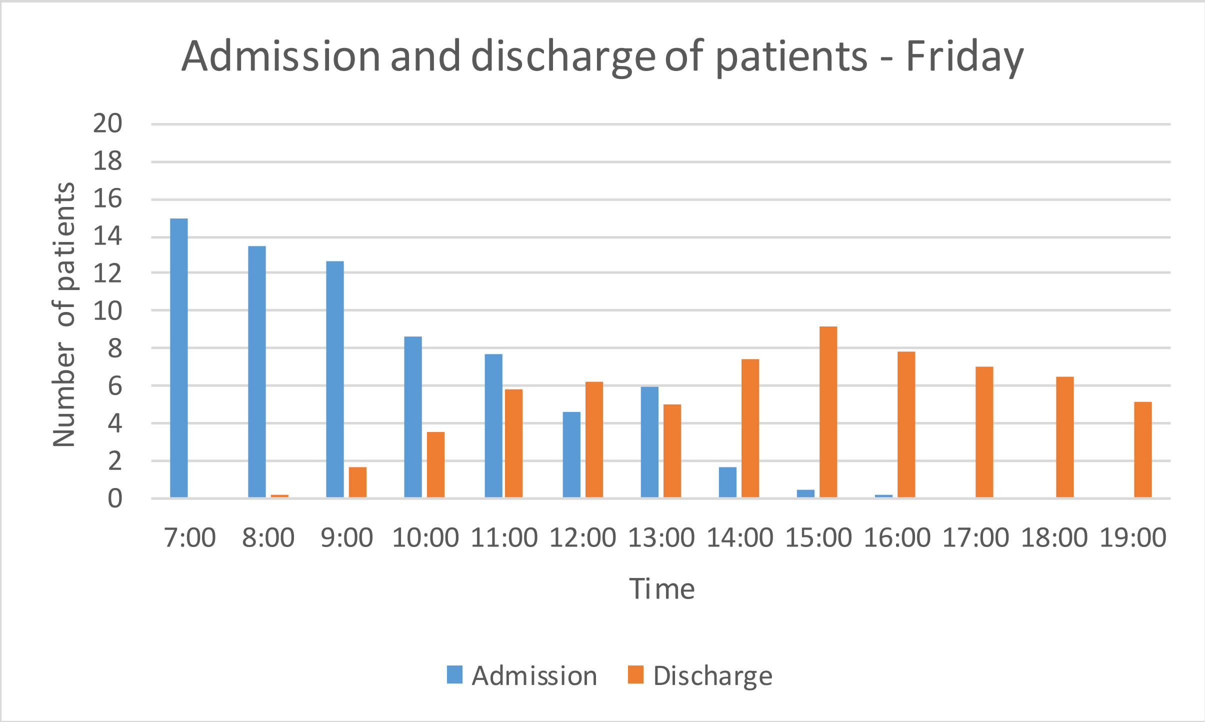
Figure D5: Ward Occupancy per hour - Friday

