Simulation of new day-treatments for a speciality of the UMC Utrecht

Bachelor Thesis - Daniël Hordijk

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Preface

Dear reader,

In front of you lies my thesis: “Simulation of new day-treatment clinic and new day-treatments for a speciality of the UMC”, the result of a long, yet enjoyable process at the UMC Utrecht, or rather, a process (mostly) at home *with* the UMC. This thesis was written to conclude my bachelor’s degree in Industrial Engineering and Management at the University of Twente.

I want to extend my sincere appreciation and gratitude to all the people at the UMC who helped with writing this thesis and performing the research. My supervisor at the UMC, Bart van den Berg, has assisted and contributed an incredible amount to this project, not only by giving relevant information and advice, but also by connecting me to the right people within the UMC. A lot of staff were involved with the study, and all their contributions are of great importance to the research. We worked with multiple business controllers, medical specialists, and planners, and although I will not mention them by name, I do want to thank these people dearly.

Furthermore, I thank my supervisor at the University of Twente, Erwin Hans, who has pushed me and helped me greatly in finalising this report. We had a rocky road in terms of communication, completely because of my own wrongdoing, yet without his comments and encouragement at the end of the project this report would not have been finished in the time I wanted it to.

Finally, I thank my parents, who took me back into their home rent-free and cooked many a great meal at the end of a long day of work during the lockdown.

Kind regards,

Daniël Hordijk Utrecht, 01/12/2020

Executive summary

Background

The Division of Surgical Specialities of the UMC Utrecht hospital manages several specialities. One of their specialities – that shall remain unnamed for confidentiality – plans to convert the patient treatment process of a select number of minimally invasive surgeries to a day-treatment. Converting treatments to day-treatments reduces the demand for clinical beds and reallocates surgeries from regular operating rooms to outpatient operating rooms. This is much needed as the speciality is struggling to keep up with the growth of their waiting list.

Goal

The goal of this research is to provide insight into the patient treatment process of the speciality and provide them with a means to test the efficacy of the new proposed day-treatments.

Approach

We design and implement a discrete-event simulation model of the process, with which we can measure how the converting of certain treatments to day-treatments affects access times, production volume and usage of capacity. The discrete-event simulation model was built in 5 phases, following a framework described by Robinson (2014). First, we build a conceptual model of the current patient treatment processes of the speciality by gathering contextual data about the speciality and their operations. Second, the conceptual model is realised by coding it in a discrete-event simulation software package, Tecnomatix Plant Simulation, and gathering the appropriate detailed data about various components of the model. Next, we perform model validation, which includes validating the process of the first two phases and comparing results of the model to real-world data. Then, we repeat the first three phases to implement the new day-treatment process into the current situation. Finally, we perform experiments with the simulation model and gather results.

During the implementation phase of the new day-treatments, we found two cases of which surgeries could change to a day-treatments. One where the “336193”, “336194A”, “336298A”, and “336790A” surgeries would be performed as day-treatments, as envisioned by a medical specialist, and one where “336790A” surgeries could not be performed as a day-treatment, as stated in the business case for the new day-treatments. Thus, we perform three experiments, one base-case measurement of the current situation, one where all three surgeries are performed as a day-treatment, and one where “336790A” surgeries are excluded.

Results

After performing the three experiments, we measure significant improvements in all statistics measured when all day-treatments are implemented. The inclusion of “336790A” treatments seems to improve all statistics further as well, yet only improves the access times significantly. Table 1 shows the results for a selection of key variables.

Table 1: Results of key variables of simulation of the speciality’s processes.

Scenario	**Operating room access times**	**Operating room waiting list increase rate**	**Production volume (patients treated per week)**
Current situation	0%	0%	47.4
“336790A” as normal	- 28.3%	- 43.0%	49.4 (+ 2.0)
All as day-treatment	- 34.3%	- 50.1%	49.5 (+ 2.1)

By performing the surgeries as day-treatments, approximately 1 hour and 10 minutes can be freed in the regular operating room each week. The occupancy of the day-treatment clinic on average is 25%.

Conclusions and recommendations

Thus, we recommend that the process of day-treatments is implemented for all the surgeries mentioned. According to the simulation, there are significant improvements on access times, waiting list reduction, production output, and utilisation of the operating room, clinical ward, and outpatient clinic capacity.

Moreover, “336790A” treatments only account for around 0.5% of the total usage of the new day-treatment clinic, which is already relatively low, yet do have significant effect on the access times of the operating room. Thus, if other minimally invasive treatments that could be performed as a day-treatment are identified, performing these as a day-treatment is likely to be beneficial as well, no matter how often they are performed.

Managementsamenvatting

Achtergrond

De Divisie Heelkundige Specialismen van het UMC Utrecht ziekenhuis overziet meerdere medische specialismen. Een van hun specialismen – die vanwege geheimhouding niet genoemd zal worden – heeft een plan om het behandelproces van een bepaald aantal miniem invasieve chirurgische operaties om te zetten naar een dagbehandeling. Dit zou vraag naar kliniekbedden verlagen en behandelingen verplaatsen van de reguliere operatiekamer naar de polikliniek. Dit is hard nodig, aangezien het specialisme moeite heeft om de groeiende wachtlijst voor de operatiekamer bij te houden.

Doel

Het doel van dit onderzoek is om het specialisme inzicht te bieden in hun patiënt-behandel proces en ze een middel te geven om de efficiëntie van de nieuwe dagbehandelingen te berekenen.

Aanpak

We ontwerpen en gebruiken een discrete-event simulatie model waarmee we de effecten van het omzetten van bepaalde operaties naar dagbehandelingen meten op toegangstijden, productie hoeveelheden en gebruik van capaciteit.

Het discrete-event simulatie model is in 5 fases gebouwd aan de hand van een kader opgezet door Robinson (2014). In de eerste fase maken we een conceptueel model van de huidige processen van het specialisme door contextuele data te verzamelen over het specialisme en hun werking. Vervolgens realiseren we het conceptuele model door het te coderen in een discrete-event simulatie software pakket, Tecnomatix Plant Simulation, en verzamelen we de benodigde data over de verschillende componenten van het model. In de derde fase valideren we het proces en de gemaakte keuzes van de eerste twee fases en vergelijken we resultaten van het model met historische data uit het ziekenhuis. Daarna voeren we de eerste drie fases opnieuw uit voor het proces van de nieuwe dagbehandelingen. Tot slot voeren we experimenten uit met de simulatie en vergelijken we de resultaten.

Tijdens het implementeren van de nieuwe dagbehandelingen vonden we twee scenario's voor welke operaties naar een dagbehandelingen omgezet kunnen worden. De eerste stelt dat "336193", "336194A", "336298A", en "336790A" operaties als dagbehandeling uitgevoerd kunnen worden, zoals opgesteld door een medisch specialist, waar een business case voor de dagbehandelingen de "336790A" operatie uitsluit. Daarom besloten we om drie experimenten uit te voeren, als eerste een nulmeting voor de huidige situatie, als tweede een experiment waarbij "336790A" operaties niet als dagbehandeling uitgevoerd worden, en als derde een experiment met alle drie de voorgestelde operaties als dagbehandeling.

Resultaten

Na het uitvoeren van de experimenten vonden we een significante verbetering in alle gemeten variabelen wanneer alle operaties als dagbehandeling uitgevoerd worden. Het ook invoeren van "336790A" als dagbehandeling heeft alleen op de toegangstijd een significant extra bevorderend effect, alhoewel de andere variabelen ook licht positief beïnvloed worden. Tabel 2 laat de resultaten van een aantal belangrijke variablen zien.

Tabel 2: Resultaten van belangrijke variabelen uit simulatie van de processen van het specialisme.

Experiment	**Toegangstijd operatiekamer**	**Groeisnelheid van wachtlijst operatiekamer**	**Productie (aantal behandelde patienten per week)**
Huidige situate	0%	0%	47.4
"336790A" uitgesloten	- 28.3%	- 43.0%	49.4 (+ 2.0)
Alles als dagbehandeling	- 34.3%	- 50.1%	49.5 (+ 2.1)

Door de dagbehandelingen uit te voeren word elke week ongeveer 1 uur en 10 minuten aan tijd in de reguliere operatiekamer bespaard. Het gebruik van de behandelkamer voor de dagbehandelingen zelf ligt rond de 25%.

Conclusie en aanbevelingen

Volgens de simulatie zijn er significante verbeteringen in toegangstijd, groeisnelheid van de wachtlijst, productieaantallen en gebruik van capaciteit van de operatiekamer, kliniek en polikliniek. Daarom bevelen we de DHS aan om het dagbehandelproces te implenteren voor alle genoemde operaties.

Verder raden we aan om ook andere miniem invasieve operaties met laag productievolume die als dagbehandeling uitgevoerd kunnen worden te identificeren, aangezien "336790A" behandelingen maar voor 0.5% van het gebruik van de dagbehandelkamer zorgen maar wel significant bijdragen aan het verlagen van de toegangstijd. Het algehele gebruik van de dagbehandelkamer is slechts ongeveer 25%, dus er is genoeg ruimte om nog meer typen operaties uit te voeren als dagbehandeling.

Contents

List of tables and figures

List of acronyms

BI	Business Intelligence
DBC	Diagnosis-treatment combination
DES	Discrete-Event Simulation
DHS	Division of Surgical Specialities
MPSM	Managerial Problem-Solving Method
OPC	Outpatient Clinic
OR	Operating Room
P&C	Planning & Control
PA	Production Agreement
UMC	University Medical Centre

1 Introduction

This research aims to develop a simulation model of the patient treatment process of a speciality – that shall remain unnamed for confidentiality – of the *University Medical Centre Utrecht (UMC)*. This model will be utilised to experiment with a plan envisioned by a medical specialist to change the process of certain surgeries to that of a day-treatment, and measure the effects on the access times, waiting list sizes production volume and occupancy of treatment rooms and facilities. This first chapter serves as a general introduction to the UMC, the speciality and the rest of the thesis, and is loosely based on a problem solving methodology described by Heerkens & Winden (2017), referred to as the *Managerial Problem Solving Method (MPSM)*.

In Section 1.1, we start with describing the process of problem identification, which according to the MPSM would normally entail selecting an action problem – defined as a discrepancy between the norm and reality as defined by the problem owner – and drafting an inventory of problems that could solve the action problem. From that inventory, you select a single core problem to tackle with your research (Heerkens & Winden, 2017). However, we kind of performed this phase in reverse, as we first select the core problem first and draft action problems the core problem could solve. Next, in Section 1.2, we describe the problem-solving approach. We then close this chapter with Section 1.3 where we will describe the research questions that followed from the problem identification phase and problem-solving approach, which serve as a basis for the research design described in Chapter 3.

This research was performed for the *Division of Surgical Specialities (DHS)* of the UMC who manages the speciality. The UMC is an academic hospital, meaning aside from providing healthcare they also strive to educate and perform scientific research. Thus, they often perform complex procedures on patients with complex or multidisciplinary diagnoses.

1.1 Problem identification

The specific goals of this project have changed a great deal throughout the problem identification phase. When starting the research, the decision on what speciality to study specifically had not even been made yet. The initial problem the DHS encountered and presented was the simple lack of a model of their patient treatment processes. This results in a lack of insight into the general process of treating patients of their different specialities, and a lack of ability to experiment on this process and measure or estimate long-term effects. This problem was selected to be the core problem, and what experiments should be performed and what effects should be measured is what changed throughout the problem identification phase. These possible experiments – or, in theory, action problems – will now be described separately.

