
Optimal treatment pattern

How could the orthopaedics best improve the utilisation of the wards by adjusting the way they plan elective admissions?

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Preface

Dear Readers,

The thesis in front of you concludes my research at Medisch Spectrum Twente in Enschede at the integral capacity department. This thesis is the final assignment of my bachelor Industrial Engineering and Management at the University of Twente. I have learned to work for a complex organisation where problems have many stakeholders. Writing this thesis, I developed my English and learned how to conduct a research. I got the opportunity to develop myself on an academic level as well as on a personal level.

I want to thank my supervisors at the UT, Erwin and Maartje, for their feedback. I also want to thank Erwin for the meetings in which I learned a lot about writing style and how to structure a report. At Medisch Spectrum Twente, Jeroen hired me to conduct this research. It was hard at the beginning to grasp the complex logistics of the hospital. Jeroen supported me with my struggles to compose a clear project plan. I also want to thank my fellow student Arnout, who also worked at his bachelor thesis at Medisch Spectrum Twente, for the many interesting conversations at the canteen of Medisch Spectrum Twente. I also want to thank him for his feedback and for being my English corrector. Finally, I want to thank all colleagues of the planning department. Their helpfulness and friendliness created a pleasant working environment.

Kind regards

Daan Stortelder

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Management summery

Introduction and problem statement

Medisch Spectrum Twente (MST) struggles with capacity problems at the wards. The two perceived problems are:

“Rejections and postponements of patient treatments” and “over- and underallocation of resources of the wards”

The main cause of these problems is the bed occupancy at the wards that fluctuates too much. A weekly as well as a cross-weekly variability in bed occupancy is causing capacity problems. The bed occupancy has a weekly pattern where peaks on Thursdays or Fridays are common. This is mainly caused by the elective flow of admissions. We focus on the relationship between the operating theatres (OTs) planning of the orthopaedics department and the bed occupancy at the wards. The knowledge problem of this research is:

“How could the orthopaedics best improve the utilisation of the wards by adjusting the way they plan elective admissions?”

Method

We focus on smoothening admissions over the week. We used the quadratic assignment programming (QAP) model provided by Glerum [10]. A categorisation of admissions was needed to use the QAP model. The categorisation is based on the designated ward of a patient and the LOS of the patients. The outputs of the QAP model suit the intervention proposed by Smit [19]. Smit [19] set up general rules of thumb. This type of intervention keeps access times low and has a high chance to be realised. As Smit [19] already researched the opportunities of the QAP model for the MST, we continued his research. Smit stated that a classification of each new patient has to be made and a pilot for one department has to be conducted first.

Categorisation

We allocated admissions into categories based on the framework created by Glerum [10] and used for the MST by Smit [19]. Figure 1 displays the categorisation of the admissions. We categorised every surgery of every department that occurred in 2017 and the first eleven months of 2018. Whether the surgery is classified as SS or LS is based on their median LOS. If the median LOS of a surgery is less than 2 the surgery is classified as SS, otherwise as LS.

Only 8 percent of the patients from the orthopaedics were falsely classified. The average throughput of categories of the OTs suggested a build-up of the bed occupancy over the week with a peak on Friday and a decreasing bed occupancy during the weekend. The distribution of categories per orthopaedic surgeon plays a role in the throughput of categories over the week.

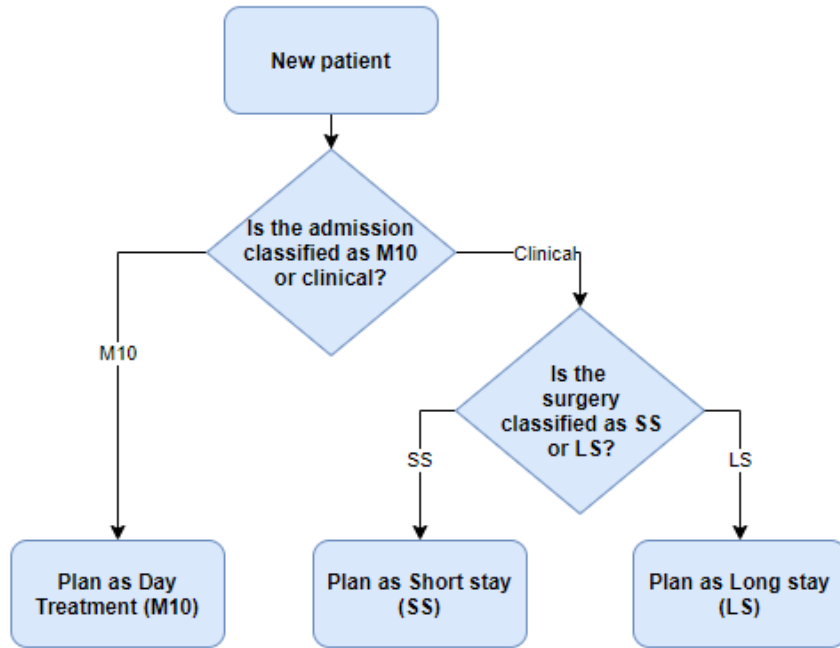


Figure 1: Flowchart of the categorisation for the admission planners.

Model outputs

We tested six different OTs schedules. We derived rules of thumb out of the results of the model. Besides SS and LS patients, we also distinguish M10 patients. These patients leave the hospital at the same day they arrived. The rules of thumb are:

- M10 - Plan M10 patients evenly over the week. Fill Tuesdays and Wednesdays first and Mondays last.
- SS - Plan SS patients at Mondays, Tuesdays and Wednesdays.
- LS - Plan LS patients on Thursdays and Fridays. Plan exceptions on Mondays, Thursdays and Wednesdays.

The secondary rules of thumb are:

- Children - Plan children evenly across the week. Fill Tuesdays and Wednesdays first.
- Prothesis - Plan patients that need a prothesis on Mondays, Wednesdays and Fridays. Fill Friday first.

For the operating schedule for the orthopaedic surgeons the recommendations are:

- The orthopaedic surgeon with the highest fraction of LS patients should be scheduled on Thursdays and Fridays.
- The orthopaedic surgeon with the highest fraction of SS patients should be scheduled at the beginning of the week
- Orthopaedic surgeons with a varied distribution should be scheduled in the beginning of the week at one week and at the end of another week.
- Two orthopaedic surgeons with a high fraction of M10 patients can be combined if the admission planners take the rules of thumb into account.

Recommendations

This section provides recommendations for MST.

- Focus on interventions with a low complexity or on an organization-wide investment in decision support tools to create an admission planning that benefits the wards. Previous years have shown that interventions that fall in between are not endurable. Interventions with a low complexity are executable by employees, do not need rescheduling often, have the possibility to include other departments and are not complicated to pass on to new employees. Setting up general rules of thumb is an example of an intervention with a low complexity.
- Use the rules of thumb stated in Section 5.4. A training session with the admission planners that focuses on making tactical decisions based on the rules of thumb is of great importance.
- Create an extra data type in Medify to label the surgeries with a category. This label should be visible for the admission planners when planning patients.
- Investigate the improvement potential at other departments. The orthopaedics stated that beds at the B4 are often occupied by patients who do not fall under the orthopaedics department. Smit [19] already showed all departments can be included in the QAP model. A more in-depth analysis of the practical problems of implementing his intervention is needed.
- Research how the operating schedule of the orthopaedics could apply the rules of thumb best. We provided some recommendations in this thesis. However an expanded QAP model with the schedule of the orthopaedics could generate more substantiated recommendations.
- Start with a pilot at the orthopaedics department. This because it is not known to what degree the admission planners are able to apply the rules of thumb.

Management samenvatting

Introductie en probleemstelling

Medisch Spectrum Twente (MST) ondervindt capaciteitsproblemen op de afdelingen. De twee waargenomen problemen zijn:

“Afgewezen en uitgestelde behandelingen” en “over- en onderbezetting van de middelen op de afdelingen”

De bedbezetting op de afdelingen varieert te veel. Zowel een wekelijkse als een doordeweekse variabiliteit van de bedbezetting ligt daaraan ten grondslag. De doordeweekse variabiliteit heeft een terugkerend patroon met pieken op donderdag en vrijdag. Dit is hoofdzakelijk het gevolg van de electieve stroom aan patiënten. Wij hebben ons gefocust op de relatie tussen de planning van de operatiekamers en de bedbezetting op de afdelingen van de orthopedie. Het kennisprobleem van dit onderzoek is:

“Hoe kan de orthopedie de bedbezetting of de afdelingen afvlakken doormiddel van het aanpassen van de manier waarop ze electieve patiënten plannen?”

Methode

We hebben ons gefocust op het juist verdelen van opnames over de week. We hebben het kwadratisch programmeer model (QAP) gebruikt van Glerum [10]. Alle studies op dit gebied hebben een categorisering van opnames gebruikt. Wij baseren de categorisering op de afdeling waar de patiënt heengaat en de verblijfsduur. De resultaten van het QAP model maken een interventie zoals Smit [19] onderzocht mogelijk. Smit [19] heeft vuistregels opgesteld voor de opnameplanners. Aangezien Smit [19] de mogelijkheden voor dit probleem al heeft onderzocht voor het MST, zullen wij zijn onderzoek voortzetten. Smit [19] stelde dat een classificatie van elke nieuwe patiënt gedaan moet worden en dat er begonnen zou moeten worden met een pilot bij de orthopedie.

Categorisatie

We hebben opnames ingedeeld in drie categorieën met behulp van de kaderstelling van Glerum [10]. Deze kaderstelling is ook door Smit [19] gebruikt voor het MST. Figuur 2 laat de categorisering van opnames zien. Of de opnames geclassificeerd wordt als kort verblijf (SS) of lang verblijf (LS) hangt af van de mediaan van de verblijfsduur van de desbetreffende operatie.

Slechts 8 procent van de patiënten van de orthopedie waren fout geclassificeerd. De gemiddelde productie van categorieën van de operatie kamers suggereert een oplopende bedbezetting over de week met een piek op donderdag of vrijdag en een aflopende bezetting in het weekend. De verdeling van de categorieën per orthopeed speelt een rol in de productie van de categorieën over de week.

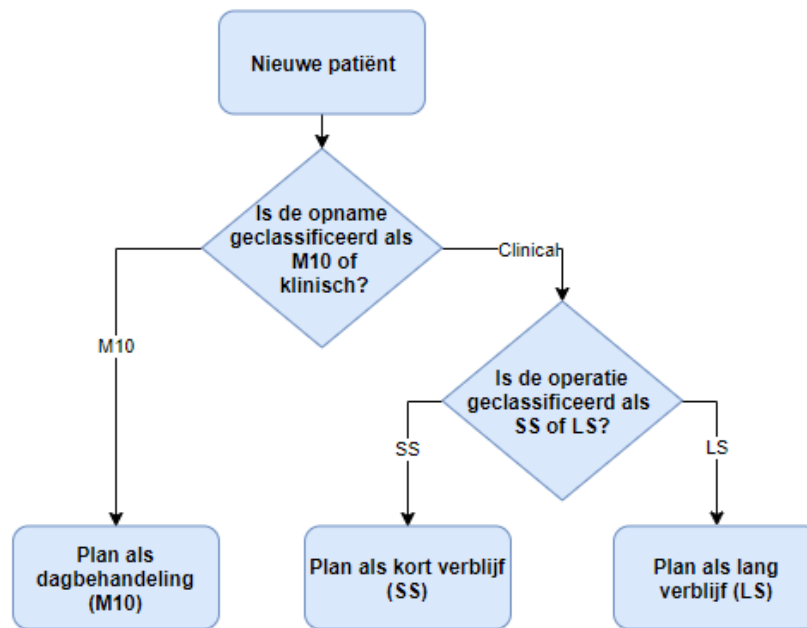


Figure 2: Flowchart van de categorisatie voor de opname planners.

Model outputs

We hebben zes verschillende roosters voor de operatiekamers getest. Uit de resultaten hebben we vuistregels afgeleid. Naast SS en LS patiënten, zijn de M10 patiënten ook een aparte groep. Deze patiënten verlaten het ziekenhuis op dezelfde als dat ze komen. De vuistregels zijn:

- M10 (dagbehandeling patiënten) - Plan M10 patiënten verspreid over de week. Vul dinsdagen en woensdagen eerst.
- SS - Plan SS patiënten op maandagen, dinsdagen en woensdagen.
- LS - Plan LS patiënten op donderdagen en vrijdagen. Plan uitzonderingen op maandagen, dinsdagen en woensdagen.

De bijkomende vuistregels:

- Kinderen - Plan kinderen verspreid over de week. Vul dinsdagen en woensdagen eerst.
- Protheses - Plan patiënten die een prothese nodig hebben op maandagen, woensdagen en vrijdagen. Vul vrijdag eerst helemaal.

De vuistregels toegepast op het werkschema van de artsen leidt tot de volgende aanbevelingen:

- De orthopeden met het hoogste percentage LS patiënten moeten op donderdag of vrijdag worden gepland.
- De orthopeden met het hoogste percentage SS patiënten moeten op maandag, dinsdag of woensdag worden gepland.
- Orthopeden met een gevarieerd pakket aan categorieën moeten de ene week aan het begin en in de daarop volgende week aan het eind van de week worden

gepland.

- Twee orthopeden met een hoog percentage aan M10 patiënten kunnen alleen worden gecombineerd als de opnameplanners vaardig genoeg zijn om de vuistregels juist toe te passen.

Aanbevelingen

Wij bevelen MST de volgende acties aan:

- Richten op interventies met een lage complexiteit of op een organisatie brede investering in een software systeem dat beslissingen op het gebied van de planning kan ondersteunen. De afgelopen jaren hebben uitgewezen dat interventies die daar tussenin liggen niet duurzaam zijn. Interventies met een lage complexiteit zijn onderhoudbaar door werknemers, hoeven niet vaak opnieuw gemodelleerd worden, kunnen andere afdelingen makkelijk meenemen en kunnen makkelijk doorgegeven worden aan nieuwe werknemers. Het opstellen van vuistregels is een voorbeeld van een interventie met een lage complexiteit.
- Gebruik maken van de vuistregels. Een training voor de opnameplanners die focust op het maken van tactische beslissingen is van groot belang.
- Aanbrengen van een extra label per operatie in Medify. Dit zodat opnameplanners weten tot welke categorie een patiënt behoort bij het plannen van de opname.
- Onderzoeken wat de potentiële verbeteringen kunnen zijn als deze interventie wordt toegepast op andere afdelingen. De orthopeden gaven aan dat bedden op de B4 vaak bezet worden door patiënten die niet bij de orthopedie horen. Smit [19] liet zien dat andere afdelingen meegenomen konden worden. Een operationeel onderzoek voor de toepassing van zijn onderzoek op andere afdelingen is nodig.
- Onderzoeken welk rooster van de artsen resulteert in de vlakste bedbezetting. Deze thesis gaat slechts kort in op de roosters van de orthopeden. Een uitbreiding van het QAP model met de roosters van de orthopeden zou beter onderbouwde aanbevelingen kunnen opleveren.
- Starten van een pilot voor de orthopedie. Dit omdat de mate waarin opnameplanners rekening kunnen houden met de vuistregels nog niet bekend is.

Definitions and abbreviations

Definitions

- **Clinical wards:** Wards where patients stay for a minimum of one night
- **M10:** Code for patients that go to the day treatment department
- **The management:** The main group of stakeholders at MST that are entitled to make decisions at the MST on the topic of integral capacity problems.
- **Session duration:** The time between the arrival and the time the patient leaves the operating theatre.
- **Access time:** The time between the moment the patient heard a surgery is needed and the surgery date.
- **Operating theatre:** A room where surgeries take place

Abbreviations

- **MST:** Medisch Spectrum Twente
- **OT:** Operating theatre
- **QAP:** Quadratic assignment programming
- **MILP:** Mixed integer linear programming
- **LOS:** Length of stay
- **KPI:** Key performance indicator
- **IC:** Intensive care
- **PACU:** Post-anaesthesia care unit
- **SS:** Category for clinical patients with a short length of stay
- **LS:** Category for clinical patients with a long length of stay

Readers guide

In the previous months, we have conducted a research at the hospital Medisch Spectrum Twente (MST) in Enschede. This report includes 6 chapters that are briefly introduced below.

Chapter 1 Introduction and Problem statement: This chapter includes an introduction of the hospital the research will be conducted at, the problem statement and the problem approach.

Chapter 2 Analysis of current situation: This chapter includes a description of the working environment of the admission planners, the relevant KPIs and the measurements of those KPIs.

Chapter 3 Modelling approach: This chapter includes a review of the body of knowledge on this topic.

Chapter 4 Categorisation of admissions: This chapter includes the determination of the categorisation of admissions that is used for the model.

Chapter 5 Model: This chapter includes the experimental approach and the experimental results. Potential planning interventions are derived from the results of the model.

Chapter 6 Main findings: The last chapter includes the main findings of the previous chapters.

1 Introduction and problem statement

This research is conducted at the integral capacity department at the Medisch Spectrum Twente (MST) in Enschede. We focus on the relationship between the operating schedule and the bed occupancy at the wards. To give more insight into this relationship, we also focus on a categorisation of admissions.

Section 1.1 introduces the hospital and the department this research is conducted for. Section 1.2 states the perceived problems and the underlying core problems. Section 1.3 states the knowledge problem and the supporting research questions.

1.1 Introduction to MST

Medisch spectrum Twente (MST, Figure 3) is a top clinical hospital located in Enschede, Oldenzaal and Haaksbergen. The hospital has, besides a regional function, also a cross-regional function due to the presence of complex, specialised care. MST employs more than four thousand people, treats over thirty thousand patients a year and has 569 beds available. This research is conducted for the integral capacity department that focuses on finding integral solutions for capacity problems within the hospital. The capacity problems of the orthopaedics department are the main focus.



Figure 3: Medisch Spectrum Twente, Enschede

1.1.1 Orthopaedics department

The orthopaedics department treats patients with conditions involving the musculoskeletal system. Most procedures involve the knee, hip or shoulder. The main goal of the orthopaedics department is to let patients move better. At the moment, there are 8 orthopaedic surgeons in MST. We focus on the relationship between the admission planning of the orthopaedics department and the utilisation of the wards where patients from the orthopaedics department are welcomed.

1.2 Problem statement

Section 1.2.1 discusses the perceived problems. Section 1.2.2 states the core problems and Section 1.2.3 discusses the scope of the research.

1.2.1 Perceived problems

At the moment, MST struggles with capacity problems of the wards. The two perceived problems are:

“Rejections and postponements of patient treatments” and “over- and underallocation of resources of the wards”

Rejections and postponements of patients admissions

In the previous year, the management perceived that there were too many rejected or postponed treatments. A rejection or postponement of a treatment occurs when there are not enough beds available. Either the physical maximum number of beds or the number of available nurses can lead to a shortage of beds. According to the management, these rejections or postponements usually occurred at the middle of the week. The shortage of beds leads to a stop on incoming patients. This leads to unused capacity of the operating theatres (OTs). Since the OTs are the most expensive resources of a hospital, a shortage of beds should be prevented [20].

Over- and underallocation of resources

According to the management, the wards also experienced over- and underallocation of resources to a high degree. Overallocation of resources, like beds and nurses, wastes money. The opposite, under allocation, increases pressure on nurses. Increased pressure reduces the quality of care provided and decreases the general occupational health of those nurses [11].

1.2.2 Core problems

The core problems are derived according the managerial problem solving methodology [13]. To derive the core problem, the underlying problems of the perceived problems have to be found until one does not have any underlying problems. This derivation is visualised by a problem cluster shown by Appendix B. The content of the problem cluster is discussed by Chapter 2. The two core problems are:

1. *“A lack of overview of the characteristics of admissions”*
2. *“A lack of knowledge about what pattern of admissions benefits the utilisation of the wards”*

1.2.3 Scope of the research

The general scope of this research is demarcated in the framework provided by Hans et al.[12] (Figure 4). At the managerial dimension, this research will be conducted at the “Resource capacity planning” layer.

At the hierarchical dimension, this research will be conducted at the strategic, tactical and offline operational level. A categorisation of admissions corresponds to the strategic level. The determination of a pattern of admissions corresponds to the tactical level. An advice will be given on how MST can obtain such a pattern in practice. This belongs to the offline operational level. This research will not focus on the online operational level since we focus on elective admissions.

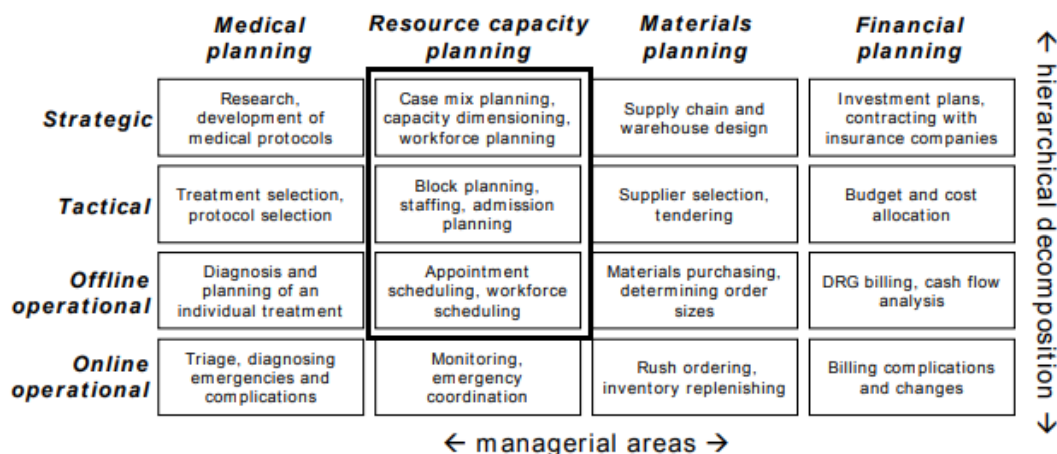


Figure 4: A framework for health care planning and control provided by Hans et al.[12]

1.3 Problem approach

To solve the problems stated in Section 1.2, knowledge is required. The knowledge problem that has to be answered is described as follows:

“How could the orthopaedics best improve the utilisation of the wards by adjusting the way they plan elective admissions?”

To answer this knowledge problem, several supporting research questions are prepared and discussed in the next section.

1.3.1 Research questions

To answer the knowledge problem, seven research question are prepared and divided into five topics: the current situation, a literature study, a categorisation, the model and the main findings. Each research question will be discussed separately.

To obtain an answer to these research questions, data is retrieved from three databases within MST: Xcare, ORSuite and Blokplan. Xcare contains general patient information. ORsuite contains the planning for the OTs and Blokplan contains the distribution of the OTs to all the specialties.

Current situation

First of all, the current situation has to be analysed. A better understanding of the environment admission planners operate in is necessary to determine the limitations and possibilities. Besides that, the current performance has to be measured to compare it with an alternative situation in a later phase.

1. What is the working environment in which the admission planners of the orthopaedics department operate?

An answer to this research question is obtained by having meetings with and observations of admission planners. Also, a meeting with the manager of the admission planners is held to get a broader perspective of the network admission planners operate in. Orsuite and Blokplan are used to obtain supporting data.

2. What is the current performance of the orthopaedics department?
 - (a) What are the relevant key performance indicators (KPI's) that represent the performance of the OTs and the wards?

To obtain answers to these questions, an interview with the head of the chain capacity department is conducted. To further measure the performance of these KPIs, data of the previous two years is analysed. These data is retrieved from Xcare, Orsuite and Blokplan.

Literature

A literature study is conducted to determine what can be used of the body of knowledge on this topic. With this literature study, an answer to the following research question is obtained.

3. What model could best improve the utilisation of the wards by adjusting the way admissions are planned at the orthopaedics department, according to the literature?

For the literature study, Scopus is used to gather relevant studies.

Categorisation

For the modelling approach, a categorisation of admissions is needed. All admissions from all the departments that start with a surgery are included. To determine which categorisation fits the research aim, the following research question is composed.

4. How could the admissions best be classified into categories?
 - (a) How does the categorisation work out for the orthopaedics department?

The answers on research question 1 and 3 and datasets containing the characteristics of each patient are analysed to answer this research question. These datasets are retrieved from Xcare, ORsuite and Blokplan.

Model

Thereafter, we determine the model. The constraints and the experimental settings are needed to generate potential interventions. The quality of these interventions are also discussed in this chapter. This chapter answers the following research questions.

5. What experimental approach suits the research aim?
 - (a) What are the inputs of the model?
 - (b) What are the scenarios to be tested?

The answers to research question 3 and 4 are used to obtain an answer to this research question. IBM optimization studio is used to program the model.

6. What are the outputs of the model?
 - (a) How do the KPIs score?
 - (b) What rules of thumb could be derived?

These research questions are answered by means of the results generated by the model programmed in IBM optimization studio. The rules of thumb are derived out of these results.

Main Findings

Finally, we summarise and reflect on the main findings in the previous chapters.