Admission and discharge of patients per day of the week



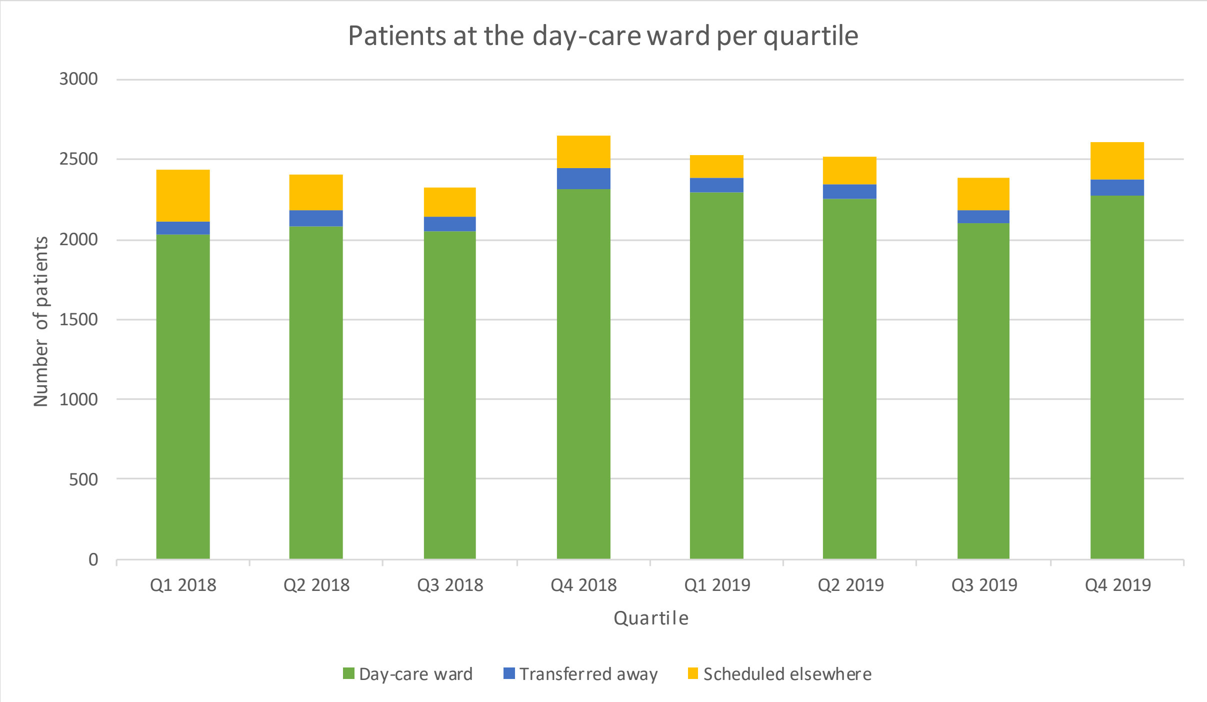

Admission and discharge of patients - Tuesday
20
18
16
14
12
10
8
6
4
2
0
Number of patients
7:00 8:00 9:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00
Time
Admission
Discharge