1.1.1 Production agreements

The initial experiment the UMC proposed to perform was related to their *Production Agreements (PAs)*. Their specialities often over- or underproduced at the end of the year which results in the DHS losing money. To alleviate this problem, the DHS needs to be able to identify what factors of their processes they should change to be able to hit the PAs. The model would serve as a method to identify these factors.

PAs are made by the *Planning & Control (P&C)* unit of the hospital with healthcare insurance providers. PAs are set in the form of a number of *diagnosis-treatment combinations (DBCs)* each speciality can perform per year. In other words, how many patients with a certain diagnosis they can treat in a certain way. If a speciality treats more patients than agreed upon in the PAs, they do not get paid for the excess patients. Contrarily, if a speciality treats less patients than the PAs allow for, they could have treated more patients and, in doing so, could have earned more.

The reason the DHS often over- or underproduces was identified as having no method to monitor or predict how many patients in a specific DBC a speciality had treated or will treat throughout the year. The DHS typically only realises how many DBCs they have performed at the end of the year, as lead-times of patients are usually long. Even more so for academical hospitals, where access times can be long because of the rare and complex procedures. The high lead-times make it difficult to estimate when a patient will finish their treatment and a DBC will be finished. This results in the DHS being unable to change anything about their operations throughout the year to steer production based on the amount of DBCs already produced or expected to be produced.

However, in exploring the idea of identifying factors or solutions to solve over- or underproduction, we were becoming doubtful whether the DHS could even influence the making of the PAs and a possible solution for over- or underproduction could not be implemented. Thus, we decided to shift our focus to the increasing access times – defined as the time a patient spends waiting on a treatment on the waiting list – observed in one specific speciality that also has a plan for stopping this increase that will be described in Section 1.1.2.

1.1.2 The speciality and new day-treatments

The speciality of the DHS wants to move some of their minimally invasive surgeries from the Operation Room (OR), where surgical procedures are carried out with strict guidelines surrounding safety and hygiene, to a converted treatment room of the outpatient clinic that would have less strict guidelines. These surgical operations typically require a patient to be admitted into a clinic for a few hours up to a day before and after the surgery, while the new suggested operations do not require lengthy admission into a clinic but only require the patients to rest briefly in a recovery area. These new treatments can be carried out in a single day; hence they are referred to as day-treatments.

The DHS is currently able to prove they can improve total throughput of patients but lacks ability to test other long-term effects, like the effect on access times. This still aligns with the initial core problem described at the start of this chapter, being the lack of a model with which they can experiment with their patient treatment process.

It should be noted that ideally, this project is done in a manner such that it can be expanded to test other scenarios or be repeated for other specialities of the DHS in the future.

1.1.3 Selection of action and core problem

We can then define the core problem as follows:

> "The DHS of the UMC Utrecht should have the ability to model the process of treating patients of the speciality and test long-term effects of implementing a new day-treatment process."

This core problem was selected as a cause for the following action problem:

> "The access times of the speciality at the UMC Utrecht are increasing."

We will now describe the problem-solving approach.

1.2 Problem solving approach

To solve the core problem, a simulation model will be made. Various factors described in Section 1.1 make other forms of modelling the long-term effects of the new day-treatments too difficult, especially when attempting to determine the effects on access times. Using methods like queuing theory or a simple Excel sheet calculation can be ruled out because of the difficulty of planning treatments involved. To better estimate the scope of this model, a preliminary conceptual model of the speciality was made, which can be found in Appendix A.

To achieve this goal, three phases will now be described along with describing the modelling process that should happen throughout all phases.

1.2.1 Analysis of current situation

First, all the current processes of the speciality will be identified and analysed in preparation for modelling the current situation. Actors (patients, medical specialists, etc.), components (ORs, clinics, etc.) and how they flow through one another will have to be described. For this, decisions on the required level of detail for the model will have to be made. From the preliminary conceptual model in Appendix A, the following steps for analysing the current situation were identified:

1. Decide on what level of detail patients and their treatments should be differentiated between and modelled,
2. Find and set up all possible treatment paths for patients on the decided level of detail,
3. Gather distributions of treatment times and required length of stay in the clinic per decided level of detail,
    - 3.1. Depending on level of detail, gather predictability of treatment plan at different consults, accuracy of diagnosis and effectiveness of treatments,
4. Decide on what level of detail to model hospital staff and capacity,
5. Identify and analyse capacity of all components of the speciality,
    - 5.1. Reduction weeks in (outpatient) clinic beds/hospital staff,
    - 5.2. Set up what specialists can perform what treatments,
    - 5.3. Identify the calculation method of PAs and how they are translated into capacity,
6. Find the arrival patterns of patients,
7. Identify how to model planning treatments,
8. Identify how often patients cannot be discharged and how long their resulting stay in clinic is,
9. Identify how to select the realised DBC at end of process depending on level of detail,
10. Decide how to select the expected DBC for monitoring purposes during treatment.

However, since these steps were identified based on the preliminary conceptual model (Appendix A) it is highly likely that changes will occur and other tasks will need to be performed. When the current situation is successfully analysed and modelled (see Section 1.2.3 for more information on the modelling process), the model should be tested and validated to ensure it is in accordance with reality and thus is reliable and a valid research tool.

1.2.2 Analysis of new day-treatments

The suggested day-treatments are already existing, minimally invasive surgeries that currently are performed in the regular OR. If a patient receives such a surgery as a day-treatment, they do not have to rest in the clinic as long as with a regular surgery, typically because the day-treatments are performed under local anaesthesia. Performing a day-treatment in the new, proposed method has a different process from the current day-treatments. This process will have to be analysed.

Precisely what treatments can change to day-treatments have already been thought out by the head of medicine of the speciality, and so, when the process is set up, the expected new parameters for the new day-treatments can be identified. These parameters include the new expected distributions of treatment times, how long a patient is expected to rest in the recovery area and how much staff and medical specialists are required for the treatments. These new day-treatments can then be implemented into the model of the current situation.

1.2.3 Modelling findings

Throughout the three stages, modelling the findings should happen simultaneously to accelerate the process. For example, when setting up the treatment paths in the analysis of the current situation, it makes sense to either do this in the model immediately, or to do it in such a way that it can be implemented into the model easily. For modelling, Tecnomatix Plant Simulation will be used. The first step in modelling should be constructing a conceptual model of the processes before coding them into the simulator. Simplifications should be made wherever possible and any assumptions must be explained and defended. Anytime a test or experiment is done, for example to gather data on the effect on waiting times because of the newly implemented day-treatments, things like the warm-up period of the model and the number of replications to perform should be considered in order to gain reliable results from the model.

The *key performance indicators (KPIs)* the model should measure should be kept in mind throughout the modelling process. The suggested KPIs are the access times, waiting list sizes, production volume and usage of the different treatment rooms (ORs, clinical wards, outpatient clinics). This process of modelling follows from a framework on simulation studies described by Robinson, that will be further described in the theoretical framework in Chapter 2 and used to set up the research design in Chapter 3 (2014).

1.2.4 Deliverables

Once these two stages have been carried out and concurrent modelling has been done, three deliverables should have been produced, which are as follows:

1. A Plant Simulation model that simulates the processes a patient of the speciality can flow through that is sufficiently accurate to reality and can calculate and predict the access times, waiting list sizes, production volume and usage of treatment rooms,
2. Data and analysis of the effects of changing certain surgical treatments to day-treatments on access times, waiting list sizes, production volume and usage of treatment rooms,

Reporting on the deliverables should be easy to understand and be done in such a way that it is easily repeatable for other specialities of the DHS or expandable to other experiments they want to perform in the future.

With the deliverables finished, the core problem will have been solved since a method will have been developed that allows testing and experimenting with the patient treatment process of the speciality in the form of the first deliverable. The use and efficacy of this method as a means of experimenting on the system will have been proven by the second deliverable.

1.3 Research questions

From the previously described stages and deliverables, the following research goal was created:

> "To analyse the effects of shifting certain surgical treatments to a day-treatment for on the access times, waiting list sizes, production volume and usage of capacity of the OR, clinical ward and outpatient clinic for the speciality of the UMC Utrecht by modelling and simulating the patient treatment process."

To achieve the research goal, research questions and sub-questions will now be set up that follow from the problem-solving approach.

1. What is the conceptual model of the speciality of the UMC Utrecht in the current situation?
2. What is the model input data?
    a. What are the different treatment paths per DBC and the probabilities a patient will follow a specific path?
    b. What are the distributions of the different treatment times per path?
    c. What is the capacity of the speciality in terms of treatment beds in the clinical ward and outpatient clinic, OR time and staffing throughout the year?
    d. What is the distribution of patient demand per DBC?
    e. What are the planning procedures that the speciality uses?
    f. How often is a patient unable to be discharged and what is the resulting extension in stay at the clinical ward?
3. What are the model validation data?
4. What are the interventions that need to be made to the model for converting certain surgical treatments to day-treatments?
    a. What is the conceptual model of the new day-treatment process?
    b. What treatments have the possibility to shift to a day-treatment and what are the new treatment paths?
    c. What are the expected distributions of treatment times of the new day-treatments?
    d. What are the capacity requirements for the new day-treatments?
5. What are the effects of the new day-treatment process on access times, waiting list sizes, production volume and usage of treatment rooms for the speciality?

These questions align with the phases of the problem-solving approach described earlier. Question 1, 2 and 3 deal with knowledge problems arising in Phase 1, analysing the current situation (Section 1.2.1). Question 4 then deals with knowledge problems that arise in Phase 2, analysis of new day-treatments (Section 1.2.2). Finally, question 5 aims to achieve the overall research goal by describing the effects of the new day-treatment process.

Note that some of the sub-questions are subject to change based on decisions to be made during conceptual modelling. For example, if in phase 1 it is decided to model treatment paths not per DBC but grouping, sub-question 2.a should be changed to fit with this decision.

In Chapter 2, a theoretical framework will be given, and key constructs and variables will be described. Then, in Chapter 3, a research design for each question will be set up.

2 Theoretical framework

In this chapter the theoretical framework will be built by conducting a brief literature review where we will analyse various studies on modelling and simulation in healthcare. First, the key concepts and variables from the research goal and problem statement will be identified. We will then search for literature to define these concepts and to draw connections between the concepts. Finally, the contribution of this research to the body of knowledge will be discussed.

2.1 Key concepts

To repeat, the problem statement is as follows:

> “The DHS of the UMC Utrecht should have the ability to model the process of treating patients of the speciality and test long-term effects of implementing a new day-treatment process.”

And the research goal is as follows:

> “To analyse the effects of shifting certain surgical treatments to a day-treatment for on the access times, waiting list sizes, production volume and usage of capacity of the OR, clinical ward and outpatient clinic for the speciality of the UMC Utrecht by modelling and simulating the patient treatment process.”

The key concepts from the problem statement and research goal are the following:

- Modelling,
- Simulation,
- Access times,
- Waiting list sizes,
- Patient treatment process (or healthcare process),
- Production volume,
- Usage of capacity.

For the purposes of this study, modelling and simulation are combined into one concept, since simulation already infers that modelling is also performed, while the opposite is false. In other words, you cannot simulate something without also modelling said thing but building a model of something does not automatically mean you are simulating it as well.

It is worth noting that the concept of the new day-treatments is not included, since it is very specific to the speciality of the UMC, and the purpose of the study is to define the concept further and find its relationship to the other concepts.

2.2 Literature search process

We will now describe how we searched for literature and how literature was selected. We should search for literature that can give insight into the definitions of and connections between the key concepts, as the goal of the theoretical framework is to provide a basis for our research and give a theoretical perspective.