7. What are the main findings of the research?

The answers to all the other research questions are used to obtain an answer to this research question.

2 Analysis of current situation

This chapter includes an analysis of the current situation at the orthopaedics department. Section 2.1 describes the working environment of the orthopaedics department and the flow of patients through the hospital. Section 2.2 states and discusses the key performance indicators.

2.1 Organisational analysis

For the organisational analysis, we start with the flow of patients through the hospital. Thereafter, we discuss the OTs, the wards, the orthopaedic surgeons, the admission planners and the type of admissions.

2.1.1 Flow of patients through the hospital

There are two main paths through the hospital for patients that undergo surgery. Figure 5 shows the two paths. The first path is the path of emergency patients. The emergency patients arrive at the hospital and are treated as soon as possible.

The second path is the path of the elective patients. Those patients visit an outpatient clinic after which a doctor decides whether an admission and a surgery is needed. If a surgery is needed, the patient first has to visit the preoperative screening to test whether the patient is able to undergo surgery. Before a patient undergoes surgery, the patient will be put on the waiting list and eventually planned by admission planners. Right before the surgery, or sometimes the day before, the patient is admitted at one of the wards. Thereafter, the patient will undergo surgery.

After a surgery, emergency as well as elective patients go to the recovery department, the post-anaesthesia care unit department (PACU) or the intensive care department(IC). Thereafter, the patient will be boarded to a ward. It is possible that patients undergo surgery multiple times or switch wards during their stay. Some patients transfer to Resort Bad Boekelo after a few days. Finally, the patient will be discharged.

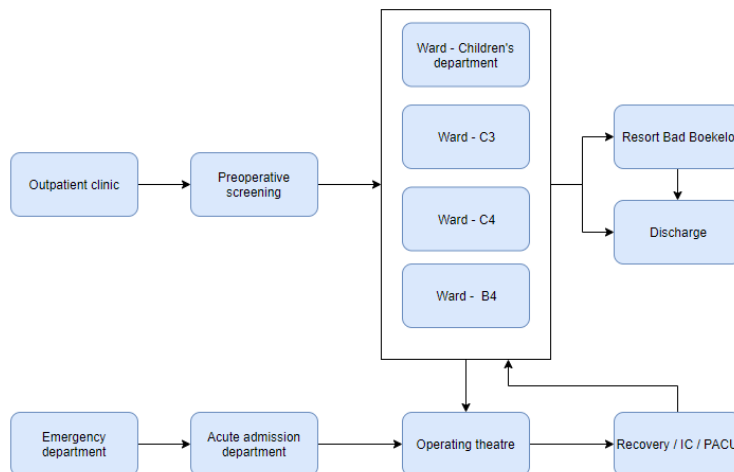


Figure 5: Paths through the hospital of patients who undergo surgery

2.1.2 Operating theatre

There are fifteen OTs in use at MST. The OTs are divided among the specialties at the beginning of the year. During the year only small adjustments are made to that schedule. Figure 6 shows the number of OTs used by the orthopaedics department per day of the week in 2018. The OTs were evenly spread over the week. Only on Mondays, there were less OTs used. At the weekends, the hospital only treats emergency patients.

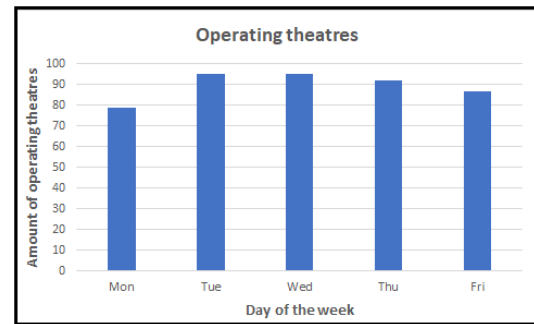


Figure 6: Total number of OTs used per day of the week. *Data retrieved from Blokplan, $n = 447,6$, 2018*

2.1.3 Orthopaedic surgeons

At the moment, there are eight orthopaedic surgeons at MST. Each orthopaedic surgeon has a different package of patients that he treats. An overview of these packages can be found in section 4.3.3. The orthopaedic surgeons make their own operating schedule. At the moment, the orthopaedic surgeons do not take the consequences of the wards into account when creating their schedule. They only noticed that it was not practical to plan the two orthopaedic surgeons with the highest throughput on the same day.

2.1.4 The wards

Right before a surgery, the patient is admitted to a ward. After a surgery, the patient spends the rest of their stay at a ward. According to Xcare and ORsuite, 1,6% of the patients are admitted on a ward a day before the surgery. Sometimes, patients from the orthopaedics department are boarded to different wards that are not intended for them due to a lack of space. We only discuss the wards where patients from the orthopaedics department are normally welcomed. Table 1 shows the number of available beds per ward.

- *C3* - Welcomes adult patients that stay for one day. We call this ward C3 as well as day treatment department in this thesis.
- *C4* - The C4 is a clinical department that welcomes adult patients from several departments. Clinical departments host patients that stay for a minimal of one night. According to the bed coordinator, the C4 does not scale down on capacity in the weekends. The C4 only closes beds when there are less OTs open due to vacations.
- *B4* - The B4 is a clinical ward where patients who need specialised care stay for at least one night. There are working nurses that are specialised in treating orthopaedical patients. Three orthopaedic surgeons argued that if a patient that needs a prothesis is treated at the B4 instead of another ward, it is likely that they leave the hospital a day earlier. Appendix H shows the surgeries that need specialised care according to one of the orthopaedic surgeons. According to the bed coordinator, the B4 only scales down in weekends when it is possible. When the C4 has available beds, the patients from the B4 are sometimes boarded to the C4.

At the moment, several other departments make use of the B4 due to capacity problems. Because of this, patients from the orthopaedic department that

need specialised care sometimes stay at the C4. Boarding between the C4 and the B4 happens smoothly.

- *Childrens department* - The children's department welcomes all children. The children's department has 20 beds available. At this ward there is also no target occupancy for the orthopaedics department. The children's department welcomes M10 patients as well as clinical patients.
- *Resort Bad Boekelo* - MST has four beds available at resort Bad Boekelo. This resort offers a recovery project with a duration of nine days. Patients who underwent a surgery for a new knee or hip can participate in the project. The costs of this project fall under the diagnostic treatment combination (DBC) of the hospital. Therefore, it is important to optimise the use of those available four beds in Boekelo. Patients that are eligible to make use of this project mostly go to Resort Bad Boekelo after spending two nights at the hospital after their surgery.

Ward	number of beds	Available for orthopaedics
C3	20	X*
C4	47	X*
B4	8	8
Children's department	20	X*
Resort Bad Boekelo	4	4

*There is no specific maximum available for the orthopaedics. A smooth occupancy is preferred.

Table 1: Number of beds available per ward for the orthopaedics

2.1.5 Admission planners

At the moment, two admission planners work part-time to plan the admissions for the orthopaedics department. They work at a centralised planning department that falls under the integral capacity department. They both plan patients for all orthopaedic surgeons. They receive the operating schedule of the orthopaedics six weeks in advance. Thereafter the admission planners fill up the operating schedule.

Emergency patients

For the short term the admission planners have to anticipate on the incoming emergency patients, no shows and other circumstances. If an emergency patients arrives at the hospital and needs a surgery on the same day, the employees who work at the OTs will plan the surgery. If an emergency patient can wait until the next day for a surgery, the admission planners have to plan the surgery. The admission planners have to decide which surgery to cancel to make room for the emergency patient. At some days, some space at the surgery schedule is reserved for emergency patients.

Elective patients

When the admission planners plan admissions in advance, they go through several steps. The admission planners check the first day at which there is empty space in the operating schedule. Then, the admission planners check which doctor operates on the concerned day and at the concerned OT. The patient that is on top of the orthopaedic surgeons waiting list and who's preferences correspond with the concerned day will be considered first. The sequence of patients on the waiting list is determined by an algorithm that takes urgency and access times into account.

There are four urgency levels: high urgency, medium urgency, low urgency and no urgency. A patient with an urgency label has to be operated within respectively 7 days, 4 weeks, 4 months and the patient with no urgency do not have a time limit. Whether the patient on top of the waiting list has the right fit depends on several aspects. The four most important aspects are described below. Appendix C includes a flowchart of this planning process.

- *The patient wants to go to Resort Bad Boekelo* - There is a special planning process for patients that want to go to Resort Bad Boekelo. Appendix C includes a flowchart of this planning process.
- *A knee or hip prosthesis* - Another aspect is whether the patient needs a knee or hip prosthesis. Most patients who undergo a knee or hip surgery spend two nights at the hospital. Therefore, the department decided to only plan these surgeries on Mondays, Wednesdays and Fridays. This is the only planning rule that takes the utilisation of the wards into account. Figure 7 shows the total number of surgeries including a knee or hip prosthesis per weekday in the first eleven months of 2018. Only on Fridays there were significantly more surgeries planned than on Tuesdays and Thursdays.

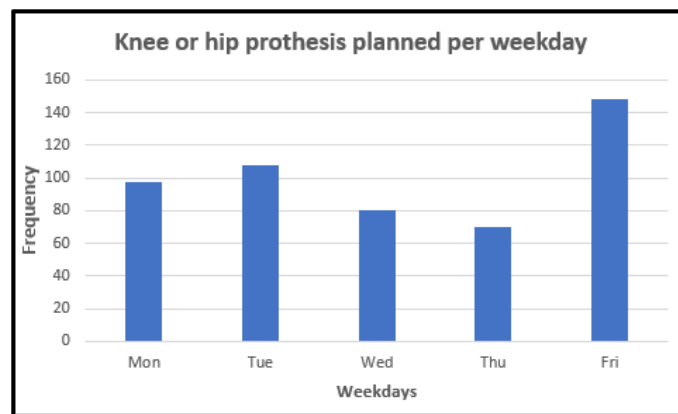


Figure 7: Number of knee or hip prostheses planned per weekday. *Data retrieved from ORsuite, $n = 504$, 01-01-2018/03-12-2018*

- *Session duration* - The session has to fit in the operating schedule.
- *Maximum number of certain surgery* - Finally, for some surgeries, there is a maximum number that can be carried out on a day. This because some surgeries need products of which there is little inventory.
- *External firms* - Some surgeries need special products or are carried out in co-operation with an external doctor. For these surgeries, the admission planners have to check with a firm whether a certain date suits them.
- *Preoperative screening* - Before a patient can undergo surgery, the patient first has to undergo a preoperative screening. This to assess the patients risks and potential problems.

2.1.6 Type of admissions

There are a few distinctions to make between admissions that are relevant for this research. The most important are described below.

- *Emergency and elective admissions* - Emergency patients have a high urgency and undergo, if needed, surgery as soon as possible. The elective patients visit an outpatient clinic first. At the outpatient clinic the doctor assesses whether the patient needs an admission.
- *Day treatment or clinical admissions* - There is a distinction between the patients that go home at the same day they visit the hospital and the patients that stay for the night. The patients that only visit for one day are classified at M10 and the others as clinical.

Not all patients go to the day treatment or clinical wards. The children, that account for 7% of the elective admissions, go to the children's department. We decided to include children in this research. According to the team leader of the children department, the children's department struggles with an inconsistent inflow of children. This capacity problem is partly caused by the orthopaedics department since they treat children.

- *Surgery during admission* - Also, there is a distinction between the patients that undergo surgery and who do not. The departments where patients mostly undergo surgery are called "cutting" and departments where patients are admitted without undergoing a surgery are called "contemplative". The orthopaedics department is classified as "cutting".
- *Strictness of orthopaedic surgeon* - The last distinction is between patients that can only be treated by one specific orthopaedic surgeon, strict patients and patient that can also be treated by other orthopaedic surgeons, non-strict patient. An orthopaedic surgeon can decide, in consultation with the patient, whether the patient can only be treated by himself or also by other orthopaedic surgeons. There is no data available to measure the number of strict patients. In an observation of an admission planners, it became clear that only one orthopaedic surgeon had some non-strict patient on their waiting list.

2.2 Performance indicators

This section includes the relevant KPIs for the OTs, the wards and the service quality.

2.2.1 Operating theatre

The performance indicators that we use for the OTs are the utilisation, the throughput, the makespan and the levelling. Each performance indicator will be discussed in this section.

- Utilisation

The utilisation is defined as the workload of a resource [5]. The utilisation can be measured as the use relative to the availability of that resource. At MST, the target utilisation for the utilisation of the OT is 85 percent. The orthopaedics had an utilisation of 83 percent in 2018.

- Throughput

The throughput of the OT is the number of patients treated per time unit [5]. The number of surgeries determines the pressure on the recovery, IC, Pacu and eventually on the wards. It is also closely related to the access time for patients.

Figure 8 displays the distribution of four surgery types the orthopaedics department treats. Only 7 percent of the total number of surgeries were classified as emergency surgeries. The greatest fraction is represented by the patients that were classified as both elective and clinical. This group counts for 56 percent of the surgeries. The remaining 37 percent were elective M10 patients.

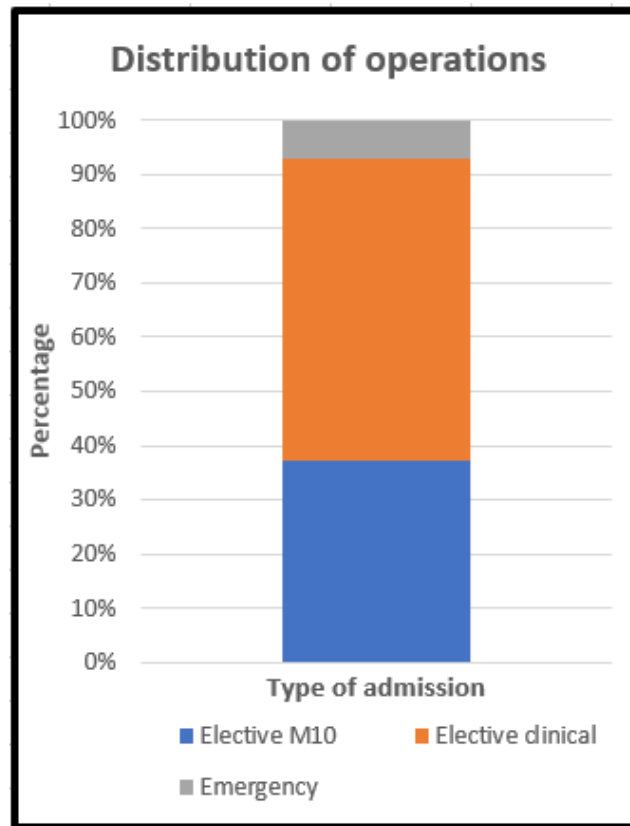


Figure 8: Distribution of surgery types. *Data retrieved from Orsuite, n=4096, 01-01-2017/03-12-2018.*

On average, the surgeries administrated as emergency were evenly spread over the days of the week. Figure 9 shows the emergency surgeries of the first 11 months of 2018.

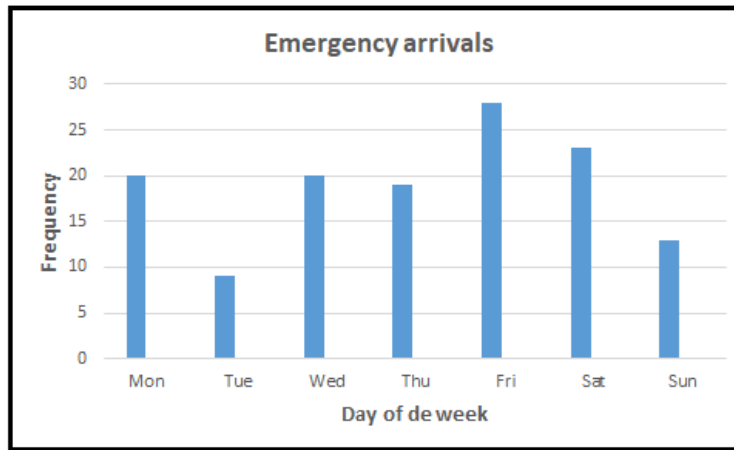


Figure 9: Emergency surgeries per day of the week. *Data retrieved from Orsuite, n=4096, 01-01-2017/03-12-2018.*

Another subgroup is the children. The children account for 7% of the elective admissions. Table 2 shows the distribution of elective children treated by the orthopaedics department.

Admission type	Total	Total children	percentage children of total
Elective admissions	3794	270	7%
Elective M10 admissions	1516	152	10%
Elective clinical admissions	2278	118	5%

Table 2: Number of children of total. *Retrieved from Orsuite, n=3794, 01-01-2017/03-12-2018.*

Figure 10 shows the throughput of the M10 patients of all the days with a minimal of one OT available in 2018. The average throughput per day is 3,55 patients and the standard deviation is 2,43.

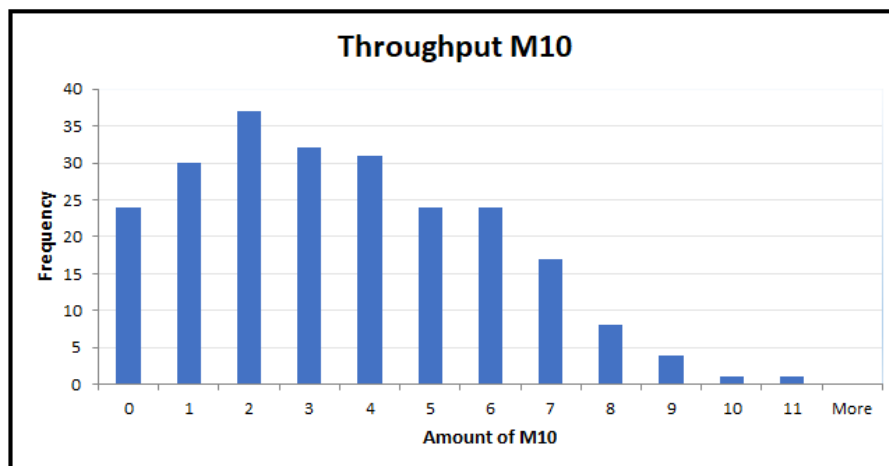


Figure 10: Throughput of M10 patients. *Data retrieved from ORsuite, n=233, 01-01-2017/03-12-2018.*

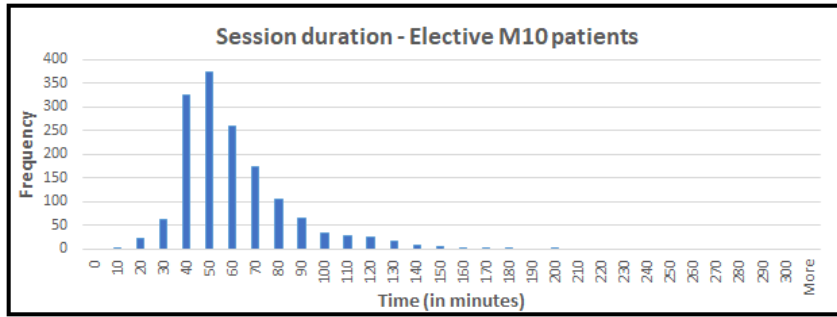
- Makespan

The makespan is the amount of time between the moment the first patient arrives at the OT and the last patient leaves at the OT on one day [5]. We describe the makespan by the session duration of the patients. The session duration is the time a patients spends at the OT. Figures 11a, 11b and 11c display the session duration of respectively the elective clinical patients, the elective M10 patients and the emergency patients. The graphs of the session duration of the patients classified as elective and M10 or clinical are right-skewed, like a lognormal distribution. Table 3 displays the averages and standard deviations.

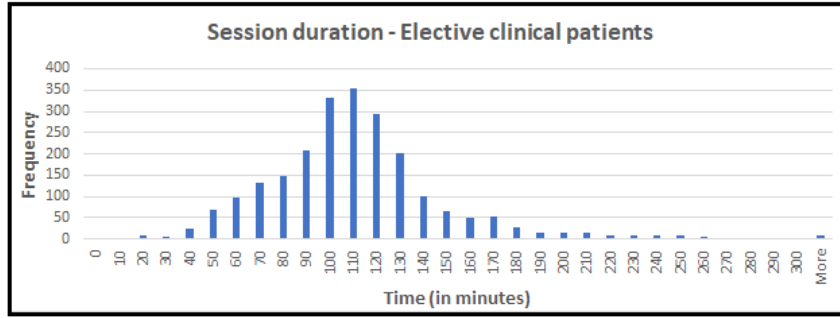
The shorter session duration of M10 patients can be explained by the lower care level these patients have. The session duration of the emergency patients is more varied. This because the group of emergency patients includes M10 as well as clinical patients.

Admission type	Average	Standard deviation
Elective clinical surgery	107	41
Elective M10 surgeries	56	24
Emergency surgeries	76	44

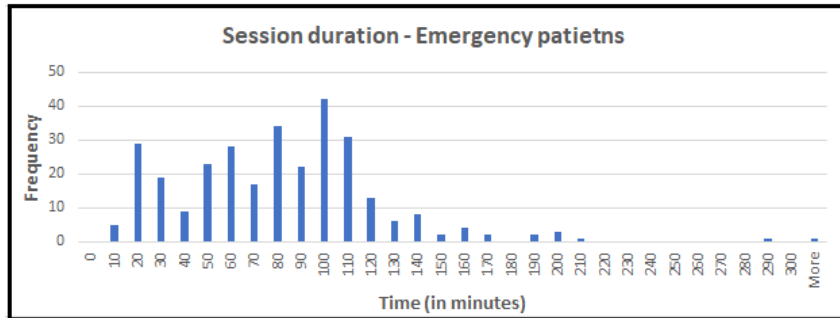
Table 3: Data analysis of session durations from patients treated by the orthopaedics department. *Data retrieved from Orsuite, n=4096, 01-01-2017/03-12-2018.*



(a) Session duration of patients classified as M10 and elective, $n=1516$



(b) Session duration of patients classified as elective and clinical, $n=2278$



(c) Session duration of patients classified as emergency, $n=302$

Figure 11: Session duration of patients treated by the orthopaedics department. Data retrieved from ORsuite, 01-01-2017/03-12-2018.

- Levelling

Levelling stands for smooth resource occupancies without peaks [5]. It is hard to organise resources around a fluctuating utilisation. We will measure the levelling of the OTs as the variability of the utilisation. Figure 12 shows the variability of the utilisation of the OTs used by the orthopaedics department in 2018. The average utilisation is 83% and the standard deviation is 8%.

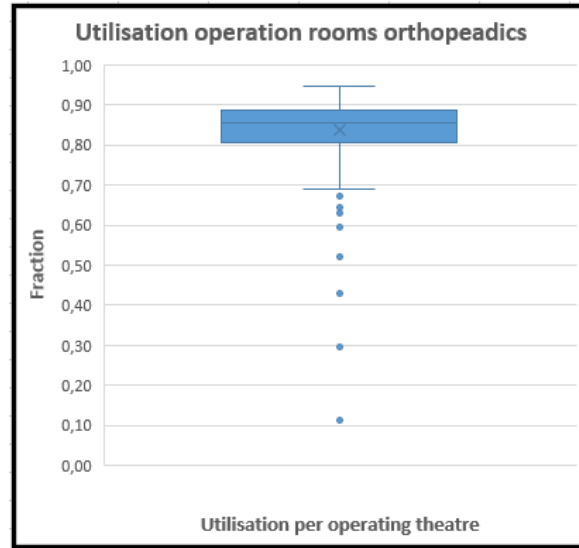


Figure 12: Utilisation of the OTs used by the orthopaedics department. *Data retrieved from ORsuite, $n=447$, 2018.*

2.2.2 The wards

The performance indicators that we use for the wards are the levelling of the bed occupancy, the throughput and the LOS. Each performance indicator will be discussed in this section.

- Levelling

For the wards, levelling means the same as for the OTs, explained in section 2.2.1. Since there is no clear maximum of beds for the orthopaedics department at some wards, we only focus on the levelling of the bed occupancy. For the across weeks levelling, the average bed occupancy per week at the clinical wards is displayed. Only weeks where the orthopaedics had nine or more OTs at their disposal are included. The average bed occupancy is 15,5.

For the within-week-smoothing, we compare the peak of the bed occupancy on a day with the peak on the Friday in the same week. Figure 14 displays all those fractions in the form of a boxplot. The average fraction builds up as the week progresses with a peak on Thursday and Friday. In the weekend, the bed occupancy decreases relative to the Friday. Once every four weeks, the peak in bed occupancy at a Monday is less than 60 percent than the peak at Friday in the same week. The same applies for Tuesdays. The figures in appendix A display the bed occupancy per hour together with the number of OTs available on a day for 2018. In all the analyses of the bed occupancy, emergency patients are included. This because in the datasets available and suited for measuring the bed occupancy, the emergency patients were not specified. In the first 11 months of 2018, 2,75 emergency arrived per week on average.

The bed occupancy at the C3 is almost equal to the throughput of M10 patients. Section 2.2.1 is used to display the throughput of the OTs.