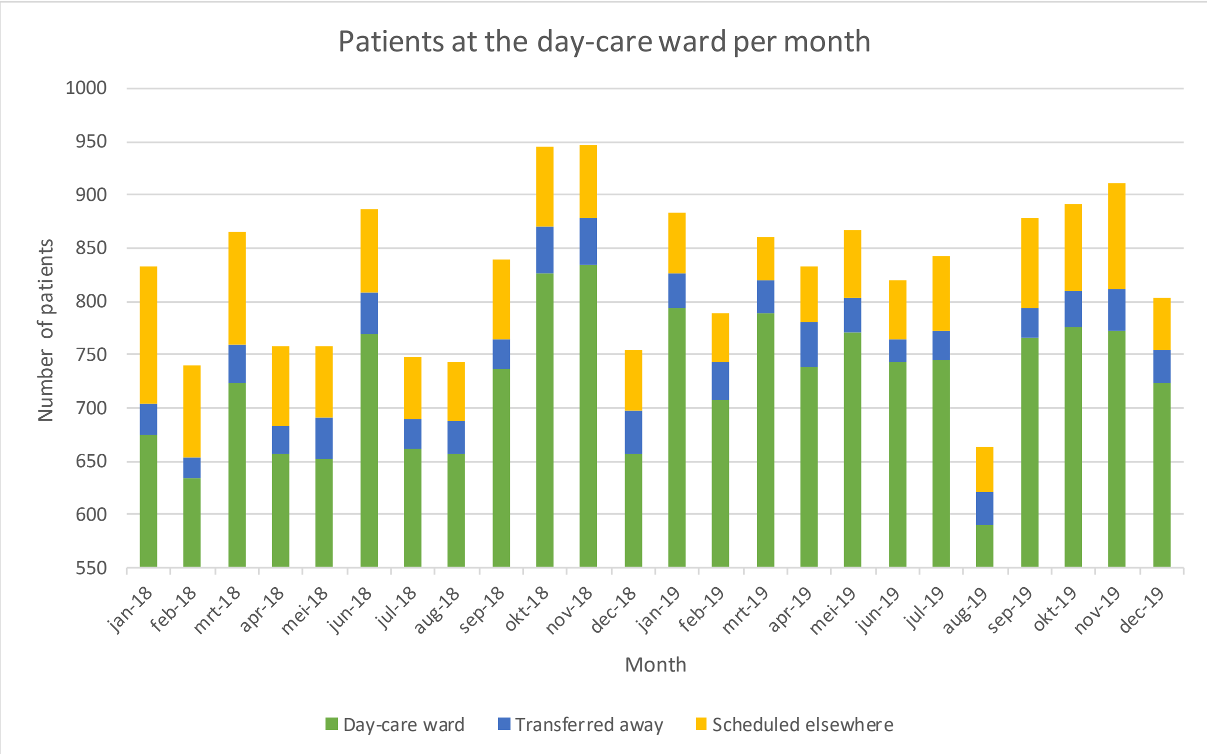

Admission and discharge of patients - Thursday
20
18
16
14
12
10
8
6
4
2
0
Number of patients
7:00 8:00 9:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00
Time
Admission
Discharge



Admission and discharge of patients - Friday
Number of patients
20
18
16
14
12
10
8
6
4
2
0
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
Time
Admission
Discharge

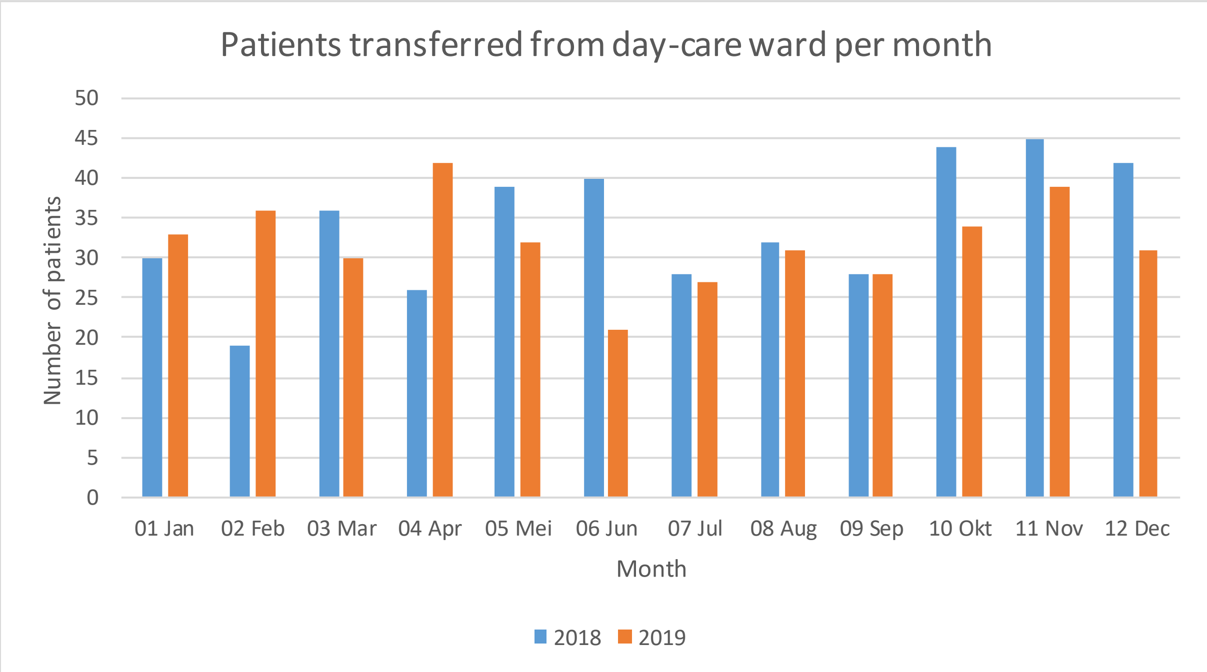
Patients at the day-care ward per quartile and month