To search for literature, we used the SCOPUS database, as it is multidisciplinary. This study combines the field of healthcare and management, so using a literature database purely focused on healthcare, like PubMed, would not give us the results we require. To perform our search, we use the key concepts of simulation and the healthcare process as our search terms. As follows from Section 2.1, simulation already infers that modelling is performed meaning that modelling as a concept does not need to be included in the search terms.

These search terms only give around 80 results. If we remove the term "process" from "healthcare process" we get over 11,000 results, yet not a lot are applicable to our study, as they also include simulations of things like the effectiveness of individual treatments, vaccines, pandemics, risk assessment, etc. To gather a little bit more results, we add "healthcare management" to our terms, which gives around 180 results.

We then select literature from the results that is concerned with experimenting with a relatively similar process change to the one we are going to test, that being the day-treatments, and that explores similar variables to ours, namely the access times, waiting list sizes, production volume and usage of capacity. Furthermore, we select literature that discusses the concepts of modelling and simulation within healthcare as a whole, like previous literature reviews on the subject. Finally, we also explore relevant sources used in the selected literature. As the amount of literature found is relatively low, we do not exclude literature based on factors like the number of citations or publishing year.

2.3 Definition of concepts

The key concepts will now be defined using the literature found from the search described in Section 2.2 where necessary.

Modelling and simulation

Although technically two different concepts, modelling and simulation are very closely related. Simulation can be defined as: "Experimentation with a simplified imitation (on a computer) of an operations system as it progresses through time, for the purpose of better understanding and/or improving that system" (Robinson, 2014). The simplified imitation that is experimented upon can then be defined as the (mathematical) model of that system, meaning that simulation is the act of experimenting on a model over time. Robinson lists four simulation methods, namely *discrete-event simulation (DES)*, Monte Carlo simulation, system dynamics and agent based simulation (2014). However, only two methods are widely used when simulating healthcare systems, which are DES and system dynamics (Brailsford, 2007), hence only these two methods will be defined here.

DES is used for modelling and experimentation with queueing systems. Processes in a system are represented by entities flowing from one activity to the next. These activities cause a time delay for the entities. When the activity time delay is longer than the rate at which entities arrive at the activity, a queue will build up. During simulation of the system, only the points in time where the state of the system changes, for example when an entity flows between activities, are represented (Robinson, 2014).

In contrast, system dynamics is a continuous simulation method, or a method where time is modelled continuously. In system dynamics, the world is represented as a set of stocks and flows, where stocks are accumulations (of things like people, materials, money) and flows change the level of a stock with inflows that increase the stock and outflows that reduce it. These inflows and outflows happen continuously, and the stocks change based on the balance of inflows and outflows of the stock (Robinson, 2014).

Patient treatment process

The patient treatment process will be defined later in this study, as for now it is unclear exactly what parts of the process will be included and what will be excluded in the model. For the purpose of the theoretical framework, the patient treatment process is defined as the activities that the speciality performs at the UMC that directly deliver healthcare to a patient. This concept can also be named the healthcare process. Since this concept is specific to the UMC and the speciality, definitions from other studies will not be given.

Access times

In this study, we define access times as the time a patient spends on a waiting list while waiting for a future treatment.

Waiting list sizes

We define the waiting list size as the number of patients present on a single waiting list.

Production volume

With production volume, we refer to the number of specific diagnoses the hospital has finished treating. This does not refer to individual patients, as there is a possibility one patient has multiple diagnoses attached to them (Nederlandse Zorgautoriteit, 2019), yet we model patients as having a single diagnosis.

Usage of capacity

This concept is self-explanatory, as usage of capacity refers to how much of the capacity of the clinical ward, outpatient clinic and OR allocated to the speciality is being used.

2.4 Connections between concepts

We will now start to draw connections between the key concepts using the literature found in Section 2.2.

Firstly, we discuss whether simulation modelling is a good fit for the patient treatment process to be studied in this project or for healthcare processes at all. Kuljis et al. mention that, at the time of their study, the application of modelling and simulation in the healthcare field is not as widespread as in other fields, where simulation and modelling can be used as part of their core operation and can be very beneficial. These benefits seem to carry over to the healthcare sector as well, making the same methods used in business and manufacturing modelling applicable to the healthcare sector (2007). Paul and Kuljis introduced seven axes of differentiation between modelling in the healthcare sector and modelling in the business sector, which are as follows:

- *Patient fear of death*, which introduces unpredictable pressures or irrationality to the system,
- *Medical practitioners*, who are a diverse community with different approaches to healing, can be highly opinionated and disagree on various issues,
- *Healthcare support staff*, who typically have a different view on a healthcare organisation,
- *Healthcare managers*, who have to make decisions that influence all levels of the organisation, leaving them in complex situations with opposing parties withing the organisation,
- *Political influence and control*, or the outside political forces that influence the operation of the healthcare organisation,
- *'Society's view'*, which is linked to the political forces in that public opinion can also exude a force on the healthcare sector,
- *Utopia*, or, in other words, the aspiration to a healthcare utopia where nobody dies.

However, Paul and Kuljis do not claim this list to be comprehensive (2007). Kuljis et al. then argue that the overall complexity of the healthcare sector combined with these seven axes of differentiation are what caused the slowness of adopting modelling and simulation practices in the healthcare sector. Therefore they suggest to always take the seven axes of differentiation into consideration when modelling and simulating in healthcare (2007).

We will now discuss which of the two simulation methods described in Section 2.3 is most fit for this study. As mentioned, when modelling and simulating healthcare processes the two main simulation methods typically used in research are DES and system dynamics (Brailsford, 2007). According to Kuljis et al., DES in the healthcare field has many uses, which include logistics, scheduling and queue management, patient pathway design, reengineering, and reduction of waiting times. In comparison, system dynamics in the healthcare field can be applied to resource and asset allocation and management, patient pathway design and management, strategic and operations management, and change management (Kuljis et al., 2007).

While these lists are probably not exhaustive, they give some indication of which method is most fit to use for this study. The focus of this project is testing whether, in principle, reengineering some of the treatments the speciality performs will reduce waiting times. Resource and asset allocation will not have to be modelled since the speciality rarely deals with delays or other hiccups caused by resource management. Furthermore, when using system dynamics patients are not individual entities but are one stock, which means every patient will have the same characteristics (Brailsford, 2007). For testing the new day-treatment process, patients will need individual characteristics and diagnoses since not every patient will receive a renewed day-treatment. Hence, we decided that DES is the best fit for this project.

As for the other performance factors and concepts, the production volume and usage of capacity, DES also seems to be a good fit. It has, for example, been used to calculate patient throughput by Cubukcuoglu et al. (2020), to calculate the amount of elective patients treated (as well as several other factors) by Reiten et al. (2020), and to calculate the optimal average occupancy for the waiting times by Monks & Meskarian (2017). Thus, we believe discrete-event simulation will also be applicable to the variables in this study.

Bhattacharjee & Ray lay out a framework for modelling patient flows – which they define as "the movement of patients through the whole process of care" – specifically. In other words, the patient treatment process we described in Section 2.3 is also a patient flow. The four phases described are:

1. Preliminary understanding and data collection phase,
2. Data analysis phase,
3. Patient flow modelling phase,
4. Performance analysis phase (2014).

These phases are not specific to DES however, yet align greatly with a framework described by Robinson for performing simulation studies that will be used to set up the research design in Chapter 3, not only because it focuses specifically on DES but also simply because it is more extensive and detailed than the framework of Bhattacharjee & Ray. The four phases described by Robinson are:

1. Conceptual modelling phase,
2. Model coding phase,
3. Experimentation phase,
4. Implementation phase (2014).

Where the preliminary understanding phase of Bhattacharjee & Ray aligns with the conceptual modelling phase described by Robinson; the data collection phase, data analysis phase and patient flow modelling phase described by Bhattacharjee & Ray align with the model realisation phase described by Robinson; and performance analysis phase described by Bhattacharjee & Ray aligns with the experimentation and implementation phase described by Robinson.

2.5 Contribution to body of knowledge

Although the reports mentioning that the use of simulation in the healthcare field is not as widespread as in other sectors are relatively old (namely from 2007), this still seems to ring true today. A quick SCOPUS search for healthcare and simulation delivers around 9,000 results, while business and simulation gives around 68,000 results (Scopus, n.d.). Thus, performing this proposed research will add to the existing research and help modelling and simulation reach the same level of prevalence in the healthcare field as in other sectors.

3 Research design

In this chapter, a research design for the research questions described in Section 1.3 will be given. In the theoretical framework, we selected DES as our simulation method. Furthermore, we decided to use a framework described by Robinson for DES. This framework consists of 4 phases, which are conceptual modelling, model coding, experimentation, and implementation. The process is non-linear and iterative, meaning that during any phase you might need to make changes to something done in the previous phase (2014). The implementation phase is left out since extensive implementation and solution testing does not have to be performed for this project. The phases are briefly described at the relevant research questions.

As mentioned before, a preliminary conceptual model (Appendix A) was made to estimate what data would be required and to get some insights into what data was available. The problem-solving approach (see Section 1.2) and the research questions followed from gaps in knowledge recognised in the preliminary model. Once all research questions are discussed, limitations of the research design are discussed in Section 3.7, and a validity and reliability assessment are given in Section 3.8.

3.1 What is the conceptual model of the patient treatment process of the speciality of the UMC Utrecht in the current situation?

The first research question is concerned with the first phase of the simulation process as described by Robinson. For this, contextual data will need to be gathered, which is any data that is needed to get a thorough understanding of the problem simulation. This data is not needed for detailed analysis, and as the data gathering is likely going to be unstructured, this question is not expanded on extensively. From this data, a conceptual model will be built, which is defined by Robinson as: “a non-software specific description of the computer simulation model (that will be, is or has been developed), describing the *objectives*, *inputs*, *outputs*, *contents*, *assumptions* and *simplifications* of the model.” (2014).

The content of the model can be aligned along two dimensions, which are the *scope* of the model and the *level of detail*. The scope sets what parts of the system should be included and what parts can be excluded in the model. The level of detail then sets how detailed each component of the model should be or how to model them. In the content of the model, you will want to make various assumptions and simplifications either because no data is available or to speed up the modelling process (Robinson, 2014).

This question is already partly answered with the preliminary conceptual model (Appendix A), which was done through unstructured interviews with the project supervisor at the UMC Utrecht, yet more data is required. To fully answer the question the content of the simulation should be fully defined. This means that all decisions regarding scope of the model and level of detail of the model need to have been made. Some examples are given in Section 1.2, yet it is likely that throughout the process more decisions will need to be made. These decisions should be explained and justified.

Once this is done, a list of components of the model that will be included and excluded should be made, as well as listing the assumptions and simplifications made. Then, a graphical model will be made using *Business Process Model and Notation (BPMN).* Once the conceptual model is finalised, it should be assessed by stakeholders of the process to ensure it is accurate enough to represent reality and to improve validity of the research. For example, medical specialist(s) should assess the model.

3.2 What is the input data?

After the conceptual model is made, the model coding phase can begin. For this, the conceptual model is converted into a software specific model that considers the speed of coding, understandability, flexibility of the code, and the speed at which the code can be executed. Then, all input data for the current situation will need to be gathered. This is any data that is required to convert the conceptual model to a software specific model (Robinson, 2014). Some examples would be detailed data on activity times or patient arrival patterns.