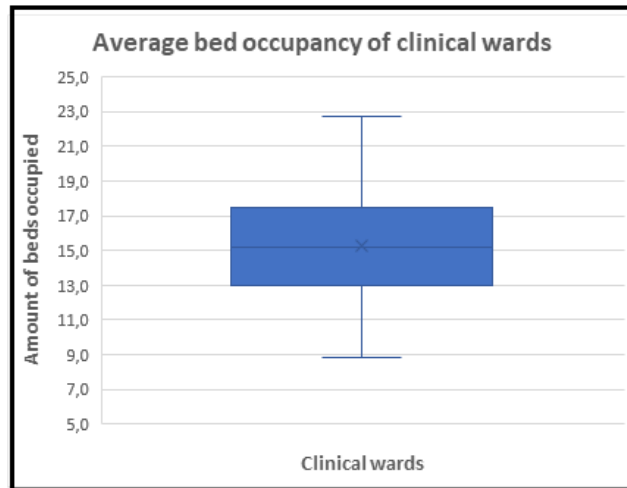


Figure 13: Average bed occupancy of clinical wards. *Data retrieved from Xcare, $n=29521$ and $n=29517$, 2018.*

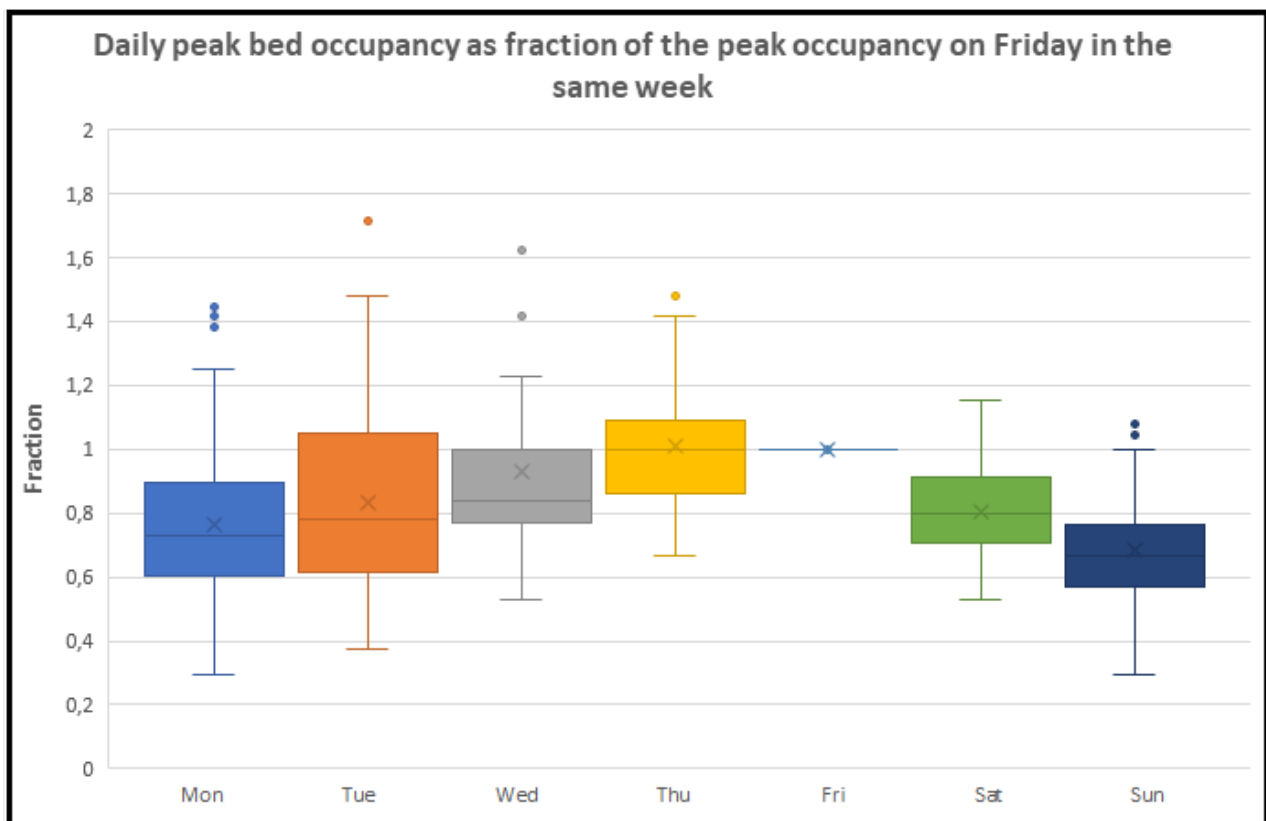


Figure 14: Daily peak in bed occupancy as fraction of the peak occupancy on Friday in the same week. *Data retrieved from Xcare, $n=52$, 2018.*

- Throughput

For the wards, throughput stands for the number of admissions and discharges per time unit. Both the number of admissions and discharges per day of the

week and the time of admission or discharge will be used to measure the throughput. Figure 15 shows the time of admissions and discharges. Admissions mostly occur in the morning and discharges mostly occur in the beginning of the afternoon.

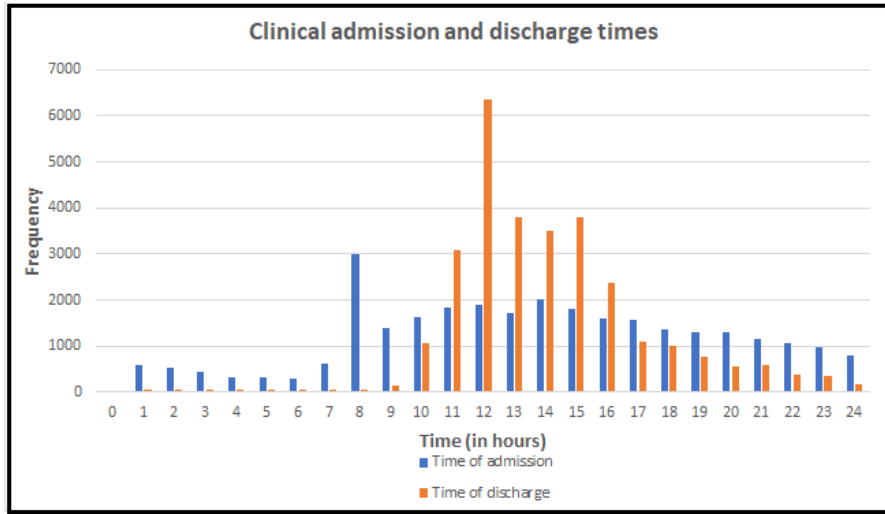
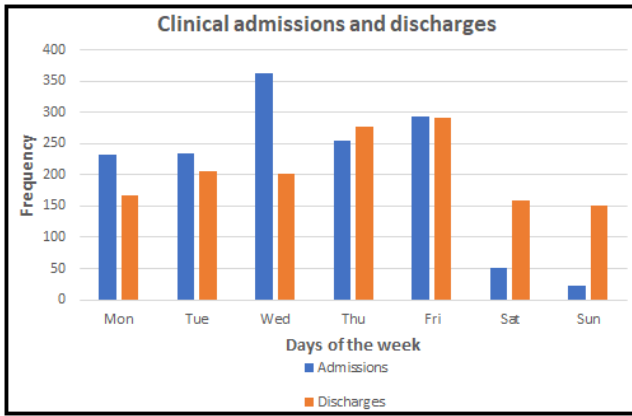


Figure 15: Admission and discharge times. *Data retrieved from Xcare, $n=29521$ and $n=29517$, 2018.*

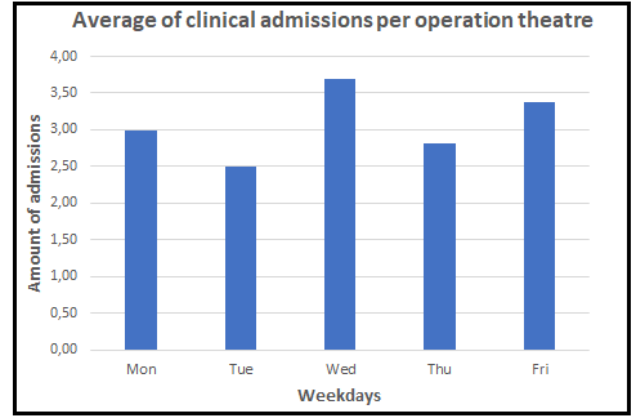
The traffic of patients is the highest at the middle of the week, shown by figure 15a. According to the management, admissions are labour intensive. Together with the high bed occupancy at Wednesdays, Thursday and Fridays, the pressure on capacity is significantly higher on these days than on Mondays or Thursdays.

The bed occupancy that is building up as the week progresses can be explained by figure 15a. From Monday to Wednesday, there were more admissions than dischargers. This indicates a growing bed occupancy. The bed occupancy is especially growing at Wednesdays.

The build-up in bed occupancy can be substantiated by the number of available OTs across the week, as shown in figure 6. As the week progresses, more OTs were available. On Wednesdays, the most OTs were used. In combination with a high throughput per OT on Wednesdays, as shown in Figure 15b, the number of admissions is high on Wednesdays.



(a) Admissions and discharges per day of the week



(b) Admissions per operation theatre per weekday

Figure 16: Clinical throughput of the orthopaedics department. *Data retrieved from Xcare and Blokplan, $n=1450$, 2018.*

- LOS

The LOS is the makespan of the wards. The LOS is the time a bed is occupied by or reserved for a patient at the wards. Figure 17 shows the LOS per clinical admission in 2018 for the orthopaedics. This figure includes the emergency patients as well as elective patients. This, because the dataset used does not contain the type of admissions except that they are clinical. Most patients stay for one or two nights.

According to the head of the integral capacity department, M10 patients occasionally stay for the night. However, we assume that M10 patients only stay for one day.

At the moment, some patients have an extended LOS due to little room at nursing homes. Patients stay at the hospital until a place at a nursing home is found. At the moment this leads to extended lengths of stay that harms the bed occupancy of the wards.

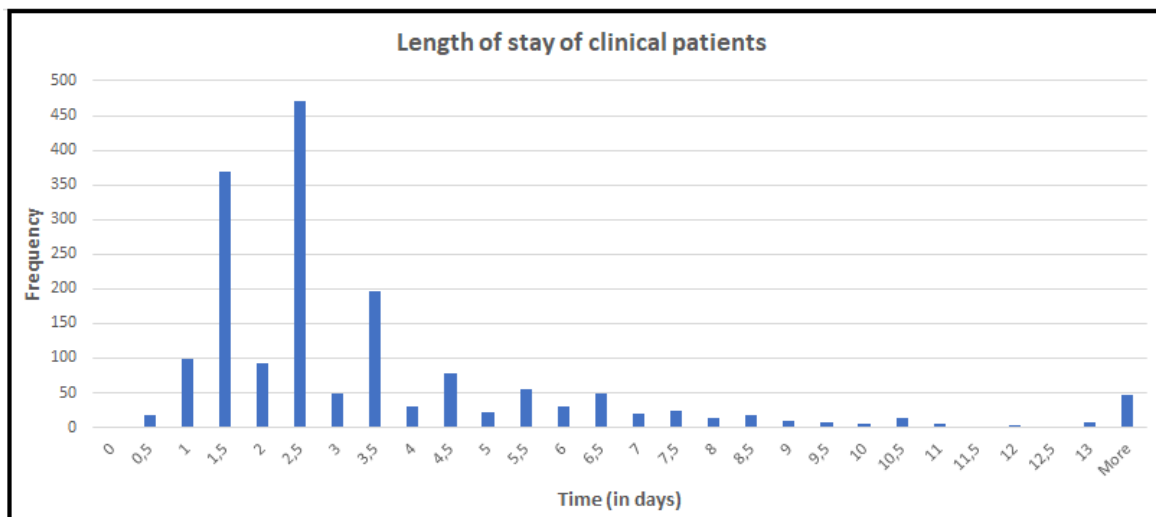


Figure 17: LOS of all clinical patients admitted and discharged in 2018 of the orthopaedics department. *Data retrieved from Xcare, n=1735, 2018.*

2.2.3 Service quality

The performance indicators that we use for the service quality are the access times and whether the patients are treated on the right ward. Each performance indicator will be discussed in this section.

- Access times

The access time includes the time a patient is on the surgery waiting list. There is no data available for the access times for patients of the orthopaedics department. However, in section 2.1.5, it is stated that the admission planners always check the first person on the waiting list first. Access times can only be decreased by a higher throughput.

- Treated on the right ward

This indicator can be defined as the number of patients that are treated on the right ward. There is no data available for this performance indicator. Three orthopaedics assessed the occurrences of patients who should be treated on the B4 and lie at other departments as to many. They argued that they have to walk through the whole hospital to visit their patients.

2.3 Conclusion

The answers to the research questions and sub research questions are discussed below.

1. *What is the working environment in which the admission planners of the orthopaedics department operate?*

The admission planners work for the integral capacity department. They are working together with admission planners from other departments at a centralised planning room. The admission planners plan elective admissions and a part of the emergency patients. The patients go to four different wards after their surgery. The admission planners mainly focus on filling the operating schedule. Only occasionally, the bed occupancy of the wards is taken into

account.

2. *What is the current performance of the orthopaedics department?*

The bed occupancy fluctuates too much. A weekly as well as a cross-weekly variability in bed occupancy is causing capacity problems. The bed occupancy has a weekly pattern where peaks on Thursdays or Fridays are common. This is mainly caused by the elective flow of admissions.

(a) *What are the relevant key performance indicators (KPI's) that represent the performance of the OTs ,the wards and the service quality?*

For the OT, the wards and the service quality, performance indicators are determined. For the OTs, the utilisation, the throughput, the makespan and the levelling are the performance indicators. For the wards, the smoothness of the bed occupancy, the LOS and the throughput are the performance indicators. For the service quality, the access times and whether a patient lies on the right department are the performance indicators.

3 Modelling approach

In this chapter, we check what can be used from the body of knowledge on this topic. Section 3.1 defines the theoretical perspective. Section 3.2 determines the modelling approach by means of a literature study.

3.1 Theoretical perspective

The theoretical perspective used in this chapter is that of determining a planning method for elective admissions that benefits the bed occupancy of the wards by means of operations research. Benefitting the bed occupancy of the wards means reducing the variability of the bed occupancy. Operations research is a collective name for mathematical methods that support decision making.

3.2 Modelling approach

In this literature study, we elaborate several aspects of a model. Section 3.2.1 states a general review of how capacity problems are tackled by means of planning adjustments in the literature. Section 3.2.2 determines the mathematical models used. Section 3.2.3 discusses the complexity of the model. Section 3.2.4 discusses the resources taken into account by the model. Section 3.2.5 discusses the categorisation of admissions and Section 3.2.6 discusses potential interventions.

3.2.1 General review

Improving the bed occupancy of the wards by adjusting the way a hospital plans admissions can be done at different levels. One of the highest planning level is the level where OT time is allocated to the different specialties. The outcome of that allocation is called a master surgical schedule (MSS). The impact of a MSS on the wards is researched by Vanberkel et al.[20] and Kortbeek et al.[17]. Vanberkel et al. provided a model to generate a MSS that benefits the wards. Wopereis [21] provided a model for the MST that could create such a MSS.

The lowest level is the level of the admission planners. According to Adan et al. [1] the admission planners plan admissions based on their experience instead of using formal procedures. At the moment, admission planners at the MST do the same. Fieldston et al. [9] showed that hospitals for children, with a difference of 10%-point in ward occupancy between week and weekend occupancy, could reduce their week-day peak by 7,5%- point by means of within-week-smoothing of admission. They stated that a mean of 7,4 patient have to be planned on a different day of the week to achieve within-week-smoothing. Another approach to improve bed occupancy, studied by Conforti et al.[6], is to reduce the LOS by creating an admission and discharge schedule that takes into account the available clinical services. We will focus on smoothing admission over the week/weeks. This because we assume this has the highest chance to be realised.

3.2.2 Mathematical models

There are several studies that make use of a model that smoothens admissions over the week or weeks to improve the bed occupancy of the wards[1][2][4][8][10][14][15][16][19]. Since MST is not likely to invest in new software systems in the short term, live decision support systems, as done by Hutzschenreuter [15], would not work. According to the literature, another approach to generate a pattern of patient groups is using mathematical programming. Mathematical programming is a tool to solve optimisation problems.

The two main models used are mixed integer linear programming (MILP) models

[1][2][8][16] and quadratic assignment problem (QAP) models[4][10][19]. The main difference between those models is the objective function that optimises the use of the concerned resources. The MILP models all minimise the absolute difference between the desired utilisation and the realised utilisation of the resources. The QAP models minimise the quadratic difference between the desired utilisation and the realised utilisation of the resources. Bekker and Koelemans[4] assumed that the consequences of a deviation from the desired bed occupancy is not linear in the size of the deviation. Since greater deviations have a greater weight with a quadratic objective function, Bekker and Koelemans [4] used a quadratic objective function. The MILP models as well as the QAP models use linear constraints.

According to Glerum [10], a MILP model as well as a QAP model could decrease the variability in bed occupancy. Glerum concluded that the QAP model generates better outputs than the MILP model. Therefore, we will use a QAP model.

3.2.3 Complexity of the model

All the mathematical programming models vary in their level of complexity. The complexity of the model correlates with the complexity of the intervention that follows from the model. The pillars of the complexity of the model are: the number of resource taken into account, the number of categories used and the degree to which the intervention is fitted to the working environment. To decide what degree of complexity fits MST, some aspects are described below.

- *Including more departments* - According to the management, more departments are struggling with capacity problems at the wards. Therefore, it would be beneficial if other departments could easily be included in the model. Including other departments would be easier with a less complex model.
- *Admission planners* - MST is not likely to invest in any planning software soon. Therefore, the outputs of a model have to be applied by admission planners. Therefore, the capabilities of the admission planners play a significant role. A less complex intervention is easier to work with.
- *Taking into account all the constraints* - Adan et al. [1] state that in reality there are many restrictions that play a role and that this could make it difficult to realise a model that works in practice. The experience of the admission planners can be used to take most constraints into account. A lower complexity increases the chance of implementation.
- *Too little employees to keep a model up to date* - A master student researched a new scheduling method for the orthopaedics department at MST in 2015. Despite the contentment of the employees about this method, they did not keep working with it after he left. This was due to the fact that this method, that was highly fitted to the operating schedule, had to be kept up to date regularly and would be useless if not. Wopereis [21] invented a optimisation tool to optimise the MSS. Again, MST did not used it because no one was able to work with it and keep it up to date. A lower complexity increases the chance that the MST could keep an model up to date.
- *High staff turnover* - At the moment, the staff turnover at the integral capacity department is high. The intervention has a smaller chance of success when a model has to be passed on to new people often. A model with a low degree of complexity has a higher chance of passing on successfully. Therefore, a low

complexity benefits the durability of the model.

- *Rewards* - Dealleart and Jeunet [8] studied different policies to implement the outputs of the model provided by Adan et al. [1]. They argued that too much deviation from the tactical plan leads to a less efficient utilisation of resources, since a less detailed and complex model indicates more freedom for certain variables. A more complex model has higher potential rewards.

Taking the above into consideration, we will focus on a model with a low degree of complexity.

3.2.4 Resources

The bed occupancy of the wards is the main resource to focus on. All studies who use a MILP or QAP model to smoothen admission over the week use the bed occupancy in their objective function. To obtain a solution that is practically feasible, other resources have to be taken into account. Table 3.2.4 discusses the resources that different studies have taken into account. We only take into account the bed occupancy of the wards and the OT time available. We assume this is the best trade-off between the efficiency and the practical feasibility of the intervention.

Resource	Studies	Comments
Bed occupancy wards	[1][2][4][8][10][14][15][16][19]	Included by each study as their objective function.
Bed occupancy IC	[1][2][8][16]	The admission planners do not take the IC into account at the moment. Therefore, we assume that neglecting this resource would not lead to problems.
Nursing workload wards	[1][2][8][16]	According to the management, the nursing workload correlates with the bed occupancy to a high degree.
Nursing workload IC	[1][2][8]	The admission planners do not take the IC into account at the moment. Therefore, we assume that neglecting this resource would not lead to problems.
OT time available	[1][2][8][10][16][19]	The available operation theatre time is the main resource on which admission planners focus at the moment. This because the OTs are the most expensive resources of a hospital [20].

Table 4: Resources that different studies, which smoothen the bed occupancy by means of a MILP or QAP model, have taken into account.

3.2.5 Categorisation of admissions

Most studies that smoothen admissions over the week used a categorisation where each category has several characteristics. This section discusses the characteristics per category and the allocation of patients into categories.

Characteristics of the categories

For each resource, certain characteristics can be used. For the bed occupancy of the wards, all studies use the LOS of the patients [1][2][4][8][10][14][15][16][19]. Some studies used a deterministic LOS [1][4], others used a stochastic LOS [2][8][10][14][19] and one study used an exponential LOS [4].

Glerum [10] and Smit [19] also used the ward where the patients stay as a characteristic. They made a distinction between patients that went to the day treatment department and patients that went to the clinical wards.

Adan et al. [2] showed that the use of a stochastic LOS generates better results than a deterministic LOS. The mathematics used by Bekker and Koelemans [4] are quite cumbersome. In combination with the time limit, we will not use an exponential LOS. Adan et al. [1] included whether a patient group arrives a day before or arrives on the day of the surgery. Since only 1.1% of the patients of the orthopaedics department arrive the day before the surgery date, we will not use this.

The studies that take the available operation theatre time into account, all use a deterministic operation duration. Since the session duration of a patient is available in the datasets, we will use session duration instead of operating duration. Concluding, we will use a stochastic LOS as characteristic to determine the bed occupancy and a deterministic session duration as a characteristic to determine the OT time.

Criteria

To obtain categories, criteria have to be determined to allocate patients into categories. Glerum [10] and Smit [19] both use 2 criteria: the designated ward and the LOS. Their categorisation resulted in 3 categories. Bekker and Koelemans [4] only used the LOS as a criteria and ended up with 2 categories. The other studies that used a categorisation used more criteria and ended up with more than 7 categories [1][2][8][16].

Glerum [10] showed that there is a correlation between the LOS and the operation duration. Therefore, a categorisation with the LOS as criterium automatically creates a distinction in operation duration. Glerum argued that the variation of the operation duration within his categories is greater than the variation in LOS. More categories would decrease this variation. Since more categories also increases the complexity of the model and the intervention, we will only use the LOS as criterium. Concluding, we will first differentiate on which ward the patient will stay and secondly on their expected LOS.

3.2.6 The use of the output of the model

This section is used to discuss how the outputs of a model can be used. Different models enable different interventions. First, a study conducted by Dealleart and Jeunet [8] is discussed. Secondly, the way Smit [19] planned to put the outputs of his model into practice is discussed.

Implementation strategies

Dealleart and Jeunet [8] have tested combinations of three different planning policies to work with the outcomes of the model created by Adan et al. [1]. The outcomes included a pattern of eight categories for a time period of one week. On each weekday a fixed number of a certain category can be planned. Each policy is discussed separately.

- Rescheduling the tactical plan

They found that the benefits of regularly rescheduling the model due to different arrival rates of the categories were not significant. They used a Poisson distribution of arrival rates that stayed the same of the whole running time. According to the management, the inflow of patients of the orthopaedics department is constant over the years. Therefore, rescheduling the model should not be done often. This study only proves that the benefits of rescheduling due to the change in composition of the waiting list are not significant. Rescheduling the model due to changes in the working environment is not included.

- The degree of flexibility

Dealleart and Jeunet [8] tested three degrees of flexibility: no, partial and full flexibility. They stated that the best strategy is to use a policy with limited flexibility. With the partial flexibility policy, the categories with at least one surgery intended on a day could exceed their maximum. The full flexibility policy did not include any logic and performed the worse based on the bed occupancy levels. The partial flexibility policy generated shortened access times compared to the no flexibility policy. The no flexibility policy produced the best bed occupancy levels.

At the moment, MST runs a campaign called "Patient Central" that aims to improve service quality. Therefore, a partial flexibility policy fits the MST the best.

- Overplanning the number of patients on a day

This policy increased the target load, calculated by the model, of each category per day. The overplanning policy decreased the access times and has little impact on the deviations from the desired utilisation.

Rules of thumb

Smit [19] used less categories and takes into account less resources than Adan et al. [1]. Therefore, his model can be classified as less complex than the model provided by Adan et al. [1]. He set up rules of thumb that he derived from the outputs of his model instead of strict numbers per category per day. This type of intervention includes partial flexibility. Less categories makes it easier to set up rules of thumb.

3.3 Conclusion

The following research question is answered in this section.