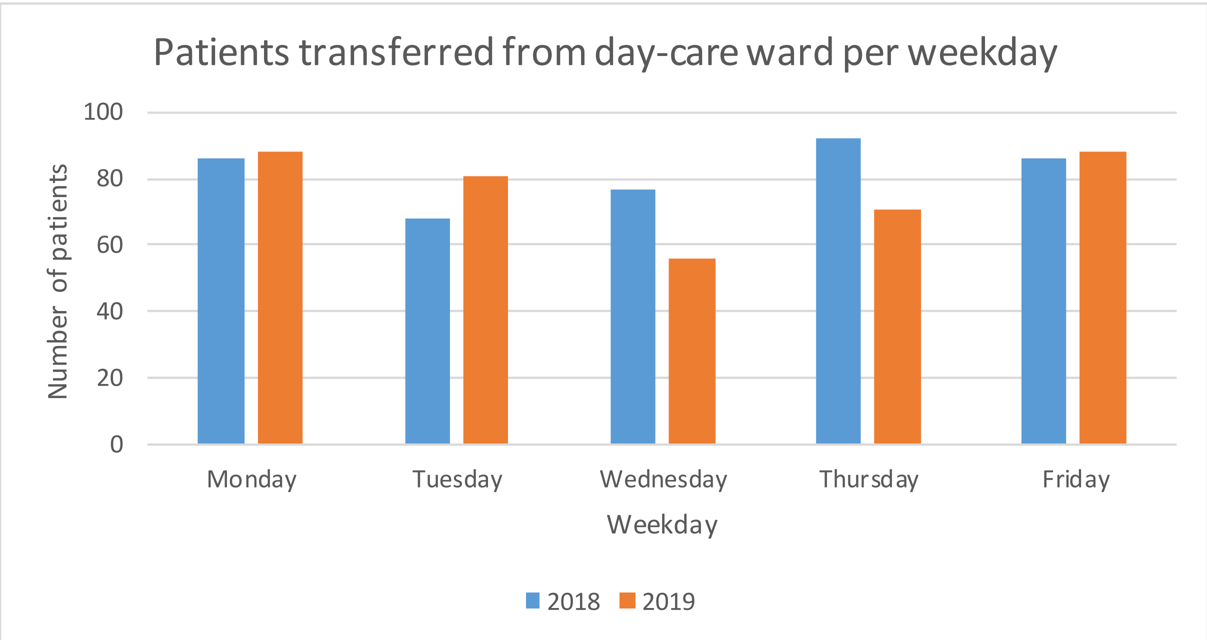




Appendix E: Transferred Patients Analysis

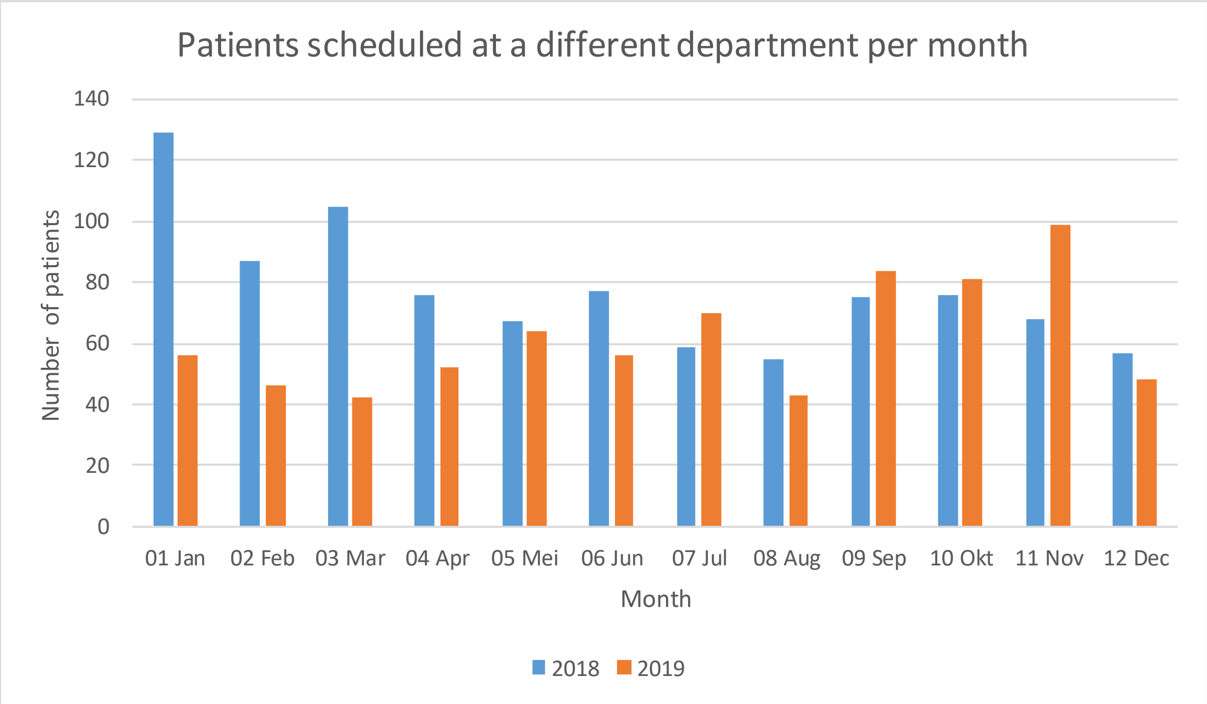
Distribution of transferred patients per month and weekday