From the preliminary conceptual model (Appendix A), some data requirements were identified. However, it is possible that during the conceptual modelling phase new data requirements can be found or changes to the current sub-questions will need to be made. Since gathering new data at the hospital is difficult because of COVID, these sub-questions might also be adapted based on what data is already available or can be adapted from available data. The current expected sub-questions will now be discussed briefly:

1. What are the different treatment paths per DBC and the probabilities a patient will follow a specific path?

This question is heavily dependent on decisions that are yet to be made for the conceptual model. What level of details to use for the patients and their flow through the system is not yet decided. Thus, the variables cannot be defined fully yet. However, the data is likely available or can be made by the Business Intelligence (BI) division of the UMC Utrecht.

2. What are the distributions of the different treatment times per path?

Again, this question depends on the method used to model the treatments and treatment times. This data should also be available. The expected values of the treatment times can be found easily, variability of the treatment times will need to be calculated either in this study or by BI. Once the data is calculated, an appropriate probability distribution will need to be selected.

3. What is the capacity of the speciality in terms of treatment beds in the clinical ward and outpatient clinic, OR time and staffing throughout the year?

Since capacity is assigned to the speciality based on their PAs for the year, it is possible that this sub-question will be changed and/or something like the following sub-question will be added: "What are the PAs for the speciality and how are they calculated?" This means that some of the capacity could be calculated in the model and thus should be in the conceptual model. In either case, the data should be easily available, and exactly what data is required depends on the conceptual model.

4. What is the distribution of patient demand per DBC?

For this sub-question, the only thing that might change is how the patients are grouped together. For example, if it is decided that patients are grouped by diagnosis group, this question will change to: "What is the distribution of patient demand per diagnosis group?" This data is readily available.

5. How often is a patient unable to be discharged and what is the resulting extension in stay at the clinical ward?

This sub-question might get removed entirely if it is decided that the discharge process is not important enough to remain in the model. If it is kept in, data is required to model this process. This data should be available.

To summarise, exactly what input data will be required is not clear yet. However, most of the data is easily available, or can be made by the BI division of the UMC. This means that little to no data gathering through something like observation will be required for model. The data used for model realisation is unlikely to contain any personal information of patients, nevertheless, extra attention should be given to handling the data and ensuring no personal information can be deducted from it.

It should be noted that the actual model coding phase should happen throughout the input data gathering. This is done to speed up the process of model coding. For more information on this topic, see Section 1.2.3.

3.3 What are the model validation data?

Here, as much data as possible for model validation should be gathered so that the results of the model can be compared to the real-world system. This means data of the outputs of the model need to be gathered. These are: average access times of the speciality, production volume and average usage of capacity of the OR, outpatient clinic and clinical ward. For this, historical data will be used.

Further validation of the coded model is required as well, and testing of the model should be performed continuously throughout the modelling process. The model needs to be verified and validated with the real system to provide proof that the results of the model are accurate and in line with the real system. Verification means ensuring that the model design or conceptual model is coded into a computer model accurately. Validation then is ensuring that the model is accurate enough to fulfil its objective. There are a couple of different forms of validation which are as follows:

- *Conceptual model validation:* ensuring that the content, assumptions, and simplifications of the model are accurate enough for the objective of the model,
- *Data validation:* determining that the data gathered for developing the model is accurate,
- *White-Box validation:* determining that the elements of the computer model represent their real-world elements accurately,
- *Black-Box validation:* determining that the overall model represents the real-world system accurately,
- *Experimentation validation:* determining that the experiments are providing results that are accurate enough for the objective,
- *Solution validation:* ensuring that the results are accurate for the objective at hand or comparing the proposed solution in the model to the implemented solution in the real-world.

Again, both verification and validation should be performed throughout the modelling process so that any errors are quickly identified and fixed (Robinson, 2014). Conceptual model validation is addressed at the respective research question on the conceptual model through assessment of the model by appropriate medical staff. Data validation should be performed throughout the input data gathering for research question 2. Black-box and white-box validation should be performed during the model coding phase. Finally, experimentation validation and solution validation are addressed in the following research question on the to be performed experiments.

3.4 What are the interventions that need to be made to the model for converting certain surgical treatments to day-treatments?

For this research question, the cycle of conceptual modelling and model coding has to be performed again. As described in Sections 1.1.2 and 1.2.2, the speciality wants to shift certain surgical treatments to a day-treatment, which should speed up treatment times and save time in the OR. First the process of the new day-treatments is analysed to make the conceptual model of this intervention. Then, the input data has to be estimated (since no real-world data is available). The intervention can then be coded into the model and analysations can be performed. 4 sub-questions have been set up to answer this research question.

1. What is the conceptual model of the new day-treatment process?

This question involves gathering all the preliminary data for the new day-treatments so that the conceptual model of the current real-world system can be adapted. Any new components should be added to the component list and appropriate assumptions and simplifications should be made and justified.

When the interventions that need to be made to the conceptual model are identified, the input data should be gathered so that the interventions can be coded. Like with the second research question concerned with gathering data for the model realisation of the current system (Section 3.2), it is possible that the data requirements are different than expected after conceptually modelling the new system, so the sub-questions are subject to change. The current sub-questions are as follows:

2. What treatments have the possibility to shift to a day-treatment and what are the new treatment paths?
3. What are the expected distributions of treatment times of the new day-treatments?
4. What are the capacity requirements for the new day-treatments?

They are relatively similar to those described in Section 3.2 and thus will not be elaborated on extensively.

All the sub-questions described in this section require new data to be gathered, since the day-treatments are not yet implemented in the real system and thus no data on them is available. This data will be gathered through a semi-structured interview with a medical specialist. The questions are as follows:

- What is the process of the proposed day-treatments?
- Which current surgical treatments do you want to shift to a day-treatment?
- How much do you expect the average treatment times will change when shifting to a day-treatment?
- How much do you expect the variance of the treatment times will change when shifting to a day-treatment?
- How much staff is required for the new day-treatments and are any specialists required?

This interview should hopefully gather all the required data at once and after it the research question can be answered. After the conceptual model has been made the model should be realised and coded. Since there is no real-world data available, model validation cannot be performed. However, the conceptual model should at least be assessed by a medical specialist once it is finished. Experimentation and analysis of the outputted data is performed in Section 3.6.

3.5 Removed research question

We want to address that we originally envisioned a research question concerned with estimating capacity for the day-treatment clinic where the day-treatments were going to be performed. The question was as follows: *What is the required capacity for the new day-treatment clinic and what are the effects of the new clinic on the conceptual and computer model?* However, when performing research question 4 (see Section 3.4 and Chapter 7), we realised that this was not necessary, as the capacity of this clinic was already set in the plan for the new day-treatments (see Section 1.1.2) and was simply going to be a single treatment room. Furthermore, how this day-treatment clinic would operate what interventions needed to be made to the original conceptual model had already become apparent during research question 4 as well. The original research design for this removed research question can be seen in Appendix B.

3.6 What are the effects of the new day-treatment process on access times, waiting list sizes, production volume and usage of treatment rooms for the speciality?

For the final research question, experimentation is performed for the newly implemented day-treatments. To do this, parameters to remove bias of the simulation need to be calculated. These are the warm-up period, run-length or number of replications to perform (Robinson, 2014).

Once these parameters are known, the simulation should be run using the parameters and the outputs of the different systems should be compared. Then, the research goal, which is as follows:

> "To analyse the effects of shifting certain surgical treatments to a day-treatment for on the access times, waiting list sizes, production volume and usage of capacity of the OR, clinical ward and outpatient clinic for the speciality of the UMC Utrecht by modelling and simulating the patient treatment process."

will have been achieved.

3.7 Limitations of research design

Possible limitations of the research design will now be discussed. The first limitation is the accuracy of the expected data of the new day-treatments. Since these data will have to be estimated, it is possible that the results are not accurate. To prevent this, the data should be assessed by a medical specialist.

The second limitation is the possibility that some of the planning procedures the DHS or the speciality uses cannot be analysed since they are automated by the ERP system or patient record system the hospital uses. If this is true, a simplification or assumption will have to be made that could be very detrimental to the accuracy of the simulation.

Finally, a possible limitation is that the data generated by the simulation is not trusted by superiors at the hospital. Simulation studies are generally seen as a "lesser" way of science (Robinson, 2014), and thus any data proving the new proposed treatments or the new clinic is effective might not be trusted. This can only be prevented by validating the simulation sufficiently enough, as described in Section 3.3 and 3.8.

3.8 Validity and reliability assessment

Improving or thinking about validity and reliability of the research should happen throughout the process. As described in Section 1.2.4, ideally, reporting on the model should be done in such a manner that it is easy to understand and generalisable to other specialities of the DHS, which would improve reliability of the research. Although when using a simulation, reliability is already rather high since the simulation can just be run again and should result in similar outputs.

The validity of the research, however, can never be completely proven, as the entire purpose of a model is to be an accurate enough simplification of reality. Thus, we can never prove the model is in complete accordance with reality, yet only prove it is sufficiently accurate with regards to the objective of the model. This will depend heavily on the assumptions and simplifications made to model the system. These assumptions and simplifications should always be explicitly noted and justified.

Furthermore, as mentioned in Section 3.1, the conceptual model should be assessed by a medical specialist, as well as other healthcare workers of the speciality to perform conceptual model validation. The other methods described in Section 3.8 should be performed as well throughout the modelling phase to validate the conceptual and computer model with the real-world system. Verification also needs to be performed when the conceptual model is coded by comparing the computer model to the conceptual model to check if model realisation was performed accurately.

We will now start answering each of the research questions.

4 Conceptual model

In this chapter, the first research question: *"What is the conceptual model of the patient treatment process of the speciality of the UMC Utrecht in the current situation?"* will be answered. First, we will give the objectives, inputs, and outputs of the model. Then the content of the model and the process will be described using the two dimensions of scope and level of detail needed for the model. Any assumptions and simplifications will be discussed and justified. A graphical model will then be given. Finally, we will discuss the process of validating the conceptual model. Data for this research question was gathered through unstructured interviews with van den Berg and other employees at the hospital, and the hospital database, also referred to as the care-cube.

Since the process of making the conceptual model – and moreover, the entire simulation process – is iterative, changes will sometimes have to be made to something that was performed in a previous 'stage' of the process. For example, if during model coding you find errors or shortcomings in the conceptual model, you will have to change the original conceptual model to the new findings (Robinson, 2014). We will present the final conceptual model in this chapter, and in following chapters, the final models and data are presented. If any noteworthy or major changes occurred, these are described in the relevant chapters and paragraphs.

4.1 Objectives, inputs, and outputs

The overall objective of the model aligns with the research goal, which is as follows:

> "To analyse the effects of shifting certain surgical treatments to a day-treatment for on the access times, waiting list sizes, production volume and usage of capacity of the OR, clinical ward and outpatient clinic for the speciality of the UMC Utrecht by modelling and simulating the patient treatment process."

Some general objectives of the model are that it should be flexible, or easy to change and adapt to allow the DHS to test new experiments or repeat for other specialities. It should also be as simple as possible and easy to understand or interact with the model.

The inputs and outputs of the model follow from the research goal as well. The outputs are:

- Access times,
- Waiting list sizes,
- Production volume,
- Usage of capacity of the OR, clinical ward, and outpatient clinic.

These have been defined previously in the theoretical framework in Chapter 2.

The input is the experiment we want to test, and thus is the new day-treatment process. Although the input is not necessarily a variable, as in, a number that we can change, it can still be considered an input as we compare it to the original situation.