3. *"What model could best improve the utilisation of the wards by adjusting the way elective admissions are planned at the orthopaedics department, according to the literature?"*

We will focus on smoothening admissions over the week. The QAP model provided by Glerum [10] has the best fit. The model and the intervention should have a low complexity. Therefore, we choose to only take into account the bed occupancy of the wards and the OT time available. A stochastic LOS will be used as characteristic for the bed occupancy. For the operating time available we will use a deterministic session duration. All studies on this topic used a categorisation of admissions to use the QAP model. The categorisation will be based on the designated ward and the LOS of the patients. Also, the

outputs of the QAP model with few categories suit the intervention proposed by Smit [19].

Smit [19] set up general rules of thumb. This type of intervention keeps access times low and has a high chance to be realised. As Smit [19] already researched the opportunities of the QAP model for the MST, we will continue his research. Smit stated that a classification of each patient has to be made and a pilot for one department has to be done first. He recommended to conduct a pilot at the orthopaedics department. This research will therefore focus on creating a classification and the preparation for a pilot at the orthopaedics department.

4 Categorisation of admissions

In this chapter, we create the categorisation of admissions. We consider all patients of all departments that underwent surgery in 2017 and the first eleven months of 2018. The pilot for the orthopaedics department is a part of a greater project suggested by Smit [19]. The case study for the orthopaedics department is the first step in his implementation strategy. Therefore, the categorisation has to fit all departments.

Section 4.1 states the framework for the categorisation. Section 4.2 discusses the classification of admissions and Section 4.3 discusses how the categorisation works out for the orthopaedics department.

4.1 The framework

As stated in the literature, we use the framework made by Glerum [10] and used at MST by Smit [19]. The first differentiation they made is between the patients that stay at the day treatment department and the patients that stay at the clinical wards. The second differentiation is based on the LOS of the clinical patients. They ended up with three categories.

- Day treatment patients (M10)
- Short stay (SS) patients (LOS of less than 1,5 days)
- Long stay (LS) patients (LOS of more than 1,5 days)

4.2 Classification of admissions

Glerum [10] and Smit [19] used their framework to allocate patients from the past into categories. Smit mentioned that further research has to be done on a classification that the admission planners could use by planning admissions. This includes new patients whose LOS and the ward they will stay are not yet certain. Therefore, the ward and the LOS have to be predicted.

M10 or clinical

Patients can board from a clinical ward to another clinical ward more easily than from a clinical ward to a day treatment department. Glerum [10] and Smit [19] worked with a situation where all clinical patients from a department went to the same department. In general that is also the case in MST at the moment. At the orthopaedics department they prefer to host some clinical patients on a different department than the other clinical patients. Since this is not a hard rule, we will only make a distinction between day treatment department and the clinical departments. Other preferences or exceptions have to be captured with secondary rules of thumb. The same applies for the patients who go to the children's department.

The doctors already assess whether a patient goes to the day treatment department or to the clinical wards. We will use this prediction as it is the only prediction available.

LOS

There are three ways to predict the LOS. First, the doctors could assess whether a patient belongs to the SS or LS category. The correctness of their assessment is not known yet. Also, it increases the administrative work for the doctors.

Secondly, the LOS can be predicted by means of a machine learning algorithm at the moment the patient is set on the waiting list [7][18]. For every new patient, the

algorithm should then allocate the patient to a category. Since it is not likely that MST will invest in new software tools, this option has a low chance to be realised.

Finally, the last option is to allocate certain characteristics of the patients into categories. For example, when the patient has characteristic X, the patient belongs to category Y. Ramkumar et al. [18] proved that age, race, gender and comorbidity scores (“risk of morbidity” and “risk of illness”) were sufficient features in their machine learning model to predict the LOS of a total hip arthroplasty. There are many more characteristics that influence the LOS of a patient. The diagnosis a patients has is the major factor correlating with the LOS [3]. Patients are already labelled with a surgery type that correlates with the diagnosis. No new labels have to be created for the categorisation of this characteristic. To keep the complexity low, we choose one characteristic as a predictor for the LOS.

Taking the above into consideration, the surgery type is the best characteristic to predict the LOS of the patients. This because the correctness and the willingness of the doctors is not known and an algorithm is not likely to be implemented. Figure 18 shows a flowchart of the categorisation for the admission planners.

All the surgeries in 2017 and the first 11 months of 2018 are retrieved from ORsuite. This dataset is linked with a dataset with nursery days that is retrieved from Xcare. Since the nursery days are measured in full days. The LOS can only be measured in full days.

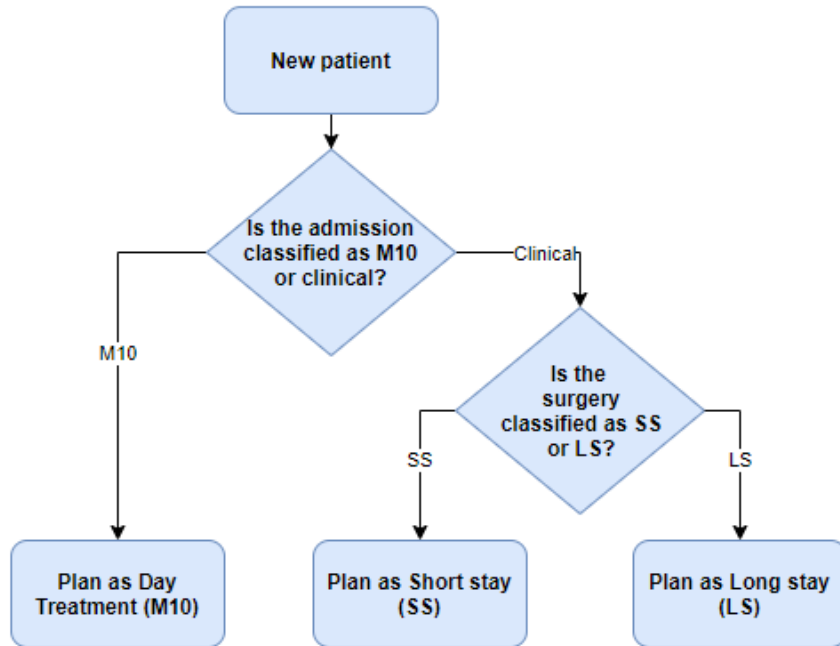


Figure 18: Flowchart of the categorisation for the admission planners.

4.2.1 Pairing admissions with surgeries

The LOS of patients that underwent a surgery is needed to decide whether that surgery belongs to the SS or LS category. For each surgery, we assessed whether the LOS of the patient was representative for the concerned surgery. If the LOS was representative, the LOS was paired with the surgery. Appendix D shows a flowchart of this process. Of all the surgeries, 86% of the LOSs after the surgery

were representative for a surgery. Whether the LOS was representative for the surgeries is based on the following criteria:

- *Elective patients* - The focus lies on elective patients. Therefore, the LOS of a surgery should represent the LOS of the elective patients who underwent this surgery. The severity of the surgery is a strong predictor of the LOS [3]. Since, emergency patients tend to have more severe problems, emergency patients are neglected.
- *More than one surgery during their stay* - Admissions of patients who underwent more than one surgery during a consecutive stay are also neglected. This because the frequency of surgeries influences the LOS [3]. A surgery does not necessarily have a causal relationship with other surgeries during that stay. It could affect the measurement of the LOS of both surgeries. Therefore, we will only use admissions during which the patient underwent one surgery.
- *Days on the IC* - One of the nursery types is the IC. When a patient had to go to the IC after their surgery or within their stay, a bed is reserved at the clinical wards. Therefore, a day on the IC is treated the same as a day on a clinical ward.
- *Surgery day* - We only include surgeries that have taken place on the first or second day of an admission. Normally, patients arrive at the hospital on the day of their surgery. Occasionally, patients are admitted on a day before their surgery. When patients are admitted two days before their surgery, they often have other problems since their arrival is not likely to be planned. This can influence the LOS.

4.2.2 Allocation of surgeries into categories

After obtaining the stochastic LOS per surgery, the surgeries can be allocated into categories. This can be done based on the average LOS or the median LOS. We have set up a fitness function to check which provides better results. Appendix D includes a flowchart that displays the whole process of allocating surgeries into categories.

The fitness function calculates the number of false classifications if a certain dividing line is used. A classification is false when an patient underwent a surgery and stayed 2 or more nights while the surgery was classified as SS. For a LS surgery, a classification is false when an patient had a LOS of less than 2 nights. In total, 86% of the surgeries met the criteria stated in section 4.2.1. The assumption that an equal proportion of occurrences of each surgery met the criteria is necessary to use this fitness function.

The fitness function does not take into account how wrong the classification is. This because an extremely long LOS is not necessarily caused by the surgery itself. At the moment, MST struggles with patients that do not have a place at a nursery home and therefore have to stay in a hospital bed. This could have an impact on the categorisation.

Some surgeries are represented by only a few occurrences. Surgeries that do not occur that often have a small impact on the utilisation of the wards. The risk that a surgery is allocated to the wrong category and consequently planned at the wrong time in the week is therefore acceptable. These surgeries will be allocated to categories despite the little data available.

Appendix F shows that the median as dividing line generates the least false classifications. Still 12 percent of the admissions are predicted falsely. Whether the doctors, besides their willingness to fill in the paperwork, can do better is not known. Therefore, for this research, the surgeries that have a median LOS that is less than 2 are classified as SS and the others are classified as LS.

Risidual surgeries

The surgeries that were not paired with an LOS and occurred as elective and clinical count for 14% of the total surgeries carried out in 2017 and the first eleven months of 2018. These surgeries had no occurrences that met the criteria stated by Section 4.2.1. The flowchart in Appendix D shows that these surgeries are allocated into categories based on their session duration, number of occurrences as M10 and the LOS of the emergency occurrences.

Not all surgeries are carried out as elective and clinical. In the future, these surgeries may be carried out as elective and clinical. Therefore, we categorised these surgeries too.

4.3 The categorisation for the Orthopaedic department

In this section, the categorisation of admissions will be discussed for the orthopaedics department. Section 4.3.1 discusses how the framework works for the orthopaedics department. Section 4.3.2 determines the characteristics per category for the orthopaedics department. Section 4.3.3 analyses the current situation using the categorisation.

4.3.1 Review of the categorisation for the orthopaedics department

The framework consists of two criteria: type of ward and LOS. Both are reviewed below.

Wards

As stated in section 4.2, the categorisation only differentiates between the clinical wards and the day treatment department. At the orthopaedics department, the patients stay at four different wards: C3, C4, B4 and the children's department. As stated in section 2.1.4, the problems that patient could not stay on the B4 is not only due to the planning of admissions at the orthopaedics department. For the patients that need to go to the B4, secondary rules of thumb have to be determined.

LOS

Only 8 percent is falsely classified when the categorisation is tested for the orthopaedics department along the fitness function explained in section 4.2.2.

4.3.2 Characteristics per category

In chapter 3.2.5, we decided to use three characteristics per category. The ward the patients will stay at is determined by whether the patient is administrated as M10 or clinical. The stochastic LOS and the deterministic session duration are stated below.

Stochastic LOS

The number of surgeries paired with an admission, explained in section 4.2.1, is less than the number of elective and clinical occurrences. The stochastic LOS of a surgery is determined by means of the surgeries paired with an admission. The share of a surgery in their category is calculated by the total number of elective and clinical occurrences of that surgery in comparison with the total number of elective and clinical occurrences of that category. After calculating the shares, the LOS of a

category is calculated by summing the multiplications of the share of each surgery within a category with its stochastic LOS. Appendix G shows the stochastic LOS for each category.

Session duration

Smit [19] and Glerum [10] used an lognormal distribution to come up with the session duration of each category. Table 5 displays the expected value of the session duration per category.

Category	\mathbb{E}
Day treatment (DT)	56 minutes
Short stay (SS)	89 minutes
Long stay (LS)	114 minutes

Table 5: Expected value of the session duration per category

4.3.3 Analysis of current situation along the categorisation

This section is used to discuss the relationship between the throughput of categories and the bed occupancy. The overall throughput will be analysed and the throughput per orthopaedic surgeon will be discussed.

Clinical wards

The bed occupancy in 2018 can be explained by the pattern of categories across the week. Figure 19 shows the average throughput per category per operation theatre for each day of the week for the first 11 months of 2018. On Tuesdays and Fridays almost no surgeries classified as SS are carried out. Figure 20 displays the results of a simulation of this throughput in a situation with two OTs available on each weekday. The bed occupancy builds up as the week progresses.

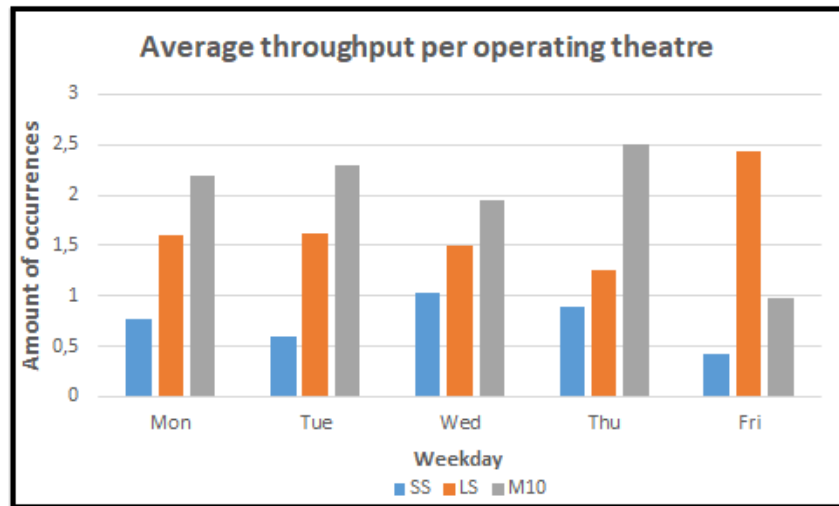


Figure 19: Average throughput per OT on a day of the week. *Data retrieved from ORsuite, $n = 2894$, 01-01-2017/03-12-2018.*

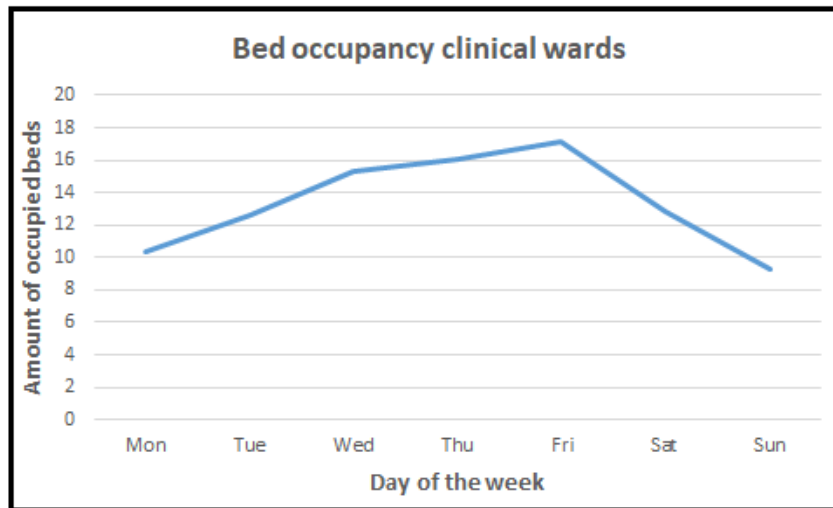


Figure 20: Simulation of throughput figure 19 for a week with two operation theatres per day available.

Day treatment

After the categorisation, nothing has changed for the M10 patients. Section 2.2.1 includes an analysis of the throughput of patients classified as M10.

Orthopaedic surgeons

The differences in the specialties of the doctors play a role in the throughput of categories. In 2018, there were working nine orthopaedic surgeons at the orthopaedics department. Figure 21 displays the distribution of the categories per orthopaedic surgeon. The orthopaedic surgeons are put in order of their percentage of surgeries classified as LS. The distributions differ significantly.

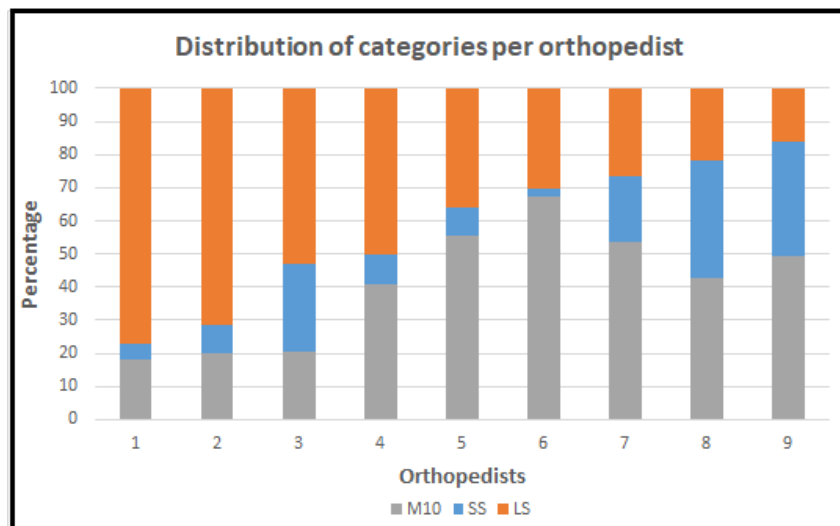


Figure 21: Distribution of categories per orthopaedic surgeon. Only elective surgeries are included. *Data retrieved from ORsuite, $n = 2894$, 01-01-2017/03-12-2018.*

4.4 Conclusion

This chapter is used to create a categorisation for the admissions. The research questions are answered below.

4. *How could the admissions best be classified into categories?*

We allocated admissions into categories based on the framework created by Glerum [10] and used for the MST by Smit [19]. The first differentiation is the whether the patients goes to the day treatment department or the clinical wards. The day treatment patients form the first category: M10. A second differentiation is made for the clinical patients. Clinical patients will be allocated to categories based on the surgery they will undergo. Surgeries with a median LOS of 1 night or less are classified as SS and the others are classified as LS.

(a) *How does the categorisation work out for the orthopaedics department?*

Only 8 percent of the patients from the orthopaedics were falsely classified. The average throughput of categories of the OTs suggested a build-up of the bed occupancy over the week with a peak on Friday. The distribution of categories per orthopaedic surgeon plays a role in the throughput of categories over the week.

5 Model

Chapter 3 reviewed models that could smoothen the bed occupancy by creating a pattern of admissions. We decided to use the QAP model provided by Glerum [10]. Since we will not change any important features of the model, we refer to Glerum [10] for a full explanation.

Section 5.1 explains the model. Section 5.2 states the input data and the scenario's. Section 5.3 states the results of the model. Section 5.4 derives the rules of thumb out of the results of the model and discusses how these can be implemented.

5.1 Model description

Since we do not change any important features of the model provided by Glerum [10], we refer to Glerum [10] Chapter 5 and 6 for a full explanation. The goals of the QAP model are:

1. Levelling the bed occupancy at the wards by improving the OK planning.
2. Creating strategies to cope with natural variation in bed demand.

5.2 Experimental approach

Section 5.2.1 states the inputs of the model. Section 5.2.2 discusses the scenarios examined by the model.

5.2.1 Model inputs

Glerum [10] uses patient characteristics, capacity constraints and the demand per category as input for the model. Section 4.3.2 states the patient characteristics. The other inputs of the model that need to be discussed are:

- *Amount of time the OTs are available per day.* - One OT that is available for one day has 480 minutes. We work with whole days of available OTs.
- *Number of beds available at each ward.* - Section 2.1.4 states that MST does not have a maximum number of beds for the orthopaedics and has a smooth utilisation as its target. Therefore, we do not use this input parameter.
- *Demand per category.* - We determined the number of each category per time period by calculating the average output per operation theatre per category of the first eleven months of 2018. The number per category per time period is then calculated by multiplying this average by the number of OTs in that time period. Since we do not include emergency patients, the number of surgeries is increased to a 85% utilisation of the OT. Table 6 shows the number per category for 1, 10 and 20 OTs.

Category	OTs		
	1	10	20
M10	1,99	20	40
SS	0,74	8	15
LS	1,69	17	34

Table 6: Number of surgeries per category per number of OTs. The numbers for 10 and 20 OTs are rounded to whole surgeries. *Data retrieved from Blokplan and ORsuite, $n = 1841$, 01-01-2018/3-12-2018.*

5.2.2 Scenarios

We model varied operating schedules to understand the relationship between the throughput of categories and the bed occupancy. Like Glerum [10], we model a cycle of two weeks. The operating schedule varies for the first week of the cycle. The second week of each cycle has two OTs on each weekday. This, because in 25 of the 52 weeks in 2019, two OTs are scheduled at each weekday. Table 7 shows all the operating schedules.

Scenarios	1	2	3	4	5	6
Mon	2	2	2	1	2	2
Tue	2	3	2	1	2	2
Wed	2	2	2	2	1	2
Thu	2	2	1	2	2	0
Fri	2	2	1	2	2	0
Sat	0	0	0	0	0	0
Sun	0	0	0	0	0	0
Mon	2	2	2	2	2	2
Tue	2	2	2	2	2	2
Wed	2	2	2	2	2	2
Thu	2	2	2	2	2	2
Fri	2	2	2	2	2	2
Sat	0	0	0	0	0	0
Sun	0	0	0	0	0	0

Table 7: Scenarios for the model. Number of OTs per day.

We will test these operating schedules with the demand per category stated in Section 5.2.1. Besides these six scenarios, the seventh scenario has the same operating schedule as the first scenario. The seventh scenario has a higher demand per category. We include this scenario because if the OTs are fully planned the model has to make harder decisions.

5.3 Experimental results

IBM optimization studio found a solution within 3.5 seconds with a 2,3 % optimality gap for the first scenario. Figure 21 displays the throughput per day of the week for the first scenario, see table 7. Figure 22 shows the bed occupancy per day as fraction of the bed occupancy of Friday in the same week. A build-up of the bed occupancy with a peak on Friday is the result for both weeks in the cycle. Compared with Figure 14 of Section 2.2, this build-up is less steep then the realized average daily peak in bed occupancy. Where the daily peak in bed occupancy on Monday was on average 72% of the peak on Friday in de same week, shown by Figure 14, the output of the model generated an average of 79%.

The M10 patients are evenly spread over the week. The SS patients are mostly planned at the beginning of the week and the LS patients are mostly planned at the end of the week with an exception on the second Monday. The throughput on Tuesdays and Wednesdays is less than on Mondays, Thursdays and Fridays. This can be substantiated by the number of surgeries that we adjusted to an average utilisation of the OTs of 85%.

The standard deviation of the utilisation of the OT is 0.21. The total throughput

of patients per day is highly constant.

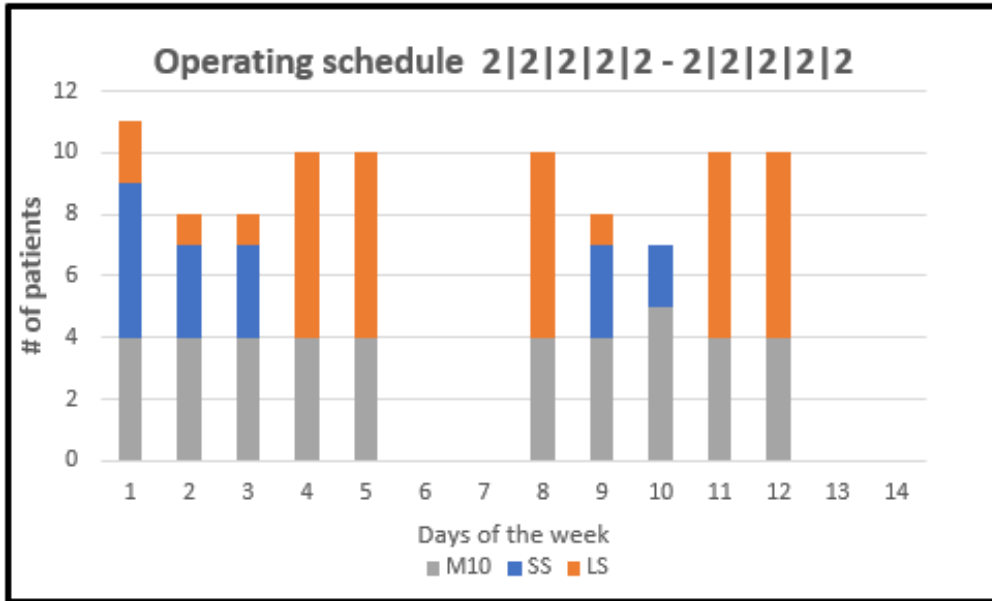


Figure 22: Throughput of categories per day of the week with 2—2—2—2—2 and 2—2—2—2—2 as operating schedules. *Results obtained with IBM optimization studio.*

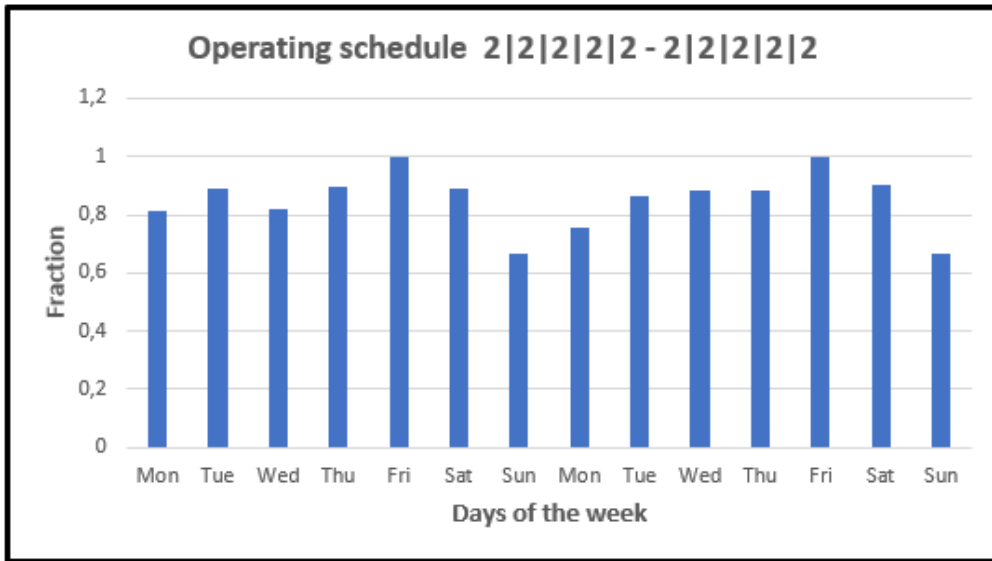


Figure 23: Bed occupancy as fraction of the bed occupancy on Friday in the same week with 2—2—2—2—2 and 2—2—2—2—2 as operating schedules. *Results obtained with IBM optimization studio.*

Figure 23 shows the throughput when the numbers are scaled up to an average utilization of 94%. Figure 24 shows the bed occupancy as a fraction of the bed occupancy at the Friday in the same week.