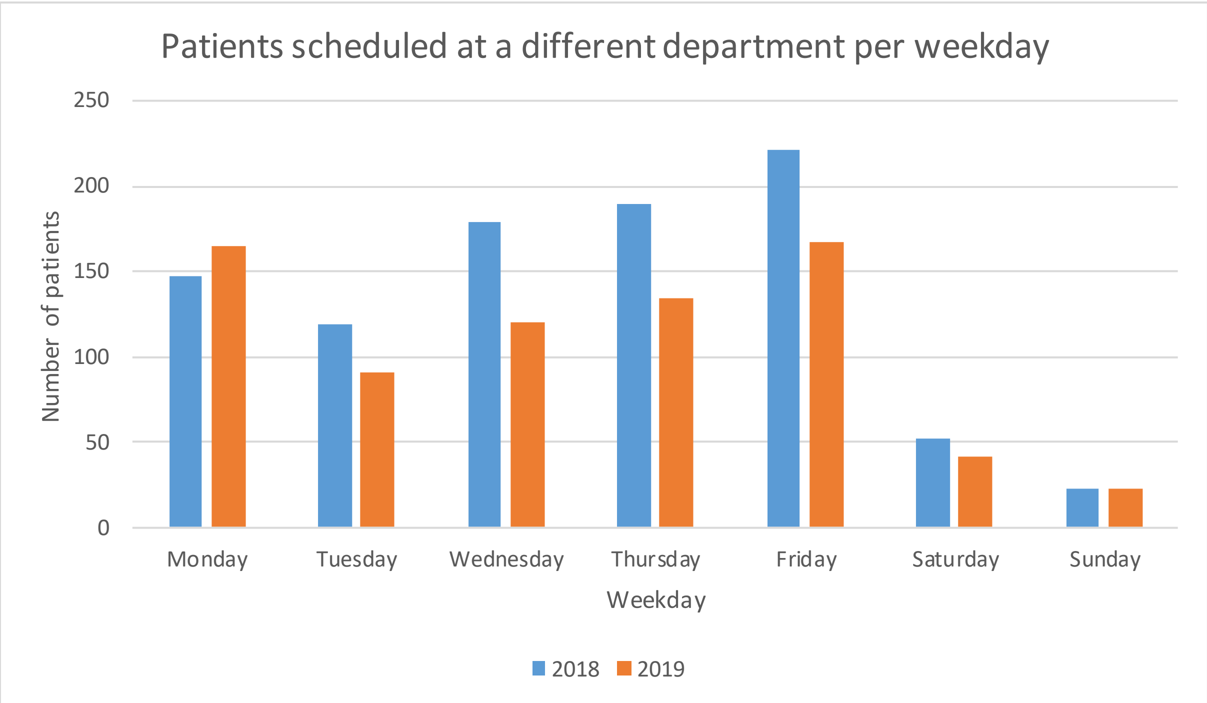




Appendix F: Patient Scheduled Elsewhere Analysis

Distribution of patients scheduled elsewhere per month and weekday





Appendix G: Treatment Time Analysis

For surgery scheduling, the 3-parameter lognormal distribution is the best fit (Leeftink & Hans, 2018). As these treatments are not surgical, the same cannot be said about them. However, given the shape of the empirical distribution of most of the treatment groups, the lognormal distribution is a likely fit. Both the 2-parameter and the 3-parameter lognormal distribution will be tested, as well as the normal distribution.