4.2 Model content

Before setting up the research design of this study, we had already made a preliminary conceptual model to estimate the scope of the model, to help identify gaps in knowledge and to estimate what data was going to be required for realisation of the model. This model was based on interviews with the project supervisor at the UMC, and can be found in Appendix A. We identified 8 main activities:

1. First consultation
2. Diagnostics
3. Repeat consultation
4. Outpatient clinic treatment
5. OR treatment
6. Admission and stay in clinic
7. Triage (for emergency patients)
8. Discharge

We used this list of main activities to find a comprehensive list of components that are present in the real-world system. These components can be grouped in 4 categories, following the structure described in Robinson (2014) for a component list, although Robinson does describe what these categories mean necessarily. Nevertheless, the categories are as follows: entities, activities, queues, and resources. We will now list the components of the real-world system, give a brief description of the component, and place them within the 4 categories. The categories should become self-explanatory at that point. Note that not all the components of the real-world system are used in the final model. Any exclusions, as well as assumptions and simplifications, will be justified after the component list.

4.2.1 Entities

Patients

A patient at the UMC Utrecht is a person receiving medical treatments at the hospital to treat a diagnosis or health issue they are experiencing. A patient can have multiple diagnoses. A complete treatment of a diagnosis is referred to as a DBC. A DBC then can consist of multiple care products, which in turn consists of various treatments the patient receives.

Throughout the treatment process, a patient is linked to a single medical specialist who decides what treatments the patient will receive, when their treatment is finished, etc.

Patients enter the speciality either through an external referral from another healthcare provider (such as a general practitioner), through an internal referral (i.e., from another department of the UMC), or through the emergency department (ER). For referrals, the patient already has a diagnosis assigned to them, for ER patients, triage will first have to be performed. Note that an elective patient can turn into an ER patient and vice-versa

Specialists

Specialists are medical specialists or surgeons of the speciality. They perform treatments and surgeries on patients. They also educate doctors in training and perform research. They each have different abilities, or treatments/surgeries they can perform, as well as different schedules.

AIOS

These are doctors in training to becoming a specialist (abbreviated to AIOS in Dutch). They work under a single specialist, meaning they can perform treatments on patients belonging to one specialist. They have similar abilities and can learn more over time, yet work on different schedules.

Nurses, anaesthetic specialists/nurses, OR assistants, clinical specialists

These 4 are grouped together since they do not work for the speciality specifically yet can perform treatments or assist during surgeries or treatments for the speciality, as well as other departments.

4.2.2 Activities

Outpatient treatments

These are treatments or activities performed on patients in the outpatient clinic rooms of the speciality. Some of these treatments require the presence of a specialist (or an AIOS working under the specialist of the patient), some do not. Patients are not admitted to the hospital for outpatient treatments, meaning they can arrive shortly before the planned time of the treatment and can leave the hospital shortly after, without needing to rest or recover in the clinic.

Surgeries/OR treatment

For surgeries, patients arrive at the hospital, are admitted into the clinic, moved to a pre-surgery room to prepare them for surgery, after which the surgery is performed. After the surgery, they are moved to a recovery room to wake up from the anaesthetic. Patients are then moved back to the clinic to rest and recover further.

Surgeries are almost exclusively performed by specialists, although occasionally an AIOS can perform a relatively simple procedure. Specialists are supported by anaesthetic specialists, anaesthetic assistants and OR assistants during surgeries.

Unless a patient is an ER patient, they are always placed on the waiting list when a request is made for a surgery. Sometimes a patient will receive an urgency level for their surgery, meaning their surgery should be planned when their urgency “expires”. If for example a patient is placed on the waiting list today with an urgency of 6 months, their surgery should be planned around 6 months ahead. This date ahead will be referred to as the urgency date or earliest plan date.

ER patients, like normal patients, are admitted into the clinic once they leave the ER (if they need surgery, that is), and will receive surgery as soon as time is available in the OR. Time can be made available by rescheduling other, non-emergency surgeries if necessary.

Admission/stay in clinic

Before receiving surgery, a patient is always admitted into the clinic. Being admitted into the clinic means that a clinic bed is assigned to the patient, even when they are receiving surgery or other treatments. A bed can only be assigned to one patient, so although a bed might not physically be occupied by a patient, it can already be assigned to someone and no other patient will be able to use that bed.

After surgery, the patient will return to their assigned clinic bed and rest until they are able to leave the hospital. Occasionally, a patient will have to rest in the clinic before receiving a treatment as well, until they are healthy enough to receive it.

Clinical treatment

These are treatments performed in the clinic while a patient is admitted and resting in a clinic bed. They are performed either by nurses or clinical specialists.

Day-treatment

In the current real-world system, a day-treatment is not vastly different from a normal surgery, as they are performed in the OR, and a patient is typically admitted to the normal clinic. However, they only need to recover in the clinic bed for a few hours, and thus can arrive to the hospital, receive the surgery, and leave within the same day.

Like a normal surgery, day-treatments are performed by specialists and have the same supporting staff present.

First/repeat consultation

Throughout the treatment process of a patient, they will have consultations with their specialist, an AIOS working under their specialist, or with a nurse. Typically, these are meetings where the specialist/nurse can discuss results of diagnostics or treatments with the patient. These can be held in person, in which case they will be held in the outpatient clinic, over the phone, or through e-mail.

A first consultation is unsurprisingly the first consultation a patient has with their specialist, they cannot be performed by nurses. Repeat or control consultations can be performed by nurses or by specialists surrounding a surgery, where results or the course of the surgery is discussed. Some patients will have multiple repeat consultations surrounding a surgery, others will have only one or zero. Repeat consultations can also be utilised as a check-up with patients where, for example, new diagnostics can be performed.

Consultations surrounding a surgery can be planned a week ahead or a week after the surgery. For these consultations patients are not placed on a waiting list. Other types of consultations are typically held 3 months after a prior consultation, treatment, or surgery. Finally, patients with a chronic condition will typically return to the hospital on a yearly basis for a consultation. For the latter 2 types of consultations, patients are placed on a waiting list. When it is time for their consultation they are called, and an appointment is scheduled.

Diagnostics

Before or after a consultation, a patient will sometimes receive a diagnostic test. Only a few types of tests are performed by specialists or other staff of the speciality, as most diagnostics are performed by another speciality or division of the UMC.

Triage

When emergency patients enter the hospital, they will receive triage, meaning the ER department determines what is wrong with the patient. When triage is finished patients are referred to the speciality (if their ailment is determined to fit their speciality) and will either receive treatment or be admitted into the clinic to rest.

Education/research

Since the UMC Utrecht is an academic hospital, a portion of the specialists' time is spent on educating students, AIOSs, or on performing research.

4.2.3 Queues

OR waiting list

When a specialist makes a request for a surgery for a patient, the patient is placed on the waiting list for the OR (unless they are an emergency patient). The patient will sometimes receive an urgency for their surgery, which will affect the time they spend on the waiting list. A patient leaves the waiting list when an appointment is scheduled for their surgery.

Patients are picked on a semi first-in-first-out (FIFO) basis unless they have an urgency rating. However, planners will do their best to make an optimal schedule based on the expected treatment times of the patients, how many clinic beds are expected to be occupied that day, etc. To achieve this, planners will select patients that are not necessarily on top of the waiting list. A patient is usually expected to comply with their surgery date as rescheduling can be difficult.

Outpatient waiting list

Patients are only placed on the outpatient waiting list for repeat consultations that are to be scheduled 3 months after surgery or for yearly consultations. Like the OR waiting list, the outpatient waiting list operates mostly on a FIFO basis, yet some liberty is given to the planner to make an optimal schedule. Furthermore, as will be described later, the schedule for the outpatient clinic is not as flexible as the OR schedule which can result in patients leaving the waiting list earlier than someone who is ahead of them. Contrary to the OR waiting list and scheduling, patients have some decisive power in the scheduling of consultations and other outpatient treatments.

4.2.4 Resources

Production agreements

Although PAs are not a physical resource, most, if not all, other resources are allocated to the speciality based on the PAs. This means it is possible to derive capacity or the number of other resources available to the speciality from the PAs. For a more detailed description, see Section 1.1.1.

OR blueprint

The OR blueprint is a document that shows what specialities get to use what OR room(s) on what days over the course of a month. The blueprint is released 3 months ahead, meaning that surgeries can be planned up to two months in advance. OR days are from 8:00 to 16:00, and there is technically no limit to how many treatments can be planned within this time.

Outpatient clinic roster

The outpatient clinic roster is linked more to the individual specialists than the outpatient clinic. Specialists typically work in the outpatient clinic for one day a week and the roster determines how many consultations of what type they can perform in that day, down to blocks of individual appointments. An example of a roster can be 2 successive first consultations at 8:15, a telephone consultation at 8:45, a repeat consultation at 8:50, etc. Even the time for writing e-mail consultations is allocated in the roster. It is made on a week-by-week basis, meaning a new one gets released every week, and it is made 14 weeks in advance. Patients are scheduled, either from the waiting list or not, to fill this roster based on the type of appointment they are waiting for.

Note that both the OR blueprint and outpatient clinic roster are, like the PAs, not actually physical resources. However, they set the capacity that the speciality can use in the OR, and the capacity of the outpatient clinic for the speciality, respectively.

Clinic beds

The speciality shares the clinic with the entire DHS, and as such, if the speciality has too many patients admitted into the clinic, this can cause clashes with other specialities leaving patients without a clinic bed. However, there technically is no limit on how many beds patients of the speciality can occupy.

Materials

The speciality uses medical supplies and other materials throughout all activities. Things like medicine, catheters, anaesthetics, clinic gowns, or even food for patients can be included.

4.3 Model scope

From the above list of components in the real-world system, we can now define the model scope used in the model. If certain components can be left out for simplicity's sake, for example because they are not required for measuring the intended output of the model, those components should be excluded (Robinson, 2014). Table 4-1 shows which real-world components are included and excluded in the model and justifies their in- or exclusion. If this justification is based on an assumption or simplification, it is also clearly listed.

Table 4-1: Component inclusion/exclusion list.

Component	Include/Exclude	Justification
Entities:		
Patients	Include	Elective patients are included since we are modelling the patient treatment process. **Simplification:** emergency patients are excluded or modelled as elective patients. The only distinction ER patients have in the real-world system are the way they are admitted into the hospital, which is performed by another division of the hospital. Furthermore, the speciality has a relatively low amount of emergency patients, and their surgeries are performed in a different OR than the OR used for elective patients. Thus, the only effect on capacity ER patients have are the time specialists need to perform those surgeries. We deemed it acceptable to model these surgeries as normal surgeries.
Specialists	Include	Each specialist has unique abilities and cannot be aggregated into one resource.
AIOS	Include	Improves flexibility, similar properties to specialists, yet all AIOSs are presumed to have same abilities. However, AIOSs work under a single specialist and thus cannot be aggregated into one resource.
Nurses**,** anaesthetic specialists, anaesthetic assistants, OR assistants, clinical specialists	Exclude	These supporting staffs are not employed by the speciality specifically and thus they are not factored into capacity calculations for the outputs. **Assumption:** supporting staffs are always available for the hours allocated to the speciality in the PAs and the resulting OR blueprint and outpatient clinic roster and thus cannot cause delays.
Activities:		
First consultation	Include	Performed in the outpatient clinic and usage of capacity is one of the outputs.
Repeat consultation	Include	Performed in the outpatient clinic and usage of capacity is one of the outputs. **Simplification:** activities are like those for first consultations, and thus no real distinction is made in the model other than the planning method used.
Outpatient treatment	Include	Usage of capacity is one of the outputs.
Clinical treatment	Exclude	Clinical treatments are not performed by medical staff of other specialities. Furthermore, the clinic bed will remain occupied by the patient, how many treatments are performed on them during that time does not matter for capacity calculations of the clinic.