The build-up of the bed occupancy across the week is steeper than the build-up when the demand is set to an average utilisation of 85%. The M10 patients are less evenly spread over the week. Again, the SS are mainly planned at the beginning of the week and the LS mainly at the end of the week.

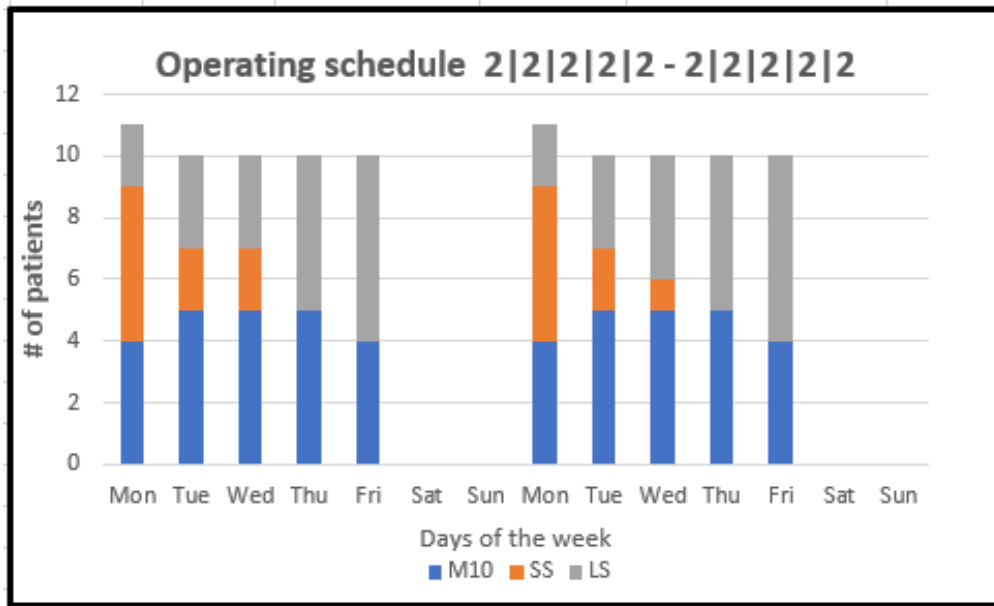


Figure 24: Bed occupancy as fraction of the bed occupancy on Friday in the same week with 2—2—2—2—2 and 2—2—2—2—2 as operating schedules. *Results obtained with IBM optimization studio.*

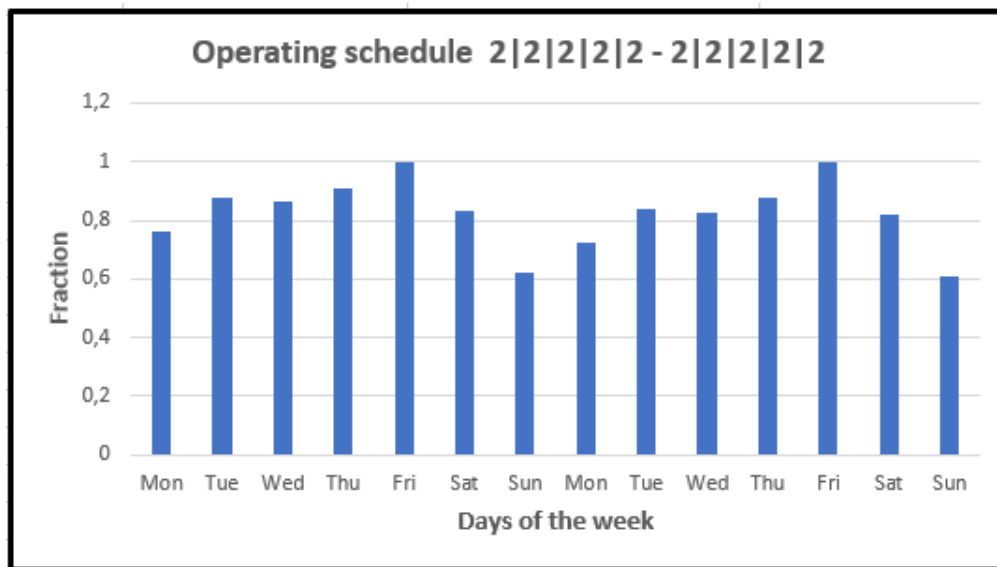


Figure 25: Bed occupancy as fraction of the bed occupancy on Friday in the same week with 2—2—2—2—2 and 2—2—2—2—2 as operating schedules. *Results obtained with IBM optimization studio.*

The standard deviation of the utilisation of the OT is 0.05. The total throughput

varies between 7 and 11 patients on a day.

Appendix I shows the throughput and bed occupancies for each scenario. In each scenario, the M10 patients are evenly spread over the week. The SS patients are planned at the beginning of the week. The LS patients are mostly planned at the end of the week with a few exceptions at the beginning of the week. With each scenario, the bed occupancy builds up as the week progresses with a peak on the day before the weekend. This to keep the bed occupancy at an acceptable level throughout the weekend.

5.4 Rules of thumb

This section discusses the implementation of the rules of thumb. Section 5.4.1 states the rules of thumb for each category. Section 5.4.2 discusses the exceptions on the rules of thumb. Section 5.4.3 discussed how the admission planners can apply the rules of thumb. Section 5.4.4 discussed how the schedule of the orthopaedics can take the rules of thumb into account. Section 5.4.5 discussed what impact the rules of thumb have on access times.

5.4.1 Rules of thumb per category

For each category, Section 5.3 shows what pattern benefits the wards. For each category the rules of thumb are:

- M10 - Plan M10 patients evenly over the week. Fill Wednesday and Tuesdays and less on Mondays first.
- SS - Plan SS patients at Mondays, Thursdays and Fridays.
- LS - Plan LS patients on Thursdays and Fridays. Plan exceptions on Mondays, Thursdays and Wednesdays.

5.4.2 Exceptions of the rules of thumb

Two groups of patients need an exception on the rules of thumb. The children go to the children's department. At the children's department they prefer a smooth and predictable inflow of children. Figure 24 shows a slightly higher throughput of M10 patients on Tuesday and Wednesday to reduce the build-up across the week at the clinical wards. The children can best be planned at Tuesdays and Wednesdays as these patients go to a different ward. Still, these patients have to be spread over the week. So the secondary rule of thumb for children is:

- Children - Plan children evenly across the week. Fill Tuesdays and Wednesdays first.

Also, the flow of patients that preferably stay on the B4 need a secondary rule of thumb. At the moment these patients are planned on Mondays, Wednesdays and Fridays. Since on Fridays only LS patients should be planned, these patients can still be planned on Fridays. The rules of thumb in section 5.4.1 state that exceptions can be planned on Mondays, Tuesdays and Wednesdays. So, this rule of thumb, that was already present, can co-exist besides the new rules of thumb.

- Prothesis - Plan patients that need a prothesis on Mondays, Wednesdays and Fridays. Fill Friday first.

The rules of thumb do not apply for the patients that go to Resort Bad Boekelo. For these patients, the admission planners can schedule them the way they used to plan them, see Section 2.1.5. These patients are LS patients. At each day of the

week LS patients can be planned. Therefore, the admission planners do not have to change the way they plan these patients.

5.4.3 Admission planners

Section 2.1.5 describes the steps an admission planner takes before planning a patient. Appendix C displays a flow chart of this process. Appendix E displays news flowchart in which the new rules of thumb are included. These new flowcharts do not include the criteria stated in Section 2.1.5. The admission planners have the experience to take these criteria into account.

Some examples of how the admission planners could apply the new rules of thumb are:

1. An orthopaedic surgeon, that mostly treats LS patients, works on a Monday and a Friday in the same week. The surgery is classified as SS. The admission planner should plan the surgery on Monday.
2. The admission planner finds a free spot in the OT planning on Monday. The orthopaedic surgeon who works that day mostly treats LS patients and normally works on varied days in the week. On top of the waiting lists is a patient that needs a surgery that is classified as LS. The second patient on the waiting list needs a surgery that is classified as SS. The admission planners should, according to the rules of thumb, pick the second patient on the waiting list.
3. The admission planner finds a free spot in the OT planning on Thursday. The orthopaedic surgeon who works that day mostly treats LS patients. The first patient on the waiting list is a LS patient. The second patient is a SS patient. The admission planner should choose to plan the LS patient since SS patients should only be planned at the beginning of the week.
4. The admission planner finds a free spot in the OT planning on Wednesday. The two orthopaedics that work on that day mostly treat LS patients. In the old situation, it is likely that a low number of M10 patients will be planned on this day. To prevent that from happening, the admission planners should try to plan a M10 on this day since the M10 patients have to be spread across the week.

5.4.4 Schedule of the orthopaedic surgeons

Section 4.3 states that the throughput per orthopaedic surgeon varies significantly. Figure 21 shows the distribution of categories for each orthopaedic surgeon. Ways in which the orthopaedic surgeons can take the rules of thumb into account are:

- The orthopaedic surgeon with the highest fraction of LS patients should be scheduled on Thursdays and Fridays.
- The orthopaedic surgeon with the highest fraction of SS patients should be scheduled at the beginning of the week
- Orthopaedic surgeons with a varied distribution should be scheduled in the beginning of the week at one week and at the end of another week. So, the SS patients the orthopaedic surgeon treats can be planned at the beginning of the week and the LS patients at the end of the week.
- Two orthopaedic surgeons with a high fraction of M10 patients can be combined if the admission planners take the rules of thumb into account. For

example, two of those orthopaedic surgeons are planned on Monday and one of those orthopaedic surgeons works at Wednesday. On that Wednesday the orthopaedic surgeons works in combination with an orthopaedic surgeon that treats almost no M10 patients. The admission planners should make the choice to plan the M10 patients of that orthopaedic surgeon on Wednesday and the SS and LS patients on Monday.

5.4.5 Access times

With the new rules of thumb, access times will have a higher standard deviation. The throughput will stay constant. Only the pattern of surgeries over the week/weeks will change. Therefore, the rules of thumb does not affect the average access time. With the new rules of thumb, it can happen that the second patient on the waiting list is planned on the first free spot. Therefore, the access time will be shortened for some patients and longer for others. So, only the standard deviation of the access time will increase.

5.5 Conclusion

The answers to the research questions and sub research questions are discussed below.

5. *What experimental approach suits the research aim?*

The model needs patient characteristics, capacity constraints and the demand per category as inputs. For the patient characteristics, we use the LOS, the session duration and the designated ward. As capacity constraints we use the operating time available per day. We do not use a maximum number of beds on a ward. We strive for a smooth bed occupancy.

We tested seven different scenarios. Six differ in the number of OTs available. The other scenario used the most common operating schedule with a higher demand.

6. *What are the outputs of the model?*

The M10 patients are spread over the week. The SS patients are mostly planned at the beginning of the week and the LS patients are mostly planned at the end of the week. Some LS patients are planned at the beginning of the week.

(a) *How do the KPI's score?*

For all scenarios, the bed occupancy at the ward showed less of a build-up as the week progresses. Peaks were still common on Fridays. The build-up was less steep than the realized bed occupancy showed. For the first and most common scenario, the average peak in bed occupancy at Mondays compared to the Friday in the same week was 3%-point higher than the realized difference in bed occupancy. For Tuesdays, this is 5%-point.

(b) *What rules of thumb can be derived?* Out of the results of the model the following rules of thumb are derived:

- M10 - Plan M10 patients evenly over the week. Fill Tuesdays and Wednesdays first and Mondays last.
- SS - Plan SS patients at Mondays, Thursdays and Wednesdays.

- LS - Plan LS patients on Thursdays and Fridays. Plan exceptions on Mondays, Thursdays and Wednesdays.

The secondary rules of thumb are:

- Children - Plan children evenly across the week. Fill Tuesdays and Wednesdays first.
- Prothesis - Plan patients that need a prothesis on Mondays, Wednesdays and Fridays. Fill Friday first.

For the operating schedule for the orthopaedic surgeon the recommendations are:

- The orthopaedic surgeon with the highest fraction of LS patients should be scheduled on Thursdays and Fridays.
- The orthopaedic surgeon with the highest fraction of SS patients should be scheduled at the beginning of the week
- Orthopaedic surgeons with a varied distribution should be scheduled in the beginning of the week at one week and at the end of another week.
- Two orthopaedic surgeons with a high fraction of M10 patients can be combined if the admission planners take the rules of thumb into account.

6 Main findings

This chapter summarizes and contemplates this research. Section 6.1 answers the research questions and solves the knowledge problem. Section 6.2 lists the recommendation for MST. Section 6.3 critically reflects on the results, research process and the thesis as a whole. Section 6.3 also discusses the limitations and proposes further research.

6.1 Conclusion

The knowledge problem with its supporting research questions, described by Section 1.3, are answered in the preceding chapters. This chapter provides a general conclusion and repeats each research question with a summary of its answer.

General conclusion

The main aim of this research is to create a pattern of surgeries that smoothenes the bed occupancy at the wards. By making a categorisation of surgeries based on their length of stay, it was possible to create such a pattern. The categorisation made it also possible to translate this pattern into clear rules of thumb. Besides that the admission planners can use these rules of thumb in their daily planning processes, orthopaedic surgeons can also use them by making their operating schedule. With this intervention the bed occupancy will still be building up as the week progresses with peaks on Friday. However, using this intervention the bed occupancy at Mondays compared to Fridays could potentially be 3%-point higher than the realized difference in bed occupancy. For Tuesdays, the intervention scores 5%-point higher than the realized difference in bed occupancy. Using this intervention, MST will have less postponements and rejections of treatments and less over- and underallocation of resources at the wards.

Research questions

1. *What is the working environment in which the admission planners of the orthopaedics department operate?*

The admission planners work for the chain capacity department. The admission planners plan elective admissions and a part of the emergency patients. The patients go to four different wards in the hospital after their surgery. The admission planners mainly focus on filling the operating schedule. Only occasionally, the bed occupancy of the wards is taken into account.

2. *What is the current performance of the orthopaedics department?*

The bed occupancy fluctuates too much. A weekly as well as a cross-weekly variability in bed occupancy is causing capacity problems. The bed occupancy has a weekly pattern where peaks on Thursdays or Fridays are common. This is mainly caused by the elective flow of admissions.

3. *What model could best improve the utilisation of the wards by adjusting the way admissions are planned at the orthopaedics department, according to the literature?*

We focus on smoothening admissions over the week. We use the QAP model provided by Glerum [10]. All studies on this topic use a categorisation of ad-

missions. The categorisation is based on the designated ward of a patient and the LOS of the patients. The outputs of the QAP model suit the intervention proposed by Smit [19]. Smit [19] set up general rules of thumb. This type of intervention keeps access times low and has a high chance to be realised. As Smit [19] already researched the opportunities of the QAP model for the MST, we will continue his research. Smit stated that a classification of each patient has to be made and a pilot for one department has to be conducted first. This research focuses on creating a classification of admissions and the preparation for a pilot at the orthopaedics department.

4. *How could the admissions best be classified into categories?*

We allocated admissions into categories based on the framework created by Glerum [10] and used for the MST by Smit [19]. The first differentiation is whether the patients goes to the day treatment department or the clinical wards. The day treatment patients form the first category: M10. A second differentiating is made for the clinical patients. Clinical patients will be allocated to categories based on the surgery they will undergo. Surgeries with a median LOS of 1 night or less are classified as SS and the others are classified as LS.

Only 8 percent of the patients from the orthopaedics were falsely classified. The average throughput of categories of the OTs suggested a build-up of the bed occupancy over the week with a peak on Friday. The distribution of categories per orthopaedic surgeon plays a role in the throughput of categories over the week.

5. *What experimental approach suits the research aim?*

The model needs patient characteristics, capacity constraints and the demand per category as inputs. We strive for a smooth bed occupancy. We tested seven different scenarios. Six differ in the number of OTs available. The other scenario uses the most common operating schedule with a higher demand.

6. *What are the outputs of the model?*

The bed occupancy at the ward showed a less of a build-up as the week progresses. Peaks were still common on Fridays. For the first and most common scenario, the average peak in bed occupancy at Mondays compared to the Friday in the same week was 3% higher than the realized difference in bed occupancy.

Out of the results of the model the following rules of thumb are derived:

- M10 - Plan M10 patients evenly over the week. Fill Tuesdays and Wednesdays first and Mondays last.
- SS - Plan SS patients at Mondays, Thursdays and Wednesdays.
- LS - Plan LS patients on Thursdays and Fridays. Plan exceptions on Mondays, Thursdays and Wednesdays.

The secondary rules of thumb are:

- Children - Plan children evenly across the week. Fill Tuesdays and Wednesdays first.

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For the operating schedule for the orthopaedic surgeons the recommendations are:

- The orthopaedic surgeon with the highest fraction of LS patients should be scheduled on Thursdays and Fridays.
- The orthopaedic surgeon with the highest fraction of SS patients should be scheduled at the beginning of the week
- Orthopaedic surgeon with a varied distribution should be scheduled in the beginning of the week at one week and at the end of another week.
- Two orthopaedic surgeons with a high fraction of M10 patients can be combined if the admission planners take the rules of thumb into account.

6.2 Recommendations

This section provides recommendations for MST that result from the preceding chapters.

- Focus on interventions with a low complexity or on an organization-wide investment in decision support tools to create an admission planning that benefits the wards. Previous years have shown that interventions that fall in between are not endurable. Interventions with a low complexity are executable by employees, do not need rescheduling often, have the possibility to include other departments and are not complicated to pass on to new employees. Setting up general rules of thumb is an example of an intervention with a low complexity.
- Use the rules of thumb stated in section 5.4. A training session with the admission planners that focuses on making tactical decisions based on the rules of thumb is of great importance.
- Create an extra data type in Medify to label the surgeries with a category. This label should be visible by the admission planners when planning patients.
- Investigate the improvement potential at other departments. The orthopaedics stated that beds at the B4 are often occupied by patients who do not fall under the orthopaedics department. Smit [19] already showed all departments can be included in the QAP model. A more in-depth analysis of the practical problems of implementing his intervention is needed.
- Research how the operating schedule of the orthopaedics could apply the rules of thumb the best. We gave some recommendations in the thesis. However an expanded QAP model with the schedule of the orthopaedics could generate more substantiated recommendations.
- Start with a pilot at the orthopaedics department. This because it is not known to what degree the admission planners are able to apply the rules of thumb.

6.3 Discussion, limitations and further research

This section critically reflects on the results, the research process, the limitations and proposes further research.

Data

We could only determine the LOS of a patient in full days. This could have affected

the categorisation of admissions. This also affected the results of the dividing line between SS or LS.

LOS

The QAP model uses stochastic LOSs derived from LOSs measured in full days. As stated in Section 2.2.2, patients arrive during the whole day but mostly at eight o'clock. Discharges mostly occur between eleven AM and four PM. Discharges and admissions could therefore count as half days. Therefore, the real bed occupancy will be somewhat lower than the results of the model show. The traffic of patients is the highest on Thursdays and Fridays. So, we assume that the build-up of the bed occupancy as the week progresses will be less steep than the results of the model show.

Categorisation

In Section 4.2.1, surgeries were paired with LOSs of patients. In total, 86% of the surgeries were paired with a LOS. It is not known if certain surgeries often happen in combination with other surgeries and may not or less represented by the categorisation.

Rules of thumb in practice

A few uncertainties arise when the rules of thumb are put into practice. First of all, the intervention proposed in this thesis assumes that admission planners are able to think tactically. To what degree admission planners are capable of applying the rules of thumb have to be further researched.

Second, a full analysis of what schedule of the orthopaedics would best apply the rules of thumb is not fully done due to the time period available. Section 5.4.4 only gives an educated guess of what schedule would benefit the wards.

Thirdly, we did not include variability of demand in our analysis. At the moment, the admission planners of the orthopaedic surgeons struggle with short waiting lists. When the waiting lists are short, there is less room for applying the rules of thumb. The relationship between the waiting lists and the bed occupancy at the wards should be further researched.

Finally, we did not include the bed occupancy at the IC in our analysis. According to the management, there are almost no patients from the orthopaedics that have to visit the IC during their stay. However, if this intervention is also implemented at other departments, this could cause capacity problems at the IC at the end of the week. Patients with a longer LOS have a greater chance to visit the IC. As our rules of thumb proposes to plan LS mostly at the end of the week. This could cause capacity constraints at the IC.