The goodness-to-fit is tested by a graphical test and by a statistical test. Both these approaches are used when testing the goodness-to-fit of the distribution. The graphical approach compares the frequency diagram of the empirical data with the frequency diagram of the proposed distribution. The statistical test used to test the goodness-to-fit is the chi-square test. Both tests are done, and if one of the two tests is passed, the proposed distribution is accepted. If both tests are failed for both lognormal and normal distributions, the treatment group is seen as an empirical distribution.

For some treatment groups, a few extreme values are excluded when testing to fit a statistical distribution. These extreme values can be seen in the table below as “Min deduction” and “Max deduction”, indicating how many lower and higher values are excluded respectively. The number of excluded values is relatively low, not surpassing 10% of the data points in the treatment group. In most of the cases, the extreme values caused difficulty when fitting a statistical distribution, as the range of duration of treatment became too high, grouping most of the data points in only a few cell ranges. When excluding the extreme values, the steps to determine if a distribution fits, as explained above, could be followed. These extreme values are not excluded when describing the distribution. These treatment groups will have a bimodal distribution of a statistical distribution and empirical distribution when excluding the extreme values results in a fitting statistical distribution.

When testing statistical distributions, the frequency diagram of the empirical distribution is made first. A visual inspection indicates which distribution is most likely to fit. In a few cases, it is immediately clear that specific distributions would not fit because of a bimodal or multimodal empirical distribution, and these treatment groups are seen as an empirical distribution. For the other treatment groups, the 2-parameter lognormal distribution is always tried first. If this distribution does not fit (and thus fails both tests), a visual inspection of the combined frequency diagram is done. This is the case for five treatment groups. Four out of those five groups have a peak that was too high, and thus the normal distribution would also not fit, even though this was tried. The fifth treatment group, Echo Punctie, has a skewness close to zero, which indicates a normal distribution is a better fit. When tested, the normal distribution fits the empirical distribution.

For all the treatment groups that have a lognormal distribution fitted and a skewness greater than 0.35 (May, Strum, & Vargas, 2000), the 3-parameter lognormal distribution is compared. As the 3-parameter lognormal distribution has the location parameter, this distribution is preferred. The location parameter indicates a minimum duration of treatment, which is lower than the lowest value in the empirical distribution of the specific treatment group. The location parameter thus ensures that there will be no value lower than its own value.

The estimation of the location parameter is done using the estimation approach suggested by May et all. (2000). The location parameter (a) is first estimated using the following approach:

$$a_1 = (x_1 x_n - {x_{median}}^2)/(x_1 + x_n - 2x_{median})$$

If a_1 is smaller than x_1 and larger than 0, then a_1 is used for the location parameter. If that is not the case, a_2 is calculated:

$$a_2 = (x_1 x_n - {x_2}^2)/(x_1 + x_n - 2x_2)$$

If a_2 is smaller than x_1 and larger than 0, then a_2 is used for the location parameter. If that is not the case, a_3 is calculated:

$$a_3 = 2x_1 - x_2$$

If a_3 is smaller than x_1 and larger than 0, then a_3 is used for the location parameter. If that is not the case, x_1-1 is used as the location parameter.

The results from these tests, and thus the distributions of treatment time for each treatment group are displayed in Table 4.3 on the next page. With empirical distributions, with the exception of the Rest groups, the average and standard deviation are shown.

Appendix H: Model verification and validation

Theory of model verification and validation

An important step of the simulation study is to validate and verify the model. Model verification is the process of making sure that the conceptual model has been sufficiently and accurately transformed into a computer model (Davis, 1992). Model validation is about confirming that the model is sufficiently accurate for the intended purpose (Carson, 1986). The aim of model verification and validation is to make sure that the model is sufficiently accurate (Robinson, 2014). Robinson also states that a model that is 100% accurate is unachievable and that a model is not meant to be completely accurate, but a simplified version of the real world that is used for comprehending and exploring reality. This is also discussed in Section 4.1.1.