OR treatment	Include	Usage of capacity is one of the outputs.
Admission into clinic and clinical stay	Include	Usage of capacity is one of the outputs. **Simplification:** admission into the clinic and stay in clinic are seen as one activity since when a patient is being admitted a clinic bed is already reserved for them.
Day-treatment	Exclude	The process of day-treatments in the current system is almost identical to that of an OR treatment, thus, day-treatments are modelled as such with the only difference being a difference in resting period in the clinic.
Diagnostics	Exclude	Only diagnostic activities performed by the speciality are included, however, these are performed similarly to outpatient treatments (and performed in the same treatment rooms) and thus diagnostics are included there.
Triage	Exclude	Triage is not performed by the speciality and thus does not cost them any capacity.
Education/research	Exclude	**Assumption:** education and research have a lower priority than treating patients and are planned around treatments. Thus, they do not affect the process of treating patients and we exclude it from the model.
Queues:		
OR waiting list	Include	Access time is an output.
Outpatient waiting list	Include	Access time is an output.
Resources:		
Clinic beds	Include	Usage of capacity is one of the outputs.
OR blueprint	Include	Required for planning of the OR. Used to calculate capacity
Outpatient clinic roster	Include	Required for planning of the outpatient clinic. Used to calculate capacity.
Materials	Exclude	It is rare to impossible for materials to affect the processes in terms of delays etc. for the speciality (but for other specialities this might be the case).
Production agreements	Exclude	**Simplification:** PAs are used to calculate capacity, yet the OR blueprint, clinic beds and outpatient clinic roster already hold the calculated capacity.

4.4 Model level of detail

In this paragraph, the used level of detail in the model will be given for all of the included components based on a template given by Robinson (2014). Like in Table 4-1, per component, some details are simplified, or assumptions are made in the model. These simplifications and assumptions will be justified.

The level of detail per component gives us a basis for the second research question, as we describe the details here, and the second research question involves filling in these details with input data from the hospital. For example, in this paragraph we attribute treatment times to the activity of OR treatments as a concept, whereas in the second research question we research what these treatment times are in terms of hours. However, it is possible that the level of detail changes throughout the data gathering stages of research question two. Again, we present the final level of detail per component used in the model here, any major changes are listed in the following chapter if they occurred during data gathering.

Table 4-2: Component level of detail.

Component	Detail	Justification/description
Entities:		
Patients	Quantity: single patients simulated, no batching or limits on quantity.	Patients can have unique care trajectories and should not be grouped.
	Arrival pattern	According to incidence throughout the year. Patients enter during hospital operating hours.
	Attribute: diagnosis	Patients are assigned a diagnosis upon entering the hospital based on the incidence rate per diagnosis. This is used to assign a care trajectory to the patient. **Simplification:** a patient can only have one diagnosis in the model, as someone in the real-world hospital with 2 diagnoses would receive separate treatments for the 2 diagnoses.
	Routing: care trajectory	The care trajectory holds the treatments, consultations and relevant information like urgency or type of consultation a patient will receive during their entire treatment process at the hospital. **Assumption:** we assume routing in the form of walking or transport through the hospital does not cause delays.
	Attribute: chronic/non-chronic	We decided to add this attribute to ensure chronic patients will return for yearly consultations even after their care trajectory is finished.
	Attribute: specialist	Each patient will be assigned a specialist upon entering the hospital, based on treatments in their care trajectory and the number of patients each specialist can treat.
Specialists	Quantity: no grouping, single entities simulated	Each specialist has unique abilities and schedules and thus they cannot be grouped together.
	Arrival pattern: according to individual, empty schedules	The "empty" schedules hold what activities specialists can perform on a day-by-day basis. Days are further divided into morning and afternoon blocks. Specialists are either assigned to the outpatient clinic, on break, or assigned to be able to work in the OR in these blocks.
	Routing: schedule	The empty specialist schedules are filled with appointments during execution of the model. This filled schedule will determine what appointment the specialist will go to next. **Assumption:** we assume routing in the form of walking through the hospital does not cause delays.
	Attribute: specialities, i.e., treatments they can perform	The specialities are used for assigning patients to a specialist.
AIOS	Same details as specialists.	
Activities:		
First/repeat consultation	Quantity	The quantity of consultations will depend on the care trajectories of patients currently in the system. Limiting factors are the schedules of specialists and the outpatient clinic roster.

	Nature (X in Y out)	1 in 1 out or 2 in 2 out, depending on whether a specialist should be present for the consultation, as they can also be performed by nurses who are excluded.
	Cycle time	Consultation times will depend on the type of consultation performed. **Assumption:** we assume treatment time is normally distributed.
	Set-up/changeover	**Assumption:** because of the simplicity of consultations, we assume the changeover time is negligible or assumed to be included in the treatment time.
	Resources: outpatient clinic roster	The outpatient clinic roster holds how many hours are available for consultations.
	Shifts	Break periods are included in the outpatient clinic roster.
	Routing	Patients arrive for their consultation 30 minutes in advance and wait in the waiting room. When their consultation can start, the patient and their specialist are moved to the treatment room. Upon finishing of a consultation, patients are placed on the waiting list, a new appointment is scheduled, or they are discharged from the hospital based on their care trajectory. Specialists are moved to their next appointment based on their schedule. **Simplification:** since for calculating occupancy of the outpatient clinic and production volume it does not matter whether the patient is physically at the hospital (the specialist is the leading factor here), consultations over the telephone and e-mail consultations are modelled the same as normal, in-person consultations. Patients arrive at the hospital as normal and are moved to the treatment room, etc.
	Other: absenteeism/tardiness of patient	**Simplification:** we exclude no-shows and tardiness of patients in the model.
Outpatient treatment	Similar details as first/repeat consultations.	
OR treatment	Quantity	The quantity of surgeries depends on the care trajectories of patients currently in the system. Limiting factors are the schedules of specialists and the OR blueprint.
	Nature (X in Y out)	2 in 2 out (one specialist and one patient).
	Cycle time	Treatment time distribution based on treatment performed. **Assumption:** we assume treatment time is normally distributed.
	Set-up/changeover	**Simplification:** change-over time is set to a static 20 minutes in the model, which is the same time planners use in between appointments for the speciality.
	Resources: OR blueprint	The OR blueprint holds how many hours are available for OR treatments.
	Shifts	Break periods are not applicable to surgeries.
	Routing	Patients can only be moved into the OR if they are admitted into the clinic. When treatment is able to start, they, and their specialist, are moved to the OR. Upon finishing of a treatment, patients are moved back to their assigned clinic bed. Specialists are moved to their next appointment based on their schedule.

	Other: absenteeism/tardiness of patient	**Simplification:** we assume patients are never late for surgery, furthermore, they arrive for admission into the clinic 2 hours in advance, so this is a rare occurrence anyways.
Admission into clinic and clinical stay	Quantity	Patients are admitted into the clinic before a surgery; thus, the quantity of admissions will depend on the number of surgeries performed.
	Nature (X in Y out)	1 in 1 out
	Cycle time	The cycle time for resting in a clinic bed depends on the surgery performed, and whether the surgery was performed as a day treatment. If so, the rest will be shorter than if it was a normal surgery. **Simplification:** the time it takes to admit a patient into a bed is ignored, as the bed is already assigned to the patient at that point. **Assumption:** we assume clinic admission time is normally distributed.
	Set-up/changeover	**Assumption:** there is no changeover time for admission. As soon as a patient is discharged, another patient will begin admission, and the bed can be assigned to the new patient.
	Resources: clinical beds	Self-explanatory that clinical beds are used.
	Shifts	Breaks are not applicable to clinic stay and admission.
	Routing	A patient arrives 2 hours ahead of their surgery, after which they are admitted. Once their surgery is able to start, they are moved to the OR. When surgery is finished the patient is moved back to their clinical bed where they rest. Once they are finished resting, based on their care trajectory, they are placed on the waiting list or an appointment is made for their next treatment, or they are discharged from the hospital entirely.
Resources:		
Clinic beds	Quantity	**Assumption:** since the clinic is shared with the rest of the hospital, we assume an infinite amount of clinic beds are available to the speciality, as we omit the other patients in the clinic from our model scope. However, OR-planners keep in mind that typically, the number of patients of the speciality admitted into the clinic should not exceed 5.
	Where required	For admission into the clinic and clinical stays.
	Shifts	Not applicable
Outpatient clinic roster	Quantity	How many treatment rooms are available and for what times will be answered in Section 5.11. **Simplification:** in the real-world system, the roster holds detailed information on what type of consultations can be performed per specialist on the days they work in the outpatient clinic. We ignore the specific types of consultations and use only the times they are available from the roster.
	Where required	Outpatient clinic treatments and consultations.
	Shifts	Will be answered in Section 5.11.
	Other	Planning in the hospital is done to a precision of 5 minutes, thus, to generate empty schedules for the outpatient clinic, we divide the days into slots of 5 minutes.

OR blueprint	Quantity	How many treatment rooms are available and for what times will be answered in Section 5.10.
	Where required	OR treatments.
	Shifts	Will be answered in Section 5.10.
Queues:		
OR waiting list	Quantity	Only one waiting list is used for the OR. Patients with or without an urgency attached to their surgery are both placed on the same waiting list.
	Capacity	Infinite.
	Dwell time	The time a patient spends on the waiting list depends on whether there is time available in the OR for their surgery. There is no minimum time patients have to spend on the waiting list unless they have an urgency level. If so, they must be on the waiting list until one month ahead of that urgency date.
	Queue discipline	Since the OR blueprint renews each month, patients are scheduled from the waiting list each month as well. This means scheduling is done for 2 months ahead. When scheduling, the model goes through the OR schedule starting on 8:00 on day one. If no patient has already been scheduled, the model first searches for patients with an urgency level that are within one month of that urgency date. If no such patient is found, the patient on top of the waiting list is selected. The model then checks whether their specialist is free for the expected treatment time for the treatment the patient is waiting on. If so, the patient is scheduled. This continues either until the waiting list is empty or the OR schedule is full. **Simplification:** no schedule optimisation is performed, meaning the model does not try to fit the most treatments in in one day, however, if it has reached an empty slot nearing the end of the day, it will continue searching through the waiting list for a patient with an expected treatment time short enough to fit them in. **Simplification:** because of the assumption made for clinic beds, the model does not consider how many clinic beds will be occupied that day when scheduling patients from the waiting list.
	Routing	Patients enter the waiting list when a previous appointment is finished and the following step in their care trajectory is a surgery. Patients leave as soon as an appointment is scheduled.
Outpatient waiting list	Mostly similar details to OR waiting list, except all patients on the outpatient waiting list have an urgency date and thus all have a minimum dwell time.	

4.5 Visual BPMN model

Although the component list above technically is already a valid representation of the conceptual model (Robinson, 2014), we still designed a visual BPMN model to aid the validation process of the conceptual model. This gave us a method to easily discuss the contents with staff of the hospital. It is also used as a basis for model coding. However, this visual model has not been adapted to the final computer model and thus will have some discrepancies with the component list and level of detail listed above. The model can be found in Appendix C.

The model is divided into 3 lanes, one for the patient, one for the specialist and one for the planning methods used for each activity. Furthermore, there are 5 columns for the main activities described in the component list above. Diagnostics is still included in this visual model, yet was excluded before starting model coding, reasoning for this will be given later in this section. A simplified structure of the model is as follows:

1. Patient enters the system and is assigned a diagnosis, specialist, and care trajectory,
2. A request for their first appointment is made based on the care trajectory of the patient,
3. Based on the type of appointment, the planner either plans the appointment or places the patient on the waiting list,
4. On the time of the appointment, the patient arrives at the hospital and the appointment is performed,
5. Upon finishing the appointment, a new appointment request is made, or the patient is discharged from the hospital,
6. Return to 3 or finished.