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Appendix

A Bed occupancy

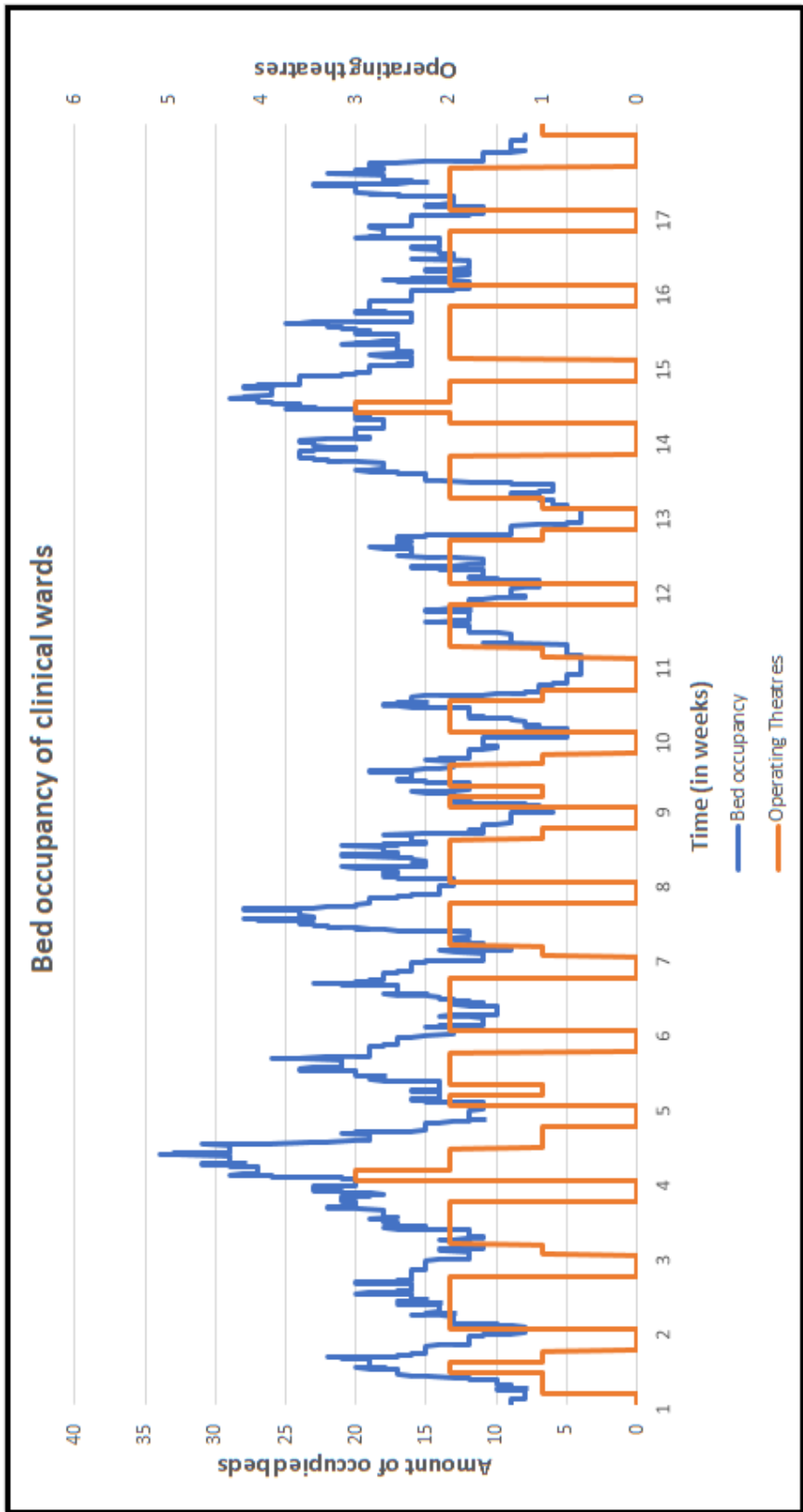


Figure A.1: Bed occupancy of the clinical wards caused by outflow orthopaedics department. Retrieved from Xcare. n=16, 2018

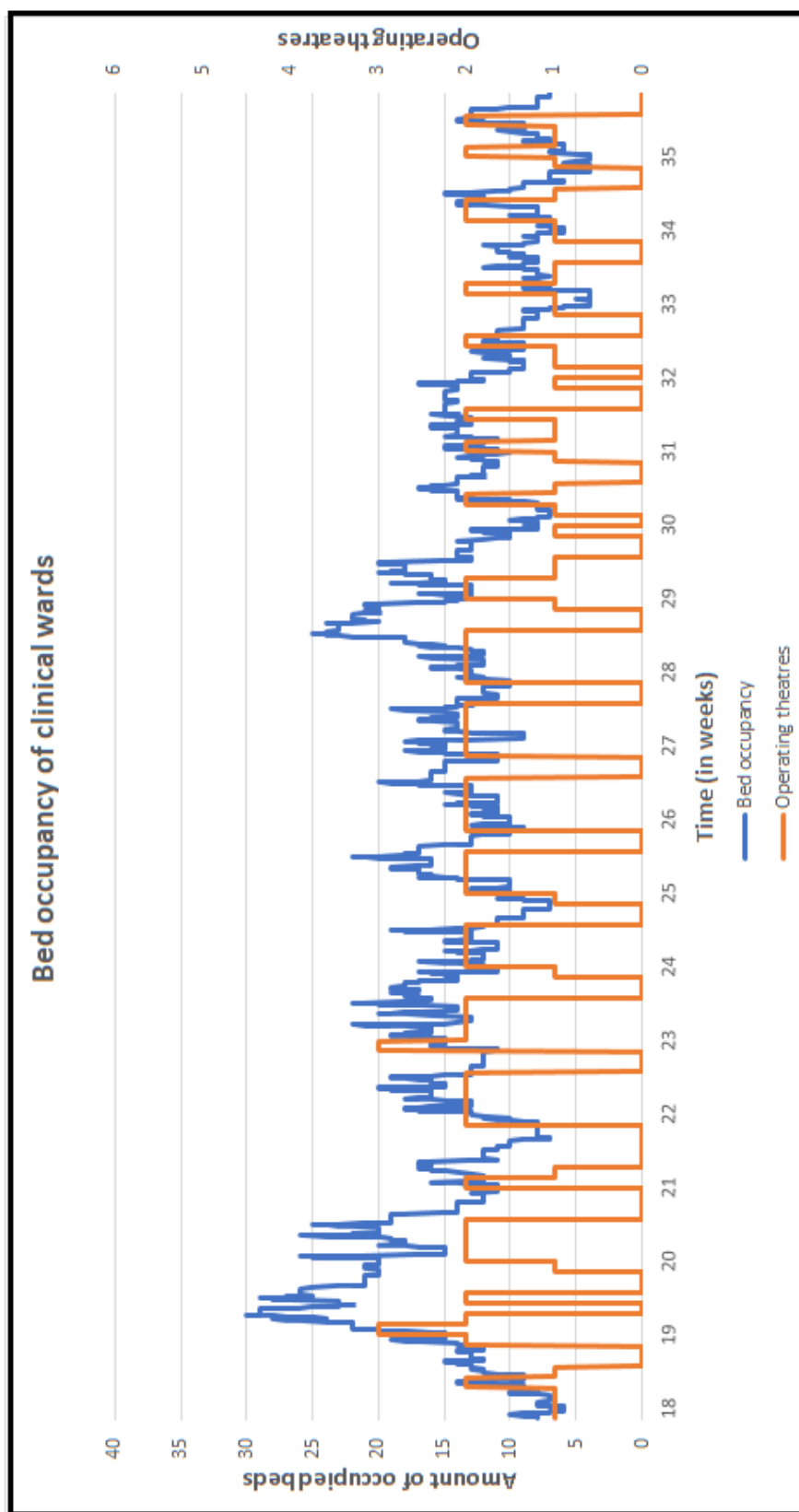


Figure A.2: Bed occupancy of the clinical wards caused by outflow orthopaedics department. Retrieved from Xcare. $n=18$, 2018

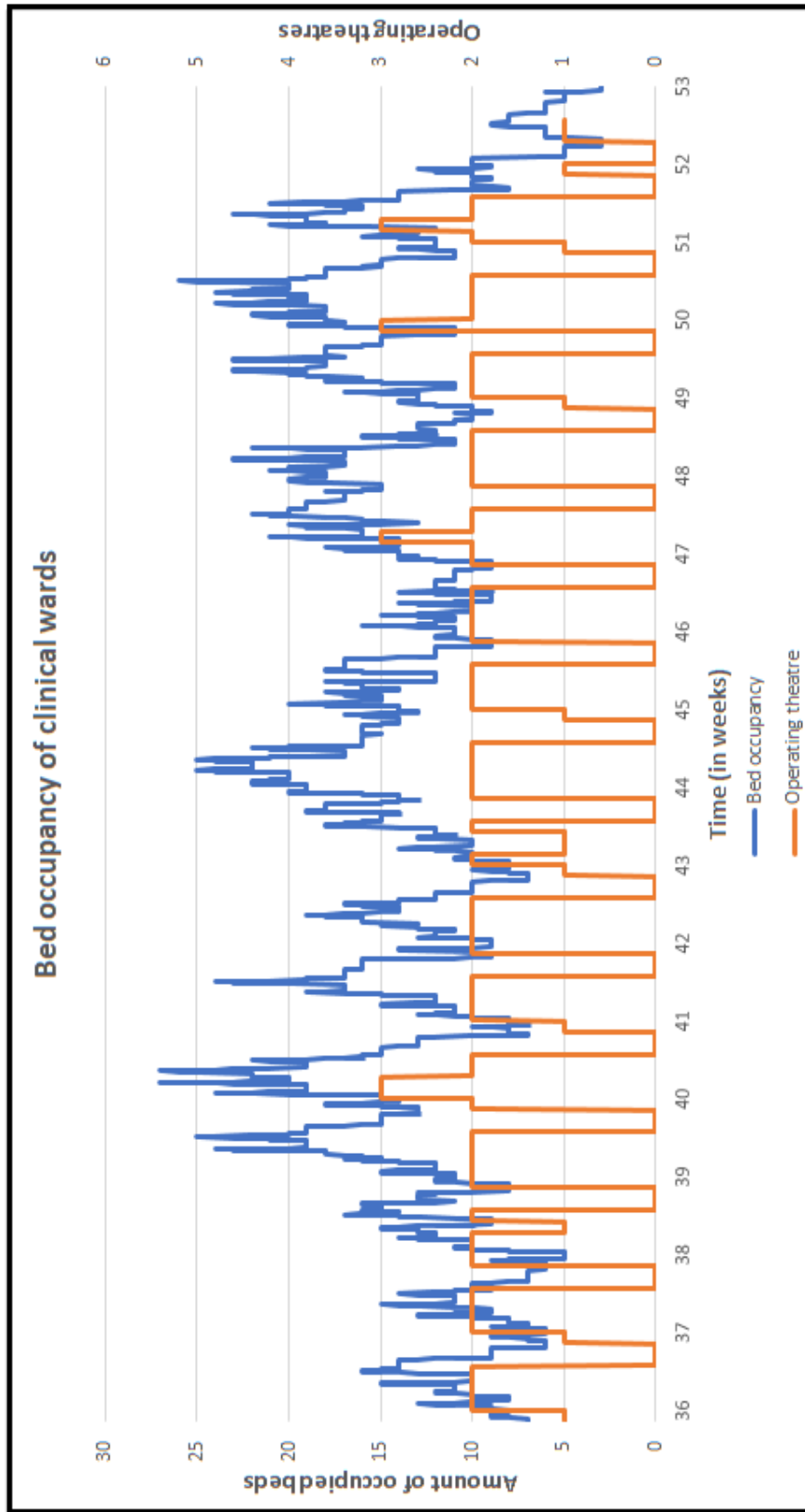


Figure A.3: Bed occupancy of the clinical wards caused by outflow orthopaedics department. Retrieved from Xcare. $n=17$, 2018

B Problem cluster

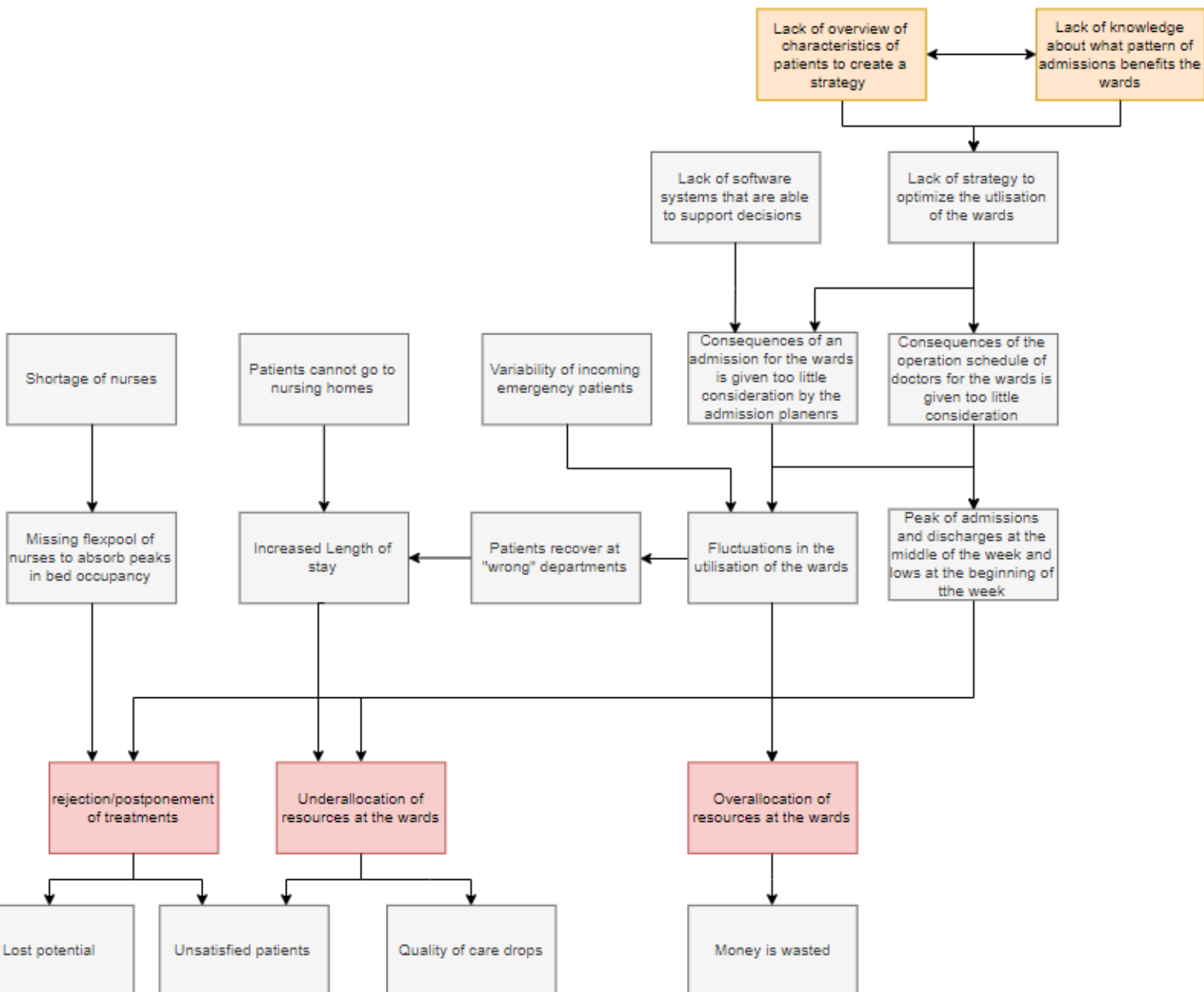


Figure B.1: problem cluster

C Planning processes

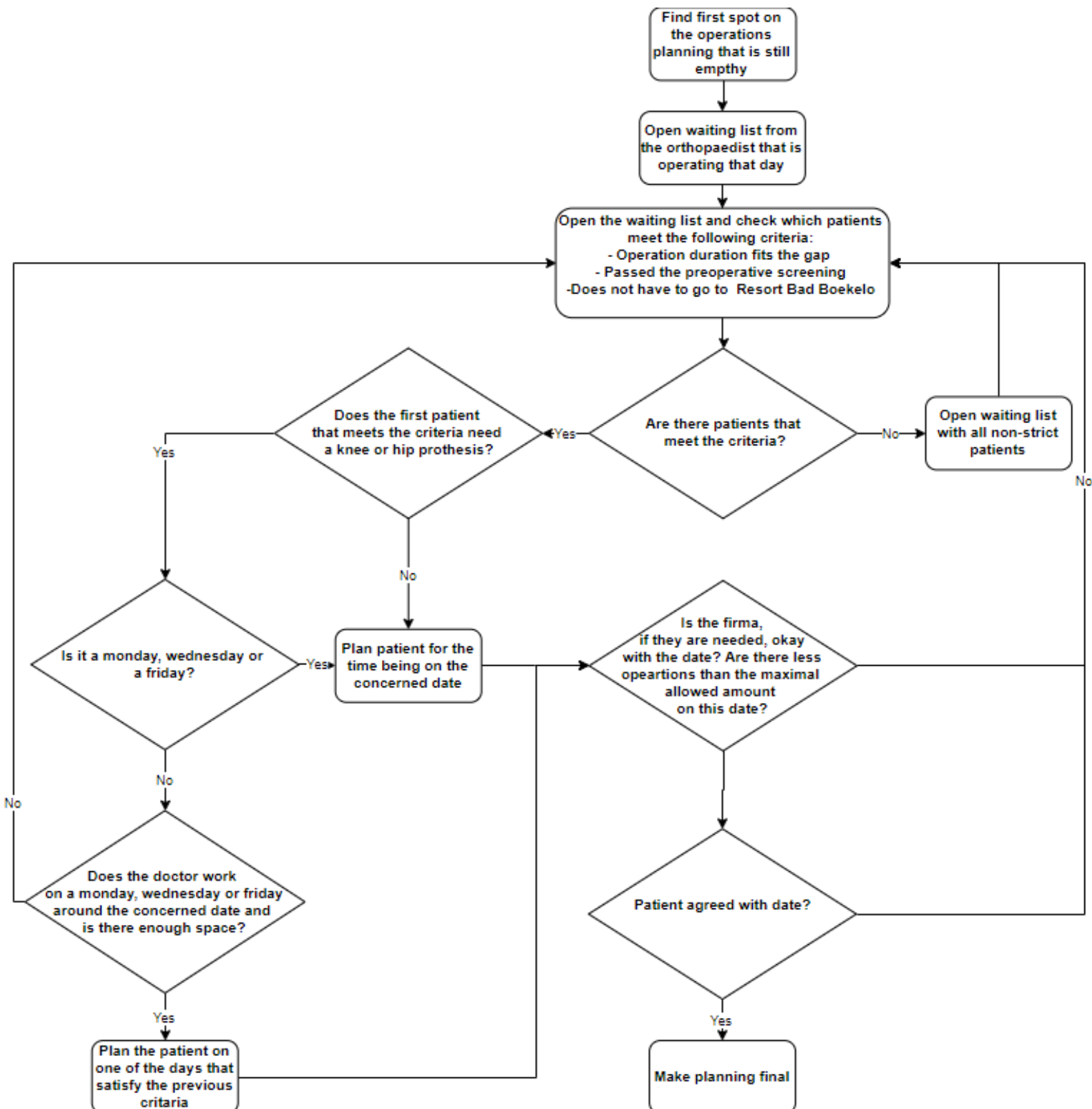


Figure C.1: Planning process of the admission planners at the moment for all patients that do not go to Resort Bad Boekelo.

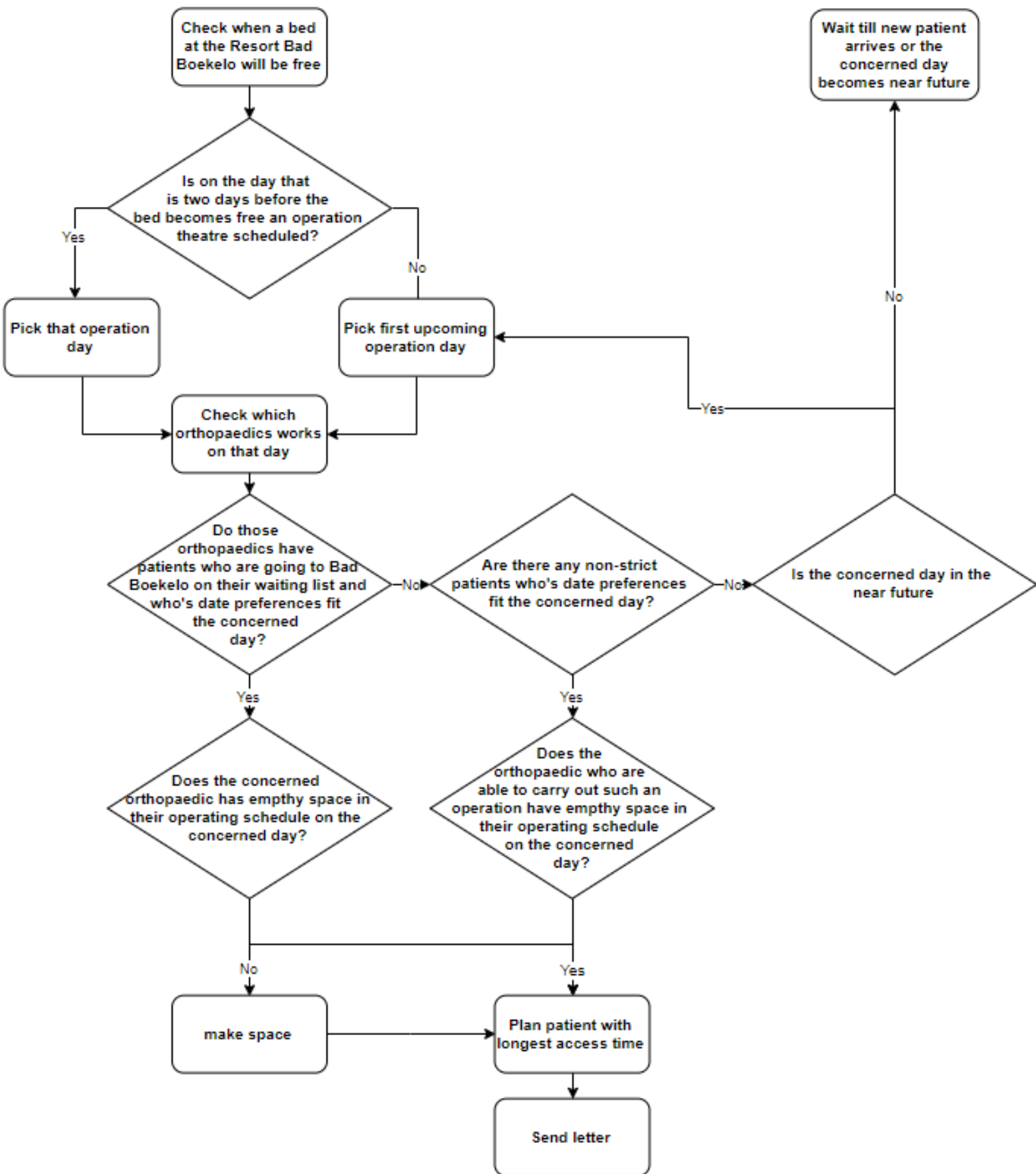


Figure C.2: Planning process of the admission planners at the moment for patients that go to Resort Bad Boekelo after their stay in MST