The assessment when asking if the accuracy is sufficient or not is related to the purpose of the model. It is therefore important that the objective, which is the purpose of the model, is established before the model can be validated. When basing the validity on the objective, the validity becomes absolute, as the model is either sufficiently accurate or it is not sufficiently accurate. With this type of validity, accuracy cannot be measured on a scale of 0 to 100 per-cent

Validation and verification is a continuous process that is carried out throughout the whole cycle of the simulation study, as previously depicted in Figure 4.1 in Section 4.1.1. Verification focuses on the development of the computer model that is based on the conceptual model, and checks if it is correctly converted. Validation determines if a model is sufficiently accurate. Robinson (2014) discusses various forms of model validation, which are the following six:

- *Conceptual model validation*
  This form of model validation determines if the proposed conceptual model is sufficiently accurate, given the objective.
- *Data validation*
  This form of model validation determines if the data used and analysed in all stages of the simulation study are sufficiently accurate, given the objective.
- *White-box validation*
  This form of model validation determines if individual parts of the computer model represent the real world with sufficient accuracy, given the objective.
- *Black-box validation*
  This form of model validation determines if the overall system represents the real world system with sufficient accuracy, given the objective.
- *Experimentation validation*
  This form of model validation determines if the experimental procedures used are giving results that are sufficiently accurate, given the objective.
- *Solution validation*
  This form of model validation determines if the results gained from the model of the proposed solution are sufficiently accurate, given the objective.

The first three are discussed in Sections 4.4.3 till 4.4.5. Experimentation validation will be discussed in Section 5.1.3. The other two types of validation will not be included for the following reasons:

First, the black-box validation is not included because of two reasons: it is not relevant to the objective and it falls outside of the time frame of this research. The objective is to compare the interventions to the simulated current situation, which is also simulated in the simulation. As the simulation objective is not to accurately represent the real world, which is represented in the assumptions and simplifications in Section 4.1.3, we decided to not include black-box validation.

Second, solution validation is not included as it falls outside of the scope. Solution validation, according to Robinson (2014), tries to assure the validity of the final solution or improvement. This should include checking whether the chosen solution that is implemented is the best suited. However, it is unlikely to determine the real world effects of alternative solutions, as it is not practical to implement multiple solutions in the day-care ward. Also, the purpose of this simulation study is to test these alternative solutions in a simulation to determine which of the scenarios works best for the day-care ward. In addition, as stated in Section 1.4, solution evaluation is not in the scope of this research. Therefore, solution validation will not be performed in this study.

Difficulties with model validation

Before discussing the five validation forms, some difficulties and challenges of model validation are discussed. Robinson (2014) mentions six difficulties, but only four apply to this simulation study, so those four will be briefly discussed.

First, general validity does not exist. A model is validated based on its objective. A different objective can change the assessment, even when the same real world system is modelled. For example, if the objective is to test different scheduling methods, the accuracy is more concerning the scheduling process. However, if the objective is to test different resource levels with the variability of the system, the accuracy is more concerning the resources, such as materials, beds, nurses, and the variability of the system, such as patient arrival times. To conclude, the objective is used to determine if the model is sufficiently accurate, which means that there is no general validity for a developed model.

Second, real world data can often be inaccurate or incomplete. As the model runs under the same conditions as the system in the real world, the data is important to make it sufficiently accurate. There are two difficulties regarding the use of real word data. Firstly, if data is inaccurate or incomplete, this can create complications when determining the validity of the model's results. Secondly, even when the real world data is sufficiently accurate or complete enough, it is still a sample of the real world system and can therefore not be completely accurate or complete. These two difficulties should be taken into account when deliberating if the model is sufficiently accurate and thus valid.

Third, there is not enough time to verify and validate everything of the model (Balci, 1997). The simulation study has a timeframe and there will not be enough time in that time to verify and validate every aspect of the simulation study. Robinson (2014) states that it is the modeller's job to make sure that as much as possible of the model is verified and validated. This counts for all parts of validation, so the overall validity, but also model details and experimentation validity.

Fourth, it is impossible to definitively prove that a model is valid. The model is validified or not, there is no way to prove that a model is valid. As Robinson (2014) states, "it's only possible to think in terms of confidence that can be placed in a model". Verifying and validating the model is not about proving it is correct, but about increasing confidence in the model and its results.