When comparing the new visual model to the preliminary conceptual model found in Appendix A, which was used to set up the research design, a major difference is the move from a linear model to a non-linear model. Initially, we envisioned the patient treatment process as linear, where patients always moved from their first consultation to diagnostics, then to a repeat consultation, then to a surgery, then to the clinic, and then to a repeat consultation. However, when studying hospital records, this linear succession of activities was not present for all patients. Some did not receive a surgery, some started with a repeat consultation (likely patients referred internally from another speciality of the hospital) or received multiple consultations before their first treatment. Thus, we decided to remove this linear structure and made it possible for all activities to follow each other.

The visual model presented here still includes diagnostics, which is excluded in the model scope from Table 4-1, and was excluded before starting model coding in research question 2. Most diagnostic activities are not performed by the speciality and thus do not cost them any capacity, yet we wanted to include them at first since patients and specialists will sometimes have to wait on results of a test before being able to move to the next activity. However, consultations can be held on a 3-month basis, and diagnostics are both performed during a consultation and their results are discussed during a consultation. Thus, we assume that this wait time for results and possible delays because of that are included in that 3-month period between consultations. Any diagnostics that *are* performed by the speciality are modelled as outpatient treatments.

4.5.1 Visual conceptual model validation

As the conceptual model changed over time during the model coding phase, we only discuss the validation of the visual model here, and the further validation of the final model will be described in the following chapter. The component list the visual model was based on at the time was developed with van den Berg, and the visual model itself has been heavily assessed by van den Berg as well. We agreed on the assumption that nurses and other supporting staff could be excluded since they would be incorporated in the capacity for the treatment rooms, and that clinic beds would have an infinite capacity because we would not be able to model other patients from other specialities in the clinic. However, usage of capacity of the clinic is one of the outputs of the model, so we do not exclude admissions into the clinic entirely.

We discussed various parts of the visual model of Section 4.5 with relevant staff of the hospital. The direct process of treating patients, found in the patients and specialist lanes, was, albeit briefly, discussed with a medical specialist. She did not have any major gripes with the model.

We also discussed the planning method used in the model with a planner for the OR to assess its accuracy. She mentioned that planning the surgeries was a task that requires experience, and a lot of the planning is not done based on a certain ruleset. Nevertheless, she found the planning method described in the model an accurate enough simplification of reality (see Queue Discipline for OR waiting list in Table 4-2).

5 Model realisation

In this chapter we will answer research question 2: *What is the input data?* Input data is any data required to convert the conceptual model from Chapter 4 into a computer model or software specific model (Robinson, 2014). This chapter will also concern the process of coding the model itself. In Section 5.1 we describe our software selection and give some general information about the functions of the software. Then in Section 5.2 we will use the component list and their level of detail to identify gaps in knowledge. We will set up sub-questions required to fill these gaps. We will then answer each sub-question and describe how the data found was implemented in the computer model in the subsequent sections. As the required data and thus the sub-questions have changed over time, changes will be described during answering of the sub-questions. We will also compare the sub-questions used to the initial sub-questions envisioned in the research design. Finally, we will give an overview of the computer model and describe components not yet presented during answering of the sub-questions in Section 5.13. Data for answering the research questions was mostly gathered from the hospital database, also known as the *"care-cube"*. It contains current hospital records and historical data and is divided into several pivot tables in Excel. Furthermore, the project supervisor at the UMC, a business controller for the DHS, and other staff members provided support in gathering and validation of the data.

5.1 Software selection and functions

As per the problem-solving approach described in Section 1.2, we selected Tecnomatix Plant Simulation as our simulation software, which is a discrete-event simulation software package. From the theoretical framework we already decided that discrete-event simulation was the best fit for this study. Furthermore, Plant Simulation is the only simulation software I am familiar with and have easy (and free) access to. The hospital did not use any simulation software packages themselves. From the preliminary and final conceptual model, the software seemed sufficient. It provides some easy to use components, like custom entities, processors, queues, etc., and allows you to write custom code for any custom logic and behaviour not covered by the built-in components (Siemens Industry Software, 2019).

We will now give some information about the functions of the software components used in the model, which are:

- **Mobile Units (MUs):** these are "parts" that are transported through the system to be processed and for work to be performed on them. You can assign custom attributes to MUs if need be, which can be of various data types.
- **Stations:** stations process parts or perform work on MUs. Single stations can hold and process a single MU, parallel stations can hold and process multiple MUs simultaneously.
- **Buffers:** these can hold parts temporarily before or after moving to a station.
- **Source/drain:** a source can generate MUs and a drain can delete MUs from the system.
- **Table:** like a spreadsheet, a table is a list with two or more columns. Tables can have indexes in rows and columns to easily find a specific cell. A cell can contain various data types like integers, real numbers, strings, or even other tables.
- **Method:** a method can hold custom code to perform required behaviour and logic. They can be started by an MU entering or leaving a station or buffer, by other methods, or on a specified time. Methods can move parts between stations or buffers, store, or reference data in a table and modify variables.
- **Global variable:** a global variable is a variable that other objects can access during simulation.
- **Generator:** a generator can start execution of a method periodically on a specified time.
- **Shift manager:** can specify working shift times.

We also want to give some attention to random number generation in the software. For components like sources, drains, and stations, the software can use a random distribution for arrival patterns or use a random distribution for processing times and generate random numbers based on those distributions. Furthermore, if necessary, the software can generate random numbers according to a specified distribution in a method, where you must specify a "seed" value the software will use to generate the random number. The software uses a pseudo-random number generator, meaning it will generate the same random numbers every time you execute the simulation, unless you manually change the seed values. This is done to help with fixing problems, as it allows you to replicate issues when they arise. Therefore, the software has an **Experiment Manager** that allows you to perform replications of the simulation. In doing so, the simulator will generate different random numbers for both random numbers in methods, but also random numbers generated in stations, sources and drains for each replication.

5.2 Data requirements and sub-questions

In Table 5-1, we will list the required data per component and detail for correctly modelling the component in the software. If no more data is required than is already given in the component list from Chapter 4, the detail or component is excluded.

Table 5-1: Data requirements per component and detail.

Component	**Detail**	**Required data**
Entities:		
Patients	Arrival pattern	Arrival patterns of patients.
	Attribute: diagnosis	Incidence rate per diagnosis.
	Routing: care trajectory	Care trajectories per diagnosis.
	Attribute: chronic/non-chronic	Rate of chronic vs. non-chronic patients per diagnosis.
Specialists	Arrival pattern: according to individual, empty schedules	Schedules per specialist.
	Attribute: specialities, i.e., treatments they can perform	Treatments each specialist can perform.
AIOS	Same details as specialists.	N/A
Activities:		
First/repeat consultation	Cycle time	Consultation times per type of consultation
	Nature (X in Y out)	Consultation types.
Outpatient treatment	Cycle time	Treatment times per type of treatment.
OR treatment	Cycle time	Surgery times per type of surgery
Admission into clinic and clinical stay	Cycle time	Clinic admission time per type of surgery
Resources:		
Outpatient clinic roster	Quantity	The amount of outpatient treatment rooms.
	Shifts	Opening hours of outpatient treatment rooms.
OR blueprint	Quantity	The amount of OR shifts.
	Shifts	Operating hours of OR shifts.
Queues:		
OR waiting list	Dwell time	Urgencies per care trajectory.
Outpatient waiting list	Dwell time	Urgencies per type of treatment/consultation.

We will now set up sub-questions to gather the required data.

1. What is the arrival pattern for patients?

This sub-question will be used to identify the arrival rates for patients. A clear definition of a patient in the model is also given here, for now, keep in mind that a patient can only have one diagnosis. The distribution of patients over diagnoses is researched in the next sub-question.

2. What are the incidence rates per diagnosis?

Incidence rate can also be referred to as occurrence, demand, etc. Basically, this sub-question will research what distribution of diagnoses to use to assign the diagnosis attribute to patients upon them entering the system.

3. What are the care trajectories per diagnosis?

Based on the diagnosis of the patient, we need to know the routing they will take through the system. Thus, this question involves finding the treatments patients need to receive throughout the system based on their diagnosis. Urgencies for OR treatments are also included here.

4. How many patients per diagnosis are chronic patients?

As we discovered during data gathering that a significant portion of patients of the speciality are chronic patients that need to return for a consultation each year, we needed to know how often this occurs per diagnosis.

5. What are the treatment times per action and the required length of stay in the clinic after surgical treatments?

For the various activities a patient is routed through based on their care trajectory, we need to know the cycle time per treatment. As the length of stay in clinic is dependent on the OR treatment performed, we also research the clinic time based on the type of OR treatment here.

6. What are the consultation types and what are their properties?

The consultation type a patient receives will dictate the dwell time on the outpatient waiting list and whether a specialist needs to be present for the consultation, thus, we need to identify the different types and assess those properties per type.

7. What are the specialities of each of the specialists?

There are certain treatments only a single specialist can perform, this means that if a patient has one of these treatments in their care trajectory, they should be assigned to a specialist that can perform it. Therefore, we need to know the specialities of the specialists.

8. What is the OR blueprint and the resulting OR capacity for the speciality?
9. What is the outpatient clinic roster and the resulting outpatient clinic capacity for the speciality?
10. What are the specialists' schedules?

The last three sub-questions are concerned with researching capacity for the speciality. For the OR, this will depend on the blueprint. For the outpatient clinic, this will depend on the roster. Finally, we also assess the schedules of the specialists to find days off in the week. For all 3 questions, we also pay attention to reduction weeks, which are weeks like holiday weeks where the hospital does not operate at full capacity.

We will now start answering the sub-questions described in this section and describing the implementation into the simulation model.

5.3 What is the arrival pattern for patients?

This question aims to find an arrival pattern for patients, such that the simulation model can accurately calculate and represent the number of patients entering the hospital. We will first define what a patient is in the model, then how data was gathered for the arrival patterns. We will also pay attention to how results were implemented in the model. Finally, we discuss possible errors and shortcomings for data gathering and implementation. For data gathering we used the hospital database, and more importantly, the financial production database that contains data on production of the hospital.

In the initial research design, we combined the distribution of patients over DBCs and the arrival pattern into the sub-question: “What is the distribution of patient demand per DBC?” However, we separated the two factors as patients enter the system based on the arrival pattern and *then* get assigned a diagnosis, instead of having an arrival pattern for each of the diagnoses. Why we chose to group patients based on diagnoses instead of DBCs will be explained in the next sections.

Patients

Patients are defined as “a person receiving medical treatments at the hospital to treat a diagnosis”, as per the component list in Chapter 4. In the real-world system, it is possible for patients to be treated for 2 diagnoses at once. In the model however, patients can only have a single diagnosis. This decision was made as individual treatments performed on a patient are always ascribed to a single diagnosis in the real-world system. Thus, a patient in a treatment process for 2 different diagnoses simultaneously can be modelled as 2 separate patients, since in the real-world system they would also receive separate treatments for each diagnosis. Therefore, our arrival pattern for patients should really reflect the number of new diagnoses entering the system.

5.3.1 Data gathering

Initially, we simply measured the amount of new DBCs opened. To repeat, a DBC is a diagnosis-treatment combination, of which a patient can receive multiple to treat a diagnosis. Treatments the patient receives will fall in a DBC, one DBC can contain multiple treatments. However, a DBC can only stretch over a 3-month period. If a patient takes longer than 3 months in between treatments, a new DBC will have to be opened. A DBC is attached to a single diagnosis and specialism within the hospital. Once the DBC is finished the specialism can receive payment for the DBC.