D Categorisation flowcharts

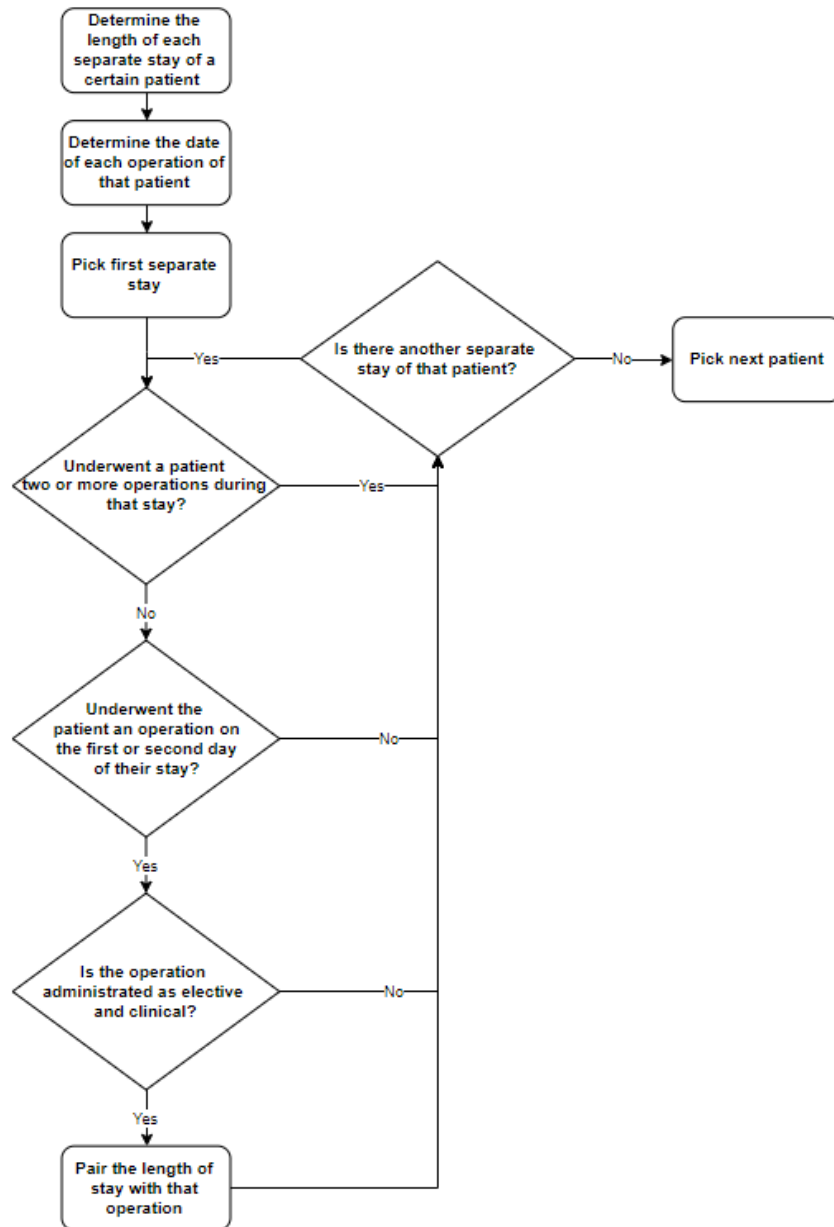


Figure D.1: Flowchart for pairing admissions with surgeries

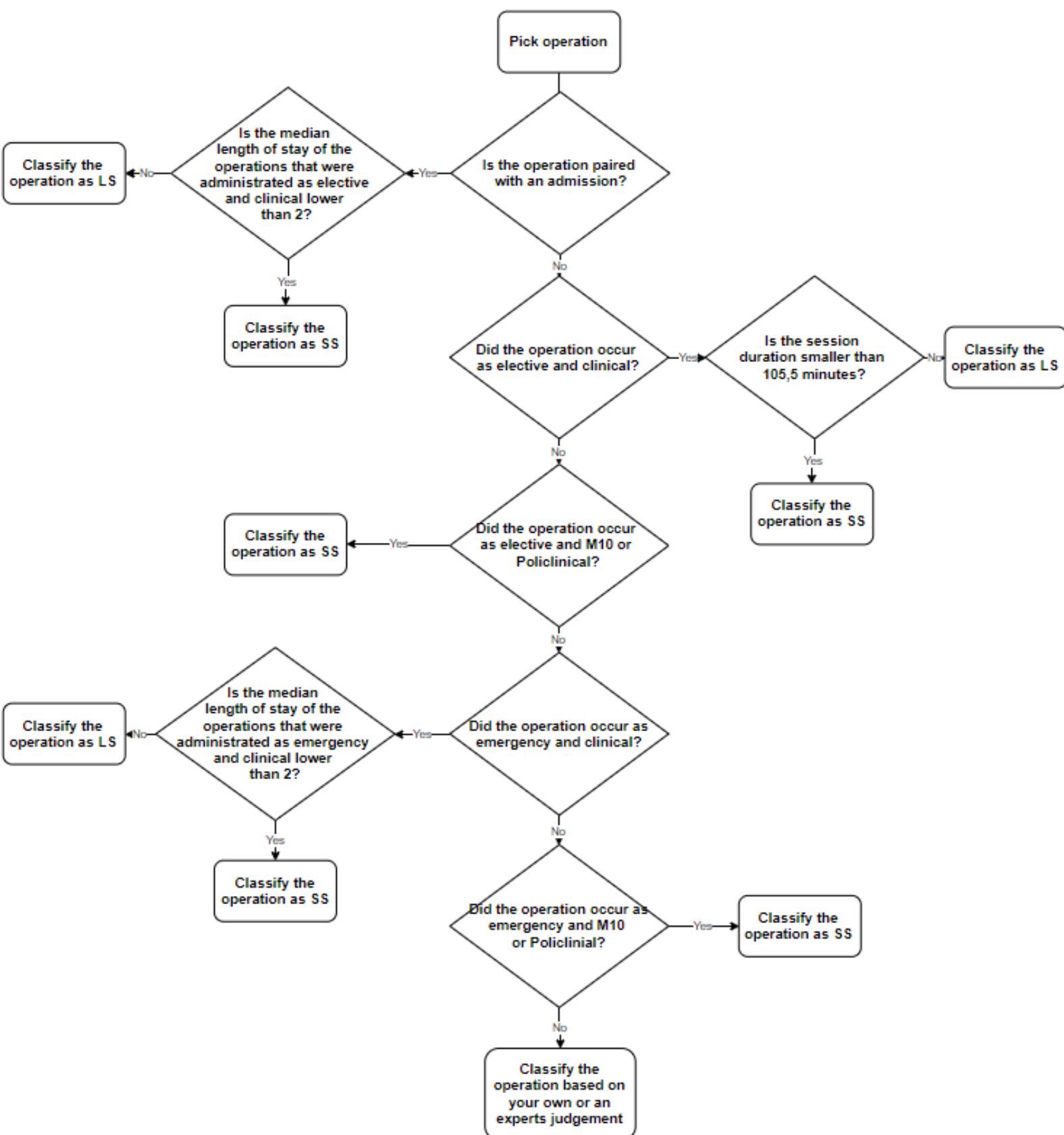


Figure D.2: Flowchart for allocating surgeries

E Flowcharts for applying rules of thumb

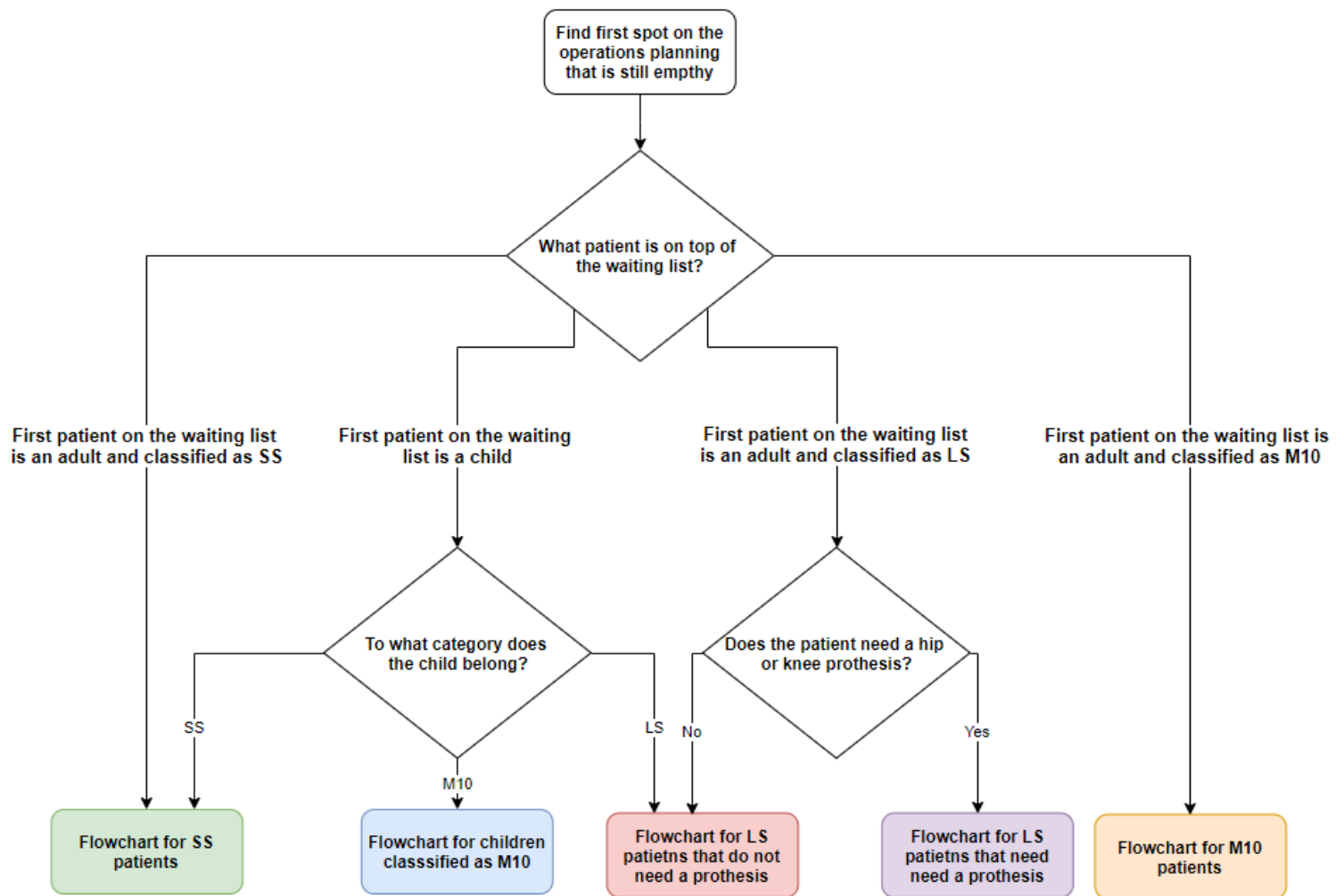


Figure E.1: An admission planner searches the first free spot. This flowchart shows what flowchart an admission planner should follow when a certain patient is on top of the waiting list.

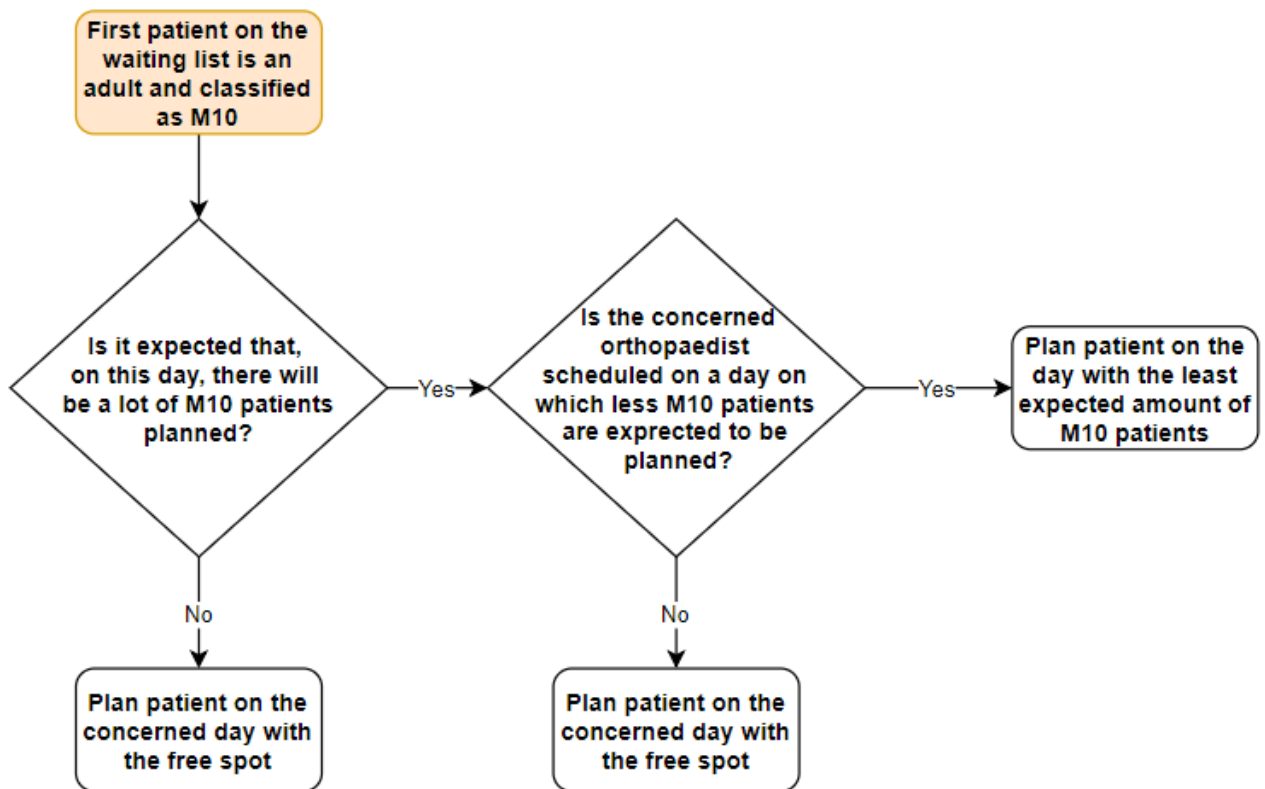


Figure E.2: Flowchart for a situation in which an adult patient classified as M10 is on top of the waiting list of an orthopaedic surgeon

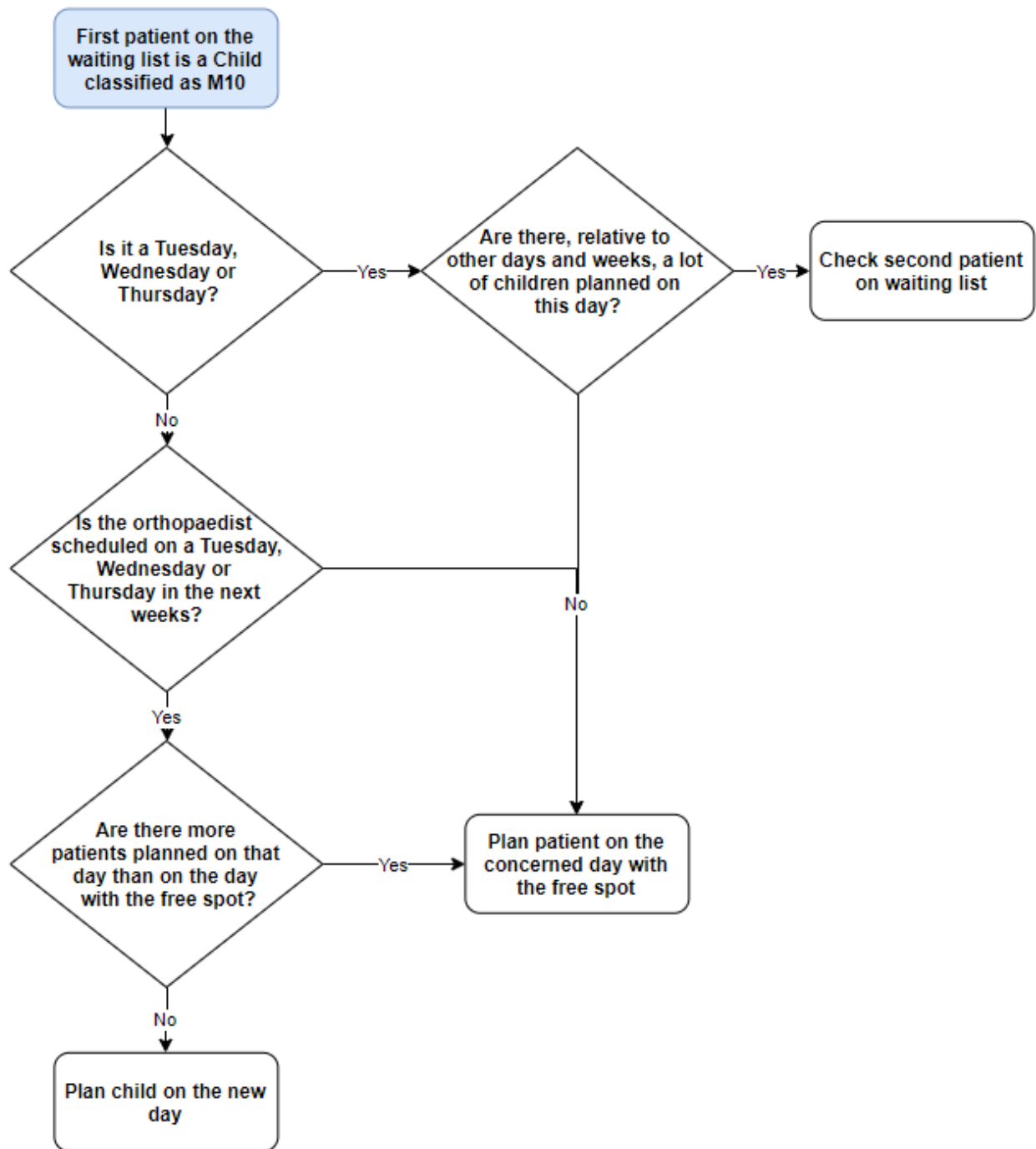


Figure E.3: Flowchart for a situation in which a child classified as M10 is on top of the waiting list of an orthopaedic surgeon.

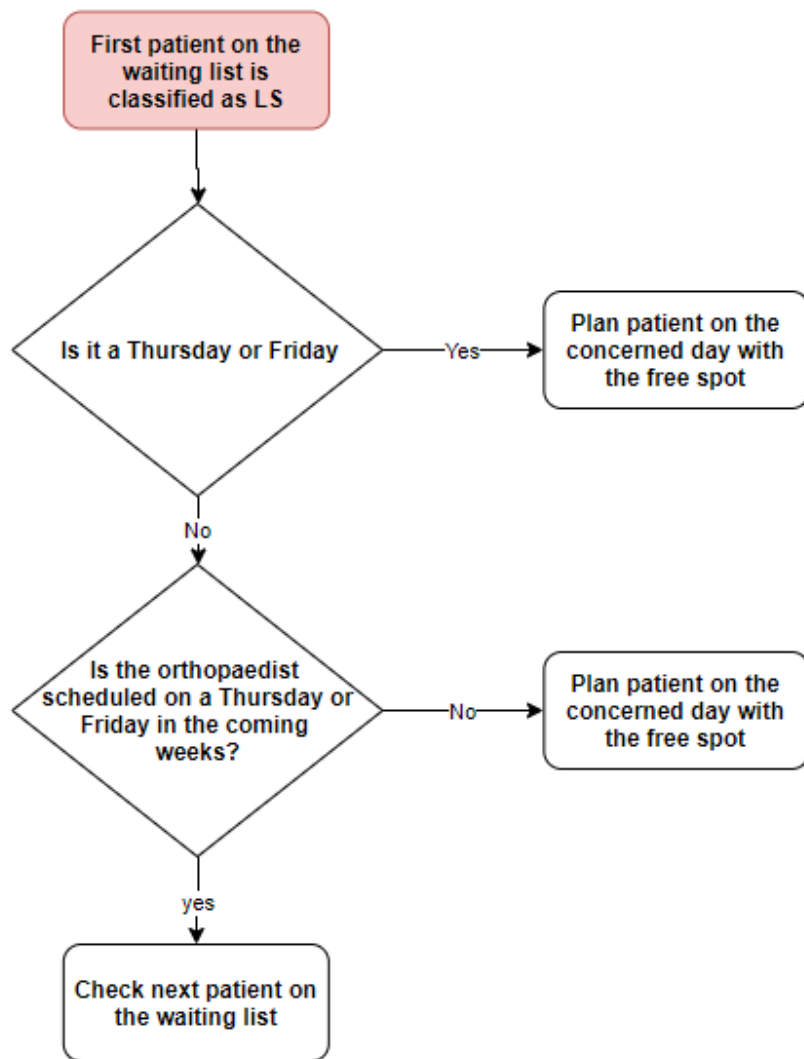


Figure E.4: Flowchart for a situation in which a patient classified as LS is on top of the waiting list of an orthopaedic surgeon.

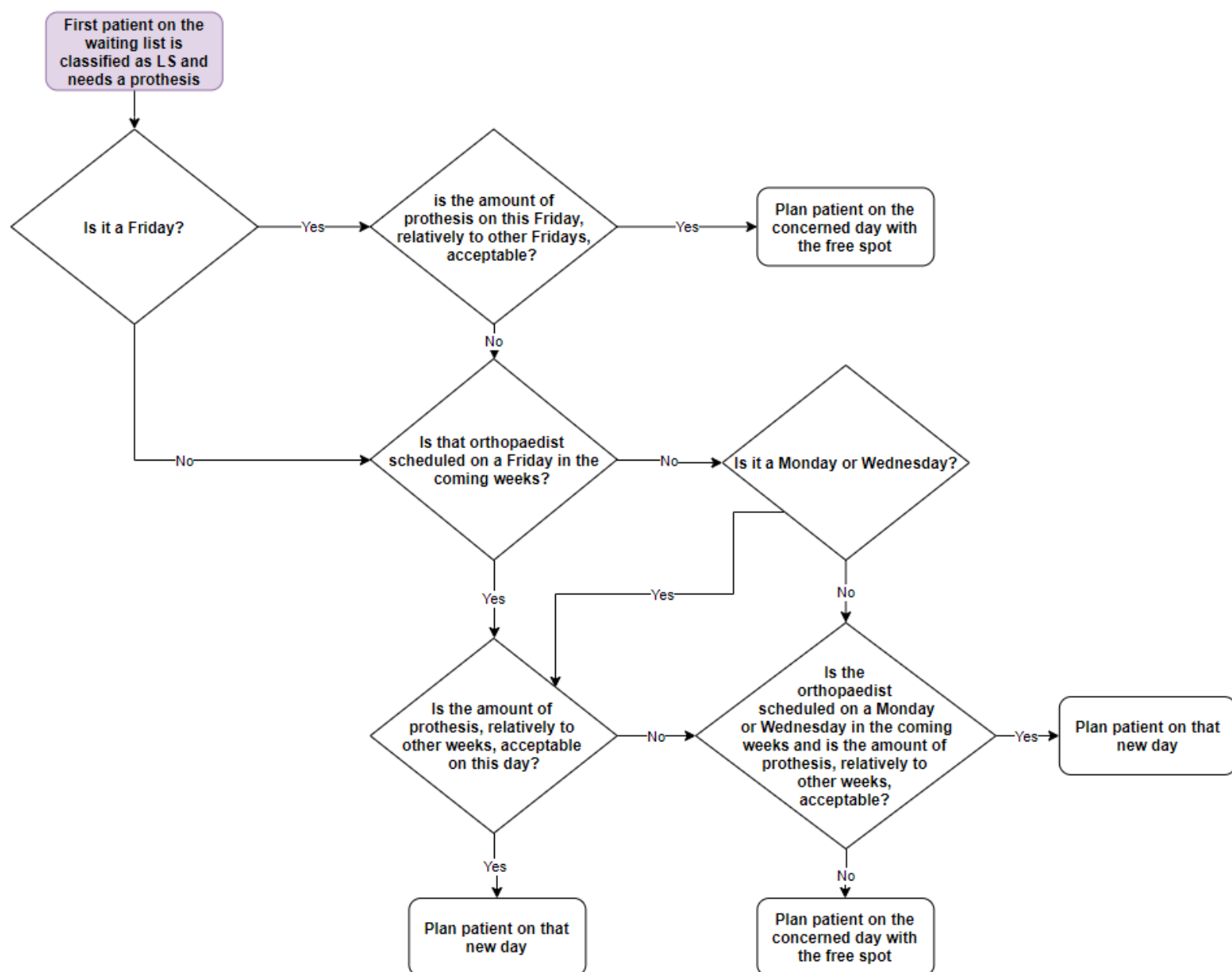


Figure E.5: Flowchart for a situation in which a patient classified as LS and needs a prosthesis is on top of the waiting list of an orthopaedic surgeon.

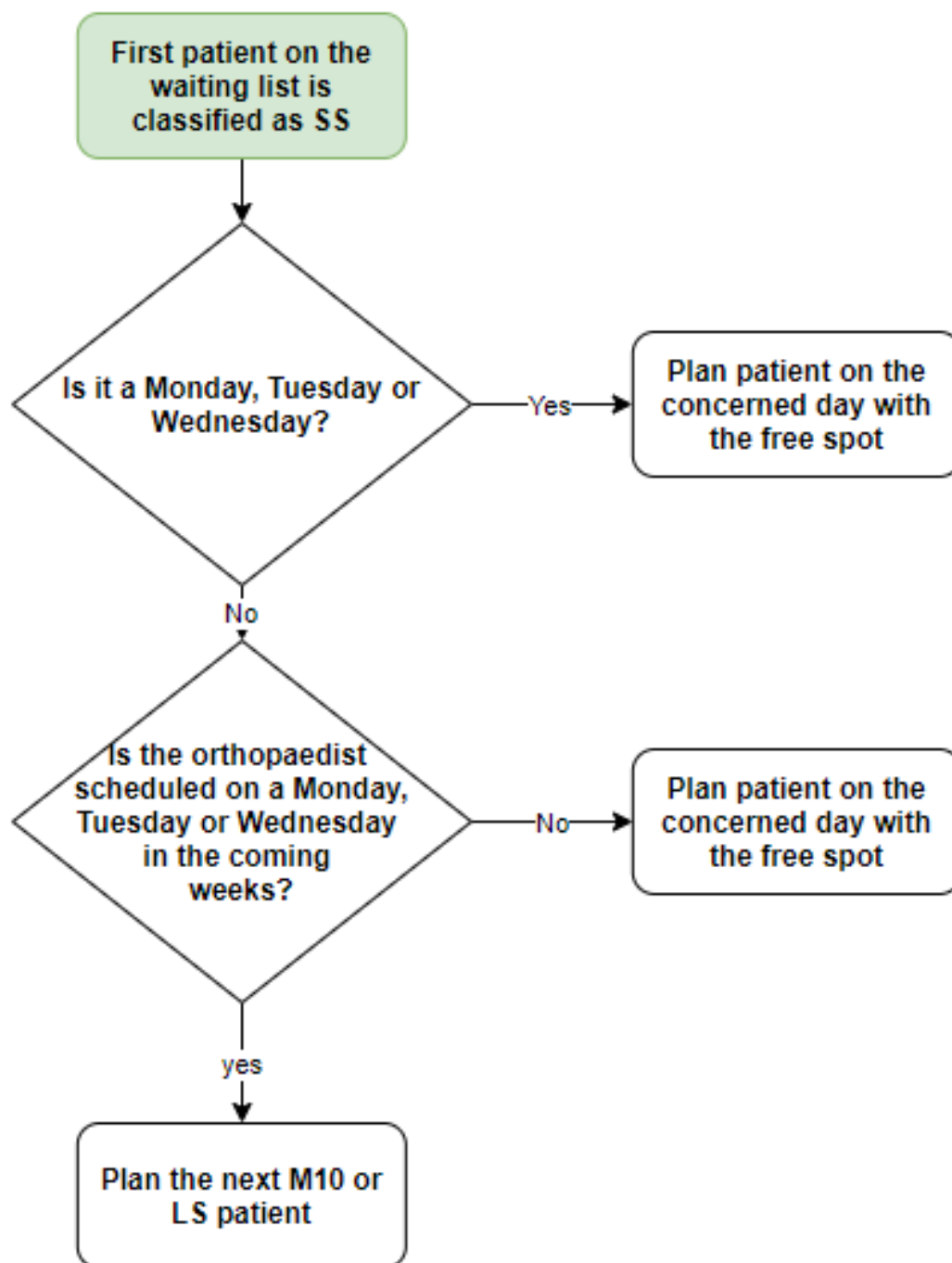


Figure E.6: Flowchart for a situation in which a patient classified as SS is on top of the waiting list of an orthopaedic surgeon.

F Fitness function

Dividing line	Percentage of patients classified as SS	Falsely classified as SS	Falsely classified as LS	Percentage of false classifications
Median<2	55%	1159	288	11,5%
Average<1,2	25%	178	3047	25,7%
Average<1,3	35%	372	2039	19,2%
Average<1,4	41%	545	1377	15,3%
Average<1,5	44%	656	1155	14,4%
Average<1,6	45%	677	1110	14,3%
Average<1,7	46%	721	1023	13,9%
Average<1,8	49%	863	752	12,9%
Average<1,9	50%	916	666	12,6%
Average<2,0	52%	1069	543	12,9%
Average<2,1	53%	1104	520	13,0%

Table F.1: Results of fitness function for categorisation

G LOS

Category	Days																									
	0	1	2	3	4	5	6	7	8	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Day treatment (DT)	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Short stay (SS)	1	0.91	0.18	0.08	0.04	0.03	0.03	0.02	0.01	0.01	0.1	0.1	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0
Long stay (LS)	1	1	0.97	0.52	0.31	0.21	0.13	0.09	0.05	0.04	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0

Table G.1: Stochastic LOS per category for the orthopaedics department

H Surgeries for the B4

Surgery	Category
Totale heup SP	LS
Totale heup Taperloc	LS
Totale knie Genesis	LS
Totale knie Specifiek	LS
Tibiakop osteotomie	LS
Doorbewegen knie	LS
MTP-dese+reconstructive voorvoer+ strekken voet	LS
Osteotomie van de femurschacht of supracondylair	LS
Inbrengen schouderprothese humeruskop	SS
MTP-dese + hallux fix	SS
Open bankart	SS
Scarf- Osteomie	SS
Schouderprothese (Humeruskop)	SS
Shouderprothese (Humeruskop en Schouderkom)	SS
Uitgebreide arthotomie knie	SS
Verwijderen prothese humeruskop en schouderkom en reimplantatie nieuwe prothese	SS

Table H.1: The surgeries where it would be beneficial if the patient stays at the B4 afterwards

I Results scenarios model

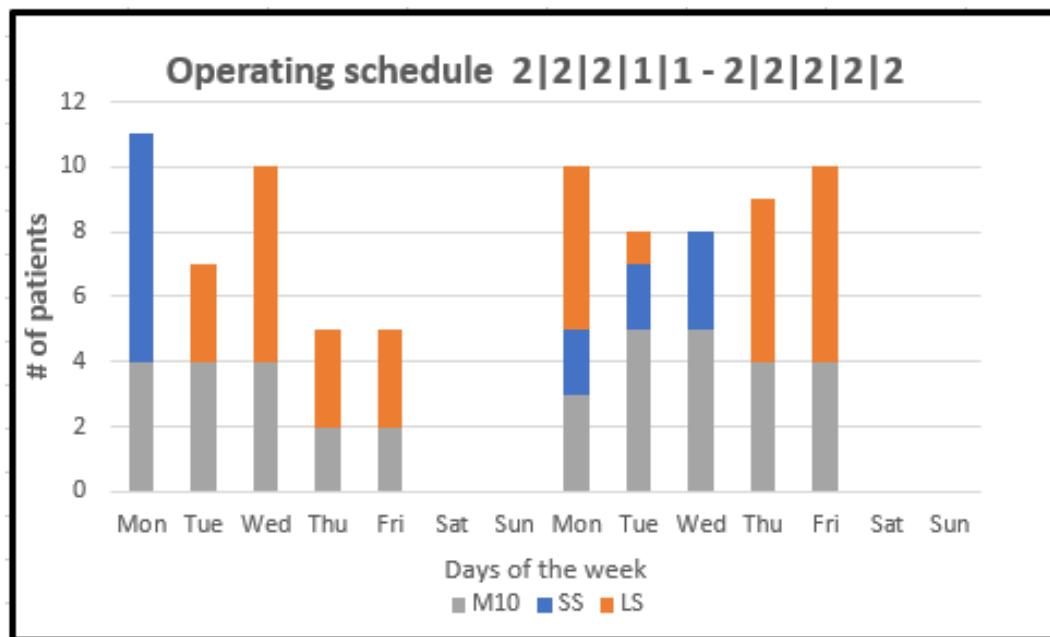


Figure I.1: Throughput of categories per day of the week with 2—2—2—1—1 and 2—2—2—2—2 as operating schedules. *Results obtained with IBM optimization studio, $n = 81$.*

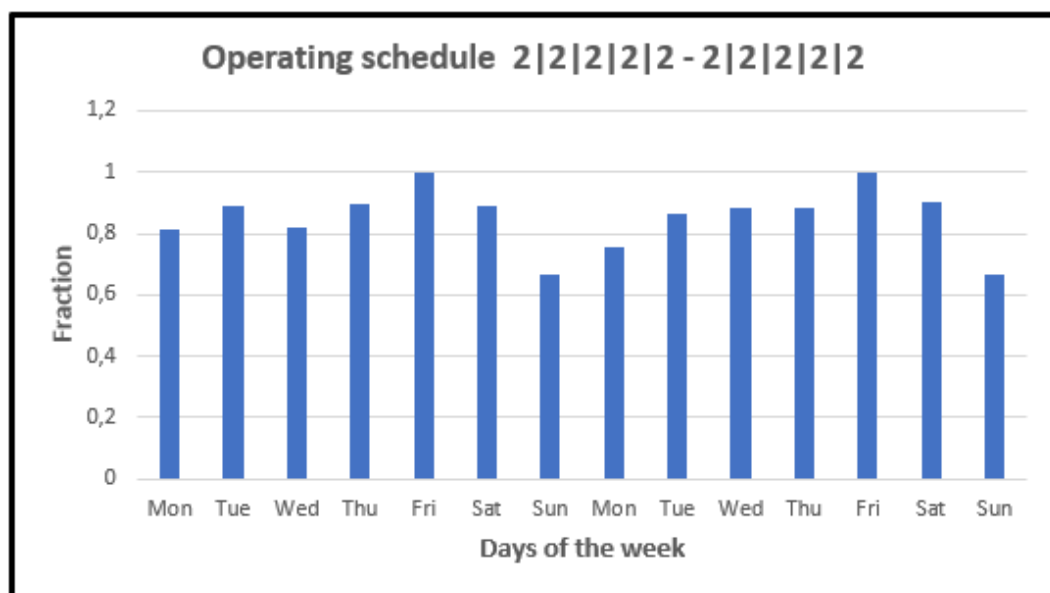


Figure I.2: Bed occupancy as fraction of the bed occupancy on Friday in the same week with 2—2—2—1—1 and 2—2—2—2—2 as operating schedules. *Results obtained with IBM optimization studio.*

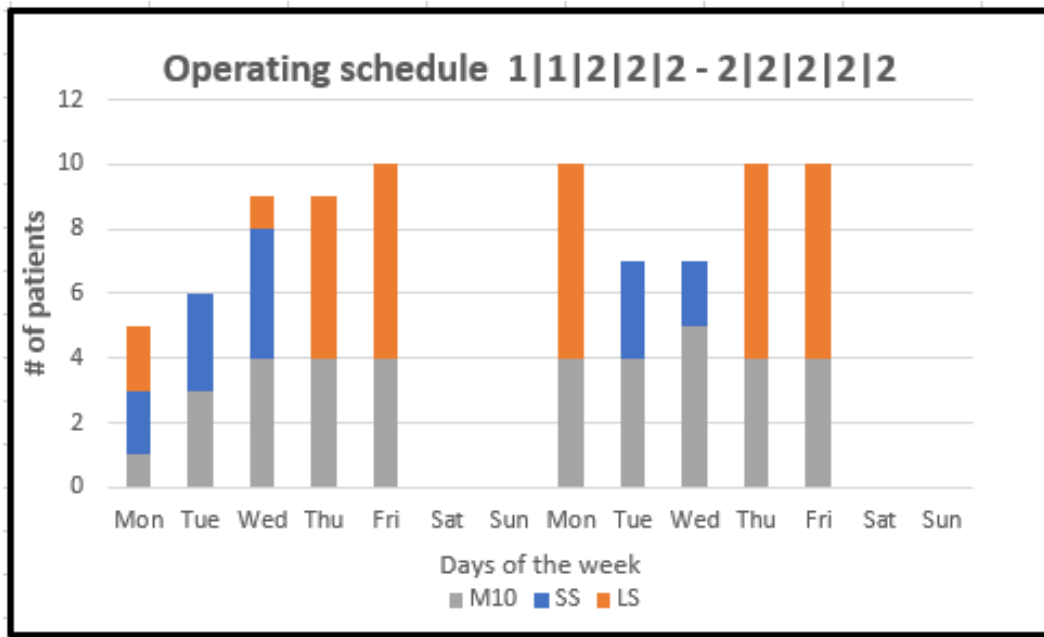


Figure I.3: Throughput of categories per day of the week with 2—2—2—1—1 and 2—2—2—2—2 as operating schedules. *Results obtained with IBM optimization studio, $n = 81$.*

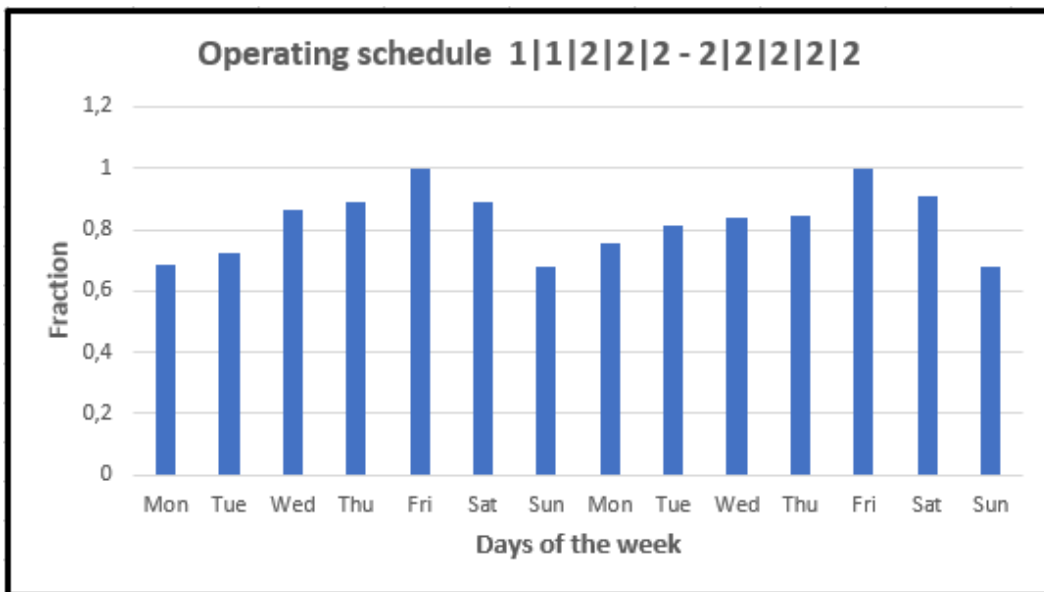


Figure I.4: Bed occupancy as fraction of the bed occupancy on Friday in the same week with 2—2—2—1—1 and 2—2—2—2—2 as operating schedules. *Results obtained with IBM optimization studio.*

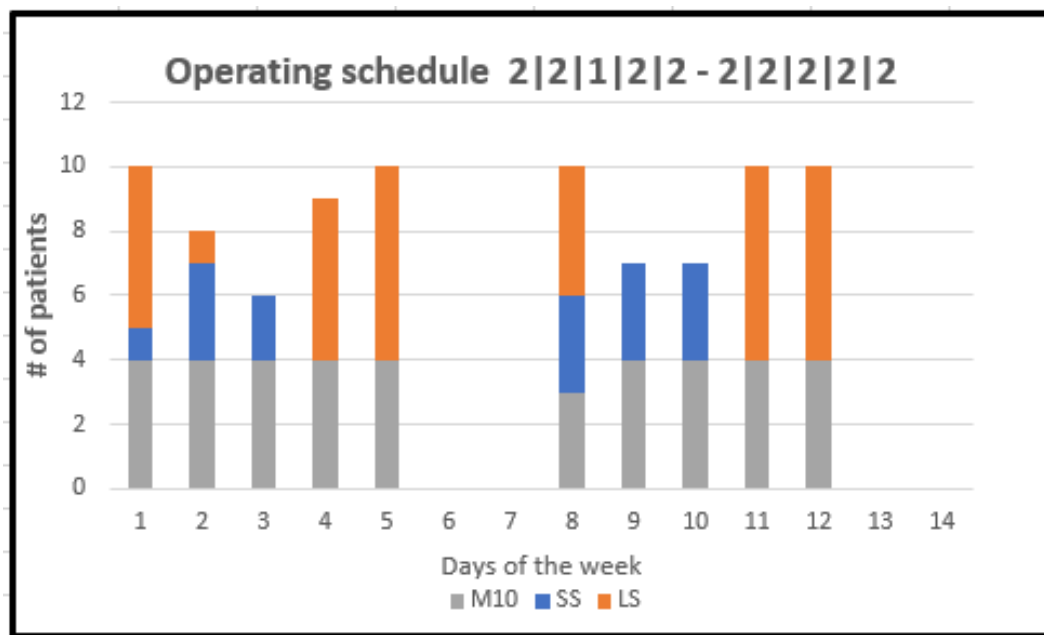


Figure I.5: Throughput of categories per day of the week with 2—2—1—2—2 and 2—2—2—2—2 as operating schedules. *Results obtained with IBM optimization studio, $n = 85$.*

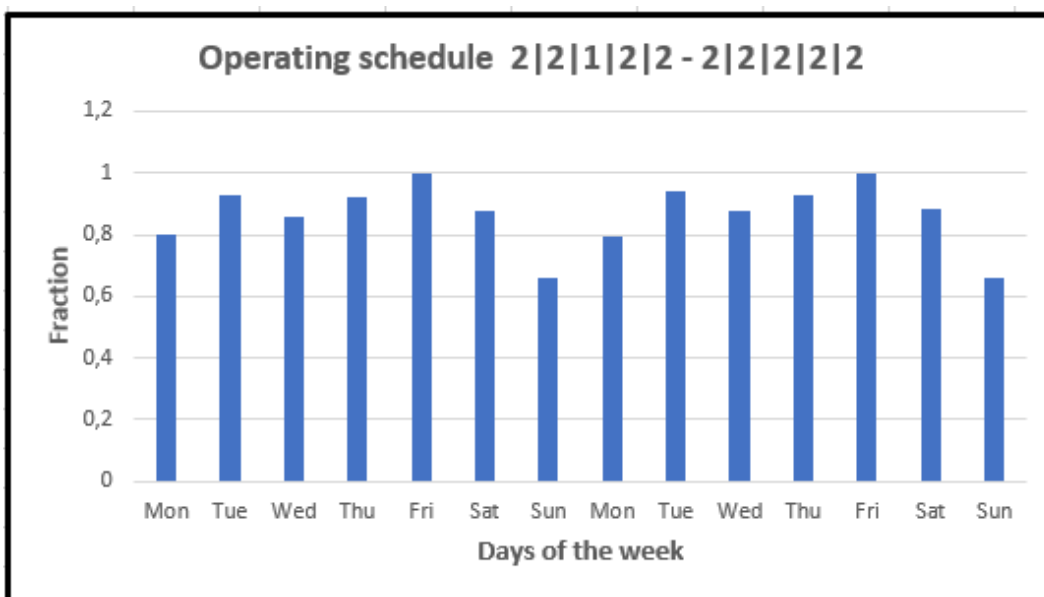


Figure I.6: Bed occupancy as fraction of the bed occupancy on Friday in the same week with 2—2—1—2—2 and 2—2—2—2—2 as operating schedules. *Results obtained with IBM optimization studio.*

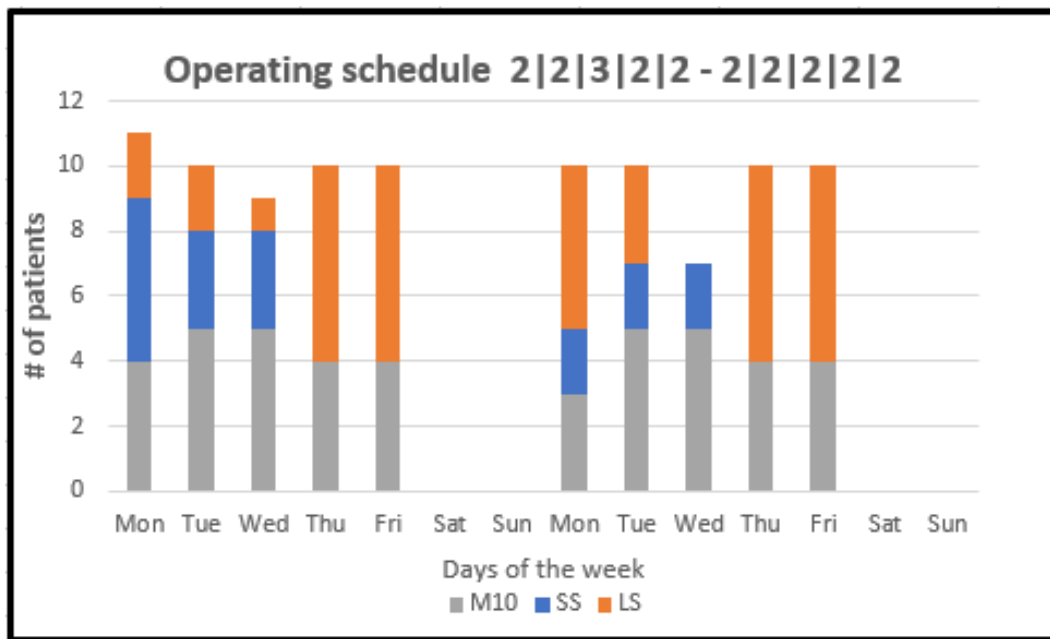


Figure I.7: Throughput of categories per day of the week with 2—2—3—2—2 and 2—2—2—2—2—2 as operating schedules. *Results obtained with IBM optimization studio, $n = 93$.*

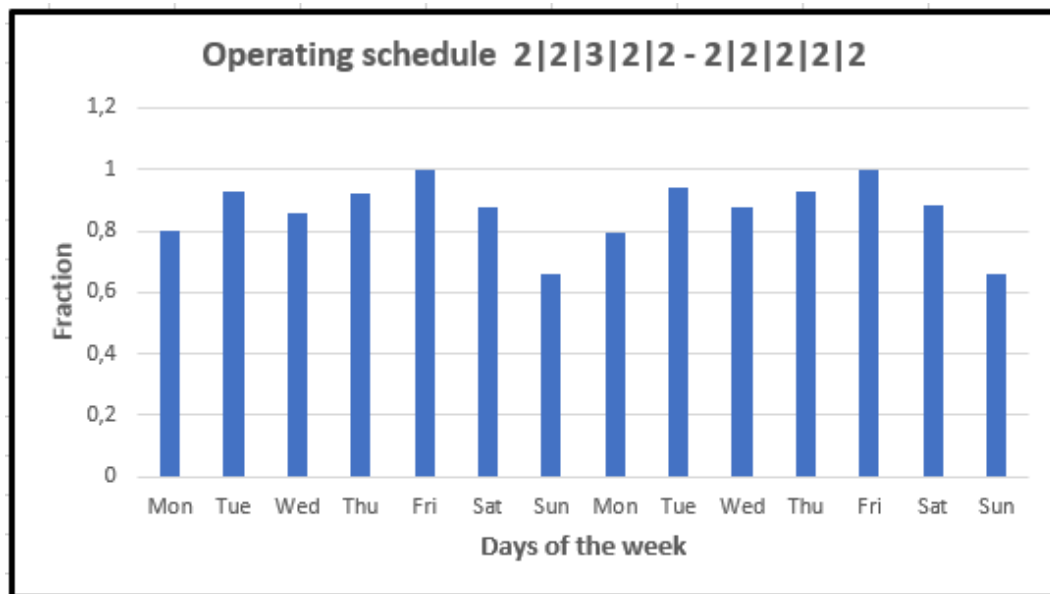


Figure I.8: Bed occupancy as fraction of the bed occupancy on Friday in the same week with 2—2—3—2—2 and 2—2—2—2—2—2 as operating schedules. *Results obtained with IBM optimization studio.*

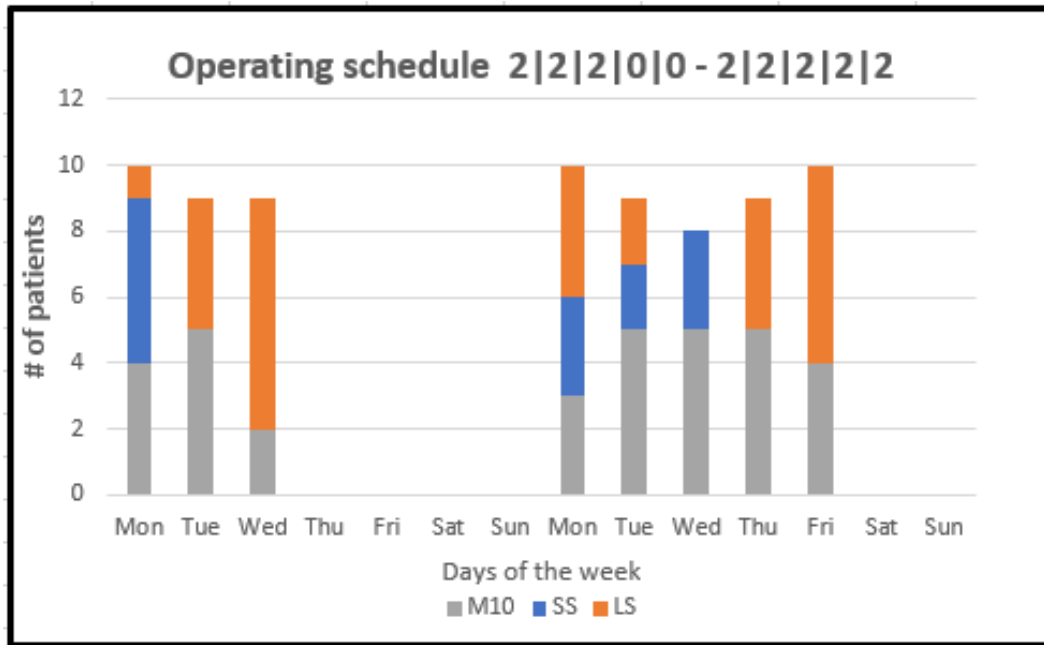


Figure I.9: Throughput of categories per day of the week with 2—2—2—1—1 and 2—2—2—0—0 as operating schedules. *Results obtained with IBM optimization studio, $n = 71$.*

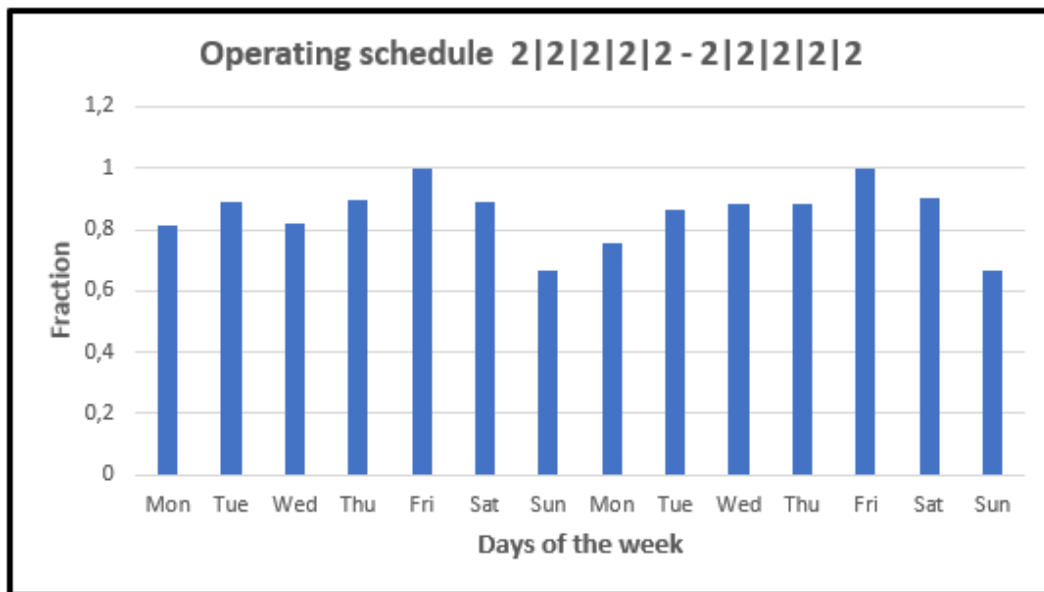


Figure I.10: Bed occupancy as fraction of the bed occupancy on Friday in the same week with 2—2—2—0—0 and 2—2—2—2—2 as operating schedules. *Results obtained with IBM optimization studio.*