To get some form of fluctuation in arrivals throughout a year in the model, we measured new DBCs per month, although this was later changed to DBCs per week of the year - as not all months are equally long and modelling on a week-by-week basis was easier. We filtered the DBCs based on the following criteria:

- Belonging to the speciality,
- Not belonging to a test patient,
- Not being a trial or empty DBC,
- Being a DBC that could be claimed for payment,
- Only containing treatments performed in the regular UMC Utrecht location.

We collected data from 2017 through 2019, since the operating conditions in 2020 are obviously not as normal and started implementing the results in the model. For the arrivals of patients, a source object is used in the model. This object can generate MUs, which are going to be our patients, based on a Poisson distribution of interarrival times. Thus, the number of DBCs per week had to be converted to interarrival times. This was done by simply dividing the amount of DBCs by hospital operating hours in a week. The model uses the interarrival times and changes them in the source object every week, based on what week of the year it is.

During execution of the model, the occupancy seemed rather high and the waiting list was growing too quickly. We discovered that using the amount of new DBCs per week as our input for arrivals was not accurate to the definition of a patient in the model. A patient with a single diagnosis can have multiple DBCs for that diagnosis, and thus we were creating too many patients in the model. We actually needed to know the number of new diagnoses entering the hospital per week, not new DBCs. Doing this required some extra steps, as a patient in the real hospital can have multiple diagnoses, meaning we could not simply measure the number of new patients entering the hospital. What we did instead is list all patients of the speciality and their diagnoses from 2016 to 2019, and then listed the weeks on which a new DBC started, using the same filters mentioned previously. This means that if a patient had two diagnoses in the hospital, they have two rows in the list. Starting from 2017, we count a DBC if no DBCs have been opened before then. We start from 2017 instead of 2016 because patients who have already entered the hospital in 2016 should not get counted in 2017. If 2016 was not included they would still get counted in 2017.

We now know for each patient and individual diagnosis in what week their first DBC was opened, and we can simply count the total amount of DBCs opened in each week of the year. We then use the average of the weeks of the three years. The resulting distribution is shown in Table 5-2. The new distribution was again converted to interarrival times and used for the source object in the model that generates patients. Using the new method of counting the first DBCs opened per diagnosis seemed to represent the arrival rate more accurately in the model, as the waiting list did not increase at alarmingly fast rates and occupancy was not unreasonably high. Furthermore, the data actually represents the number of arrivals in terms of individual diagnoses which is how patients are defined in the model, instead of the amount of DBCs.

Table 5-2: Arrival rates of patients per week. (n = 11,554, T = 2014 to 2020, source = care-cube).

Week	Patients
1	50
2	65
3	63
4	61
5	54
6	62
7	53
8	61
9	50
10	54
11	59
12	55
13	48
14	57
15	45
16	54
17	50
18	54
19	53
20	40
21	53
22	48
23	51
24	52
25	49
26	48
27	47
28	51
29	61
30	43
31	42
32	51
33	44
34	50
35	44
36	44
37	48
38	49
39	48
40	46
41	61
42	50
43	55
44	52
45	55
46	66
47	60
48	57
49	48
50	57
51	52
52	29

5.3.2 Validity assessment

We will now discuss possible issues with the data gathered and how it is used. A possible flaw in the method used is that on the occurrence that a patient has the same diagnosis twice and has finished two treatment processes, it is counted as a single patient here. The care trajectories used for routing patients will deal with this issue, as will be described later. In short, if a patient has the same diagnosis twice, this will also be reflected in the care trajectory as both occurrences are included in a single, longer care trajectory.

It is unknown whether the arrival pattern for patients in the real hospital is Poisson distributed as we cannot measure interarrival times, we simply assume it is.

The opening or starting of a DBC is not necessarily the first moment the patient contacts or enters the hospital, but it is opened upon the first treatment for a patient. In the model, the arrival pattern is used as the arrival pattern for the first contact moment. However, no data is stored on first contact or referral dates for patients and using the DBC starting date was the best alternative. How much this would affect results of the model is unclear, yet probably not significant. Most patients start with a first consultation, which typically is immediately planned around a week ahead of first contact. Thus, the real arrival week of all patients could be about a week earlier than the week we counted the DBC in, so this shift is likely to be equal for a majority of the DBCs and therefore will be ignored.

5.4 What are the incidence rates per diagnosis?

Upon entering the hospital, patients need to be assigned a diagnosis, thus we need to know what distribution of diagnoses to use to do so. We will discuss how the data was gathered and implemented and give some commentary on the validity of the data. For this, we again used the financial production database.

5.4.1 Data gathering

For the distribution of patients over diagnoses, we simply listed the diagnoses and the number of unique patients assigned to them. We filtered patients based on the following:

- Not being a test patient,
- Not having a trial or empty DBC,
- Having a DBC that could be claimed for payment,
- Having a DBC that started and ended within 2017 through 2019,
- Only had treatments performed in the regular UMC Utrecht location,
- Only had treatments performed by the speciality.

Then, by dividing the number of patients for each diagnosis by the total number of patients, we calculated the probability a new patient would receive each diagnosis. For implementation in the model, these probabilities are then turned into a cumulative probability function. Upon entering the system, a random number generator is used with a uniform distribution for a value between 0 and 1, then, a diagnosis is assigned if the random number falls within its cumulative probability.

A portion of the results can be seen in Table 5-3, and the full table can be found in Appendix D.

Table 5-3: Diagnosis incidence rates (partial) (n = 15,8033, T = 2017 to 2019, source = care-cube).

Diagnosis code	**Patients**	**Probability**	**Cumulative probability**
003	1	6.31592E-05	0.0000631592244047
009	405	0.025579486	0.0256426451083181
010	473	0.029874313	0.0555169582517527
011	553	0.034927051	0.0904440093475652
012	0	0	0.0904440093475652
012	91	0.05747489	0.0961914987683951
013	19	0.001200025	0.0973915240320849
…	…	…	…
M13	5	0.000315796	1.00
Total	**15,833**	**1.00**	

There are diagnoses like the lower "012" diagnosis that have 0 patients. These patients were either manually removed because during the setting up of care trajectories (which will be described in Section 5.5), no treatments or consultations were found for these patients, or because one diagnosis code has two diagnoses attached to it. For example, code "012" has a duplicate.

5.4.2 Validity assessment

Aside from the manual removal of some patients, the data gathered, and its implementation is assumed to be valid. The removal of patients was done for 49 out of a total 15,882 or less than 0.5% of patients, this is deemed as insignificant.

5.5 What are the care trajectories per diagnosis?

Once a patient has received a diagnosis, we need to know how to route them through the system. In other words, we need to know what treatments and consultations patients need to receive to treat the diagnosis so they can leave the system again. From here on out, we will refer to treatments, consultations, and clinical admissions as actions. All action types have a unique code in the database of the hospital. We will discuss how this data was gathered and changed over time as elements were added and assess the validity of the data and its implementation.

5.5.1 Data gathering

To gather the required data, we initially attempted to use a document that Planning & Control uses to estimate what type and number of actions, on average, are performed per care product. However, this document, called the norm profiles, was not sufficient. The norm profiles did not contain information on what order the actions are performed in, and furthermore, contained no information about clinical admissions. Which, if you remember from the component list, can be a normal or day admission following a surgery, which affects the time a patient needs to rest in the clinic.

Thus, we needed to create these care trajectories ourselves. To do so, we used the hospital database to create a long list of historical data on actions per diagnosis. Using the financial production database, we listed each patient and their diagnosis or diagnoses, and listed on what date they had what action performed. Patients were filtered based on:

- Not being a test patient,
- Having a DBC finished in 2017, 2018 or 2019,
- Having no trial or empty DBCs,
- Having a DBC that could be claimed for payment,
- Only had actions performed in the regular UMC Utrecht location,
- Only had actions performed by the speciality.

We then had all actions the speciality performed from 2017 through 2019 for finished DBCs in order of date, diagnosis, and patient. Patients still in treatment for a DBC are excluded by filtering on finished date of DBC instead of starting date. We then transformed the action data into a list that could be imported into the model using VBA. Figure 5-1 shows the result.

Patient	Diagnosis	Date	Action
A	98	01-01-2018	336174
A	98	01-01-2018	190090
A	98	01-02-2018	190013
B	48	01-01-2019	190060
B	48	01-04-2019	190013
B	41	01-06-2019	339849
B	41	01-06-2019	190013

98	
336174	1
190090	1
190013	2
48	
190060	1
190013	2
41	
339849	1
190013	1

Figure 5-1: Tables showing transformation process for care trajectories.

Next to the actions, we added a column to keep track of actions that were performed on the same day, referred to as the order number, for example to help with selecting a normal or day clinic admission. To import the resulting list the model checks for an empty row, searches for the diagnosis code below it, creates a new care trajectory for that diagnosis and copies the actions listed to the care trajectory. Once a patient is assigned a diagnosis in the model, they are randomly assigned a care trajectory from the list of trajectories for that diagnosis.

Eventually, we realised that using only the action codes was not sufficient for routing the patients, for example, for OR actions we need to know the waiting time on the waiting list (access time), or the urgency for the treatment, and for consultations we need to know the type of consultation performed. OR urgencies are not stored in the hospital care-cube, so to gather those per action and patient we requested a query into the OR database for surgeries performed by the speciality, along with their urgencies. Consultation codes are also not stored in the financial production database we were using, yet in the calendar database that stores data on outpatient clinic appointments.

We also that patients seemed to be leaving the hospital too quickly in the model. This was attributed to a lack of chronic patients in the model, of which the speciality had a significant amount. During the next sub-question, we will identify the rates of chronic patient per diagnosis. There, we also decided to expand the input data for the care trajectories by 3 years, as the average time chronic patients spent in the system was 4.6 years.

We combine the data from the three databases by using the VBA transformation described earlier. For each action from the original table, when it finds a surgical action it now also searches through the OR database for the same patient, same action, and same date. It then copies the urgency to the care trajectory if the patient and the correct action and date is found in the OR database. Then, for consultations or outpatient clinic actions, the VBA code searches through the calendar database to find the same patient and date - data on what action was performed is not included in the calendar database - and copies the consultation code attached to the care trajectory. Table 5-4 shows an example of a resulting care trajectory for diagnosis 023. In total, we have 14,373 care trajectories divided over 184 diagnoses, sampled from 12,022 patients from 2014 through 2019.

Table 5-4: Example care trajectory for diagnosis 023.

Action code	**Order**	**Urgency**	**Consultation code**
190060	1		
419040	1		N
980996T	2		TCV
980996T	3		TCV
980996T	4		TCV
190013	5		C
039860	6		
339868B	6		
190090	6		
336132	6	M3	
980996T	7		TCV
339489	8		C
190013	8		
190013	9		CNO
980996T	10		TCV

5.5.2 Request appointment

Once the patient is assigned a care trajectory, a request for their first appointment is made. Using a method object in the model, we search through the first order for the patient. We select the top action and check the type of action. If it is a consultation, we loop through the order to find a consultation code and schedule accordingly (for some consultation types the patient is placed on the waiting list, for others an appointment is immediately scheduled on the first available date and time). If it is a surgery, we search through the order to find the type of clinic admission attached to the surgery. For example, for the care trajectory above, the first row has the action code "190060", which is for a first consultation, yet has no consultation code attached. Thus, we loop through the order to find "N" as the consultation code, which is for a first consultation as well. The action "419040" is ignored in this case. Upon finding a surgery, like in order 6 of the patient above, we first search through the order for the type of clinic admission, in this case, "190090" means they had a day clinic admission for that surgery. Then, we select the urgency from the order and place the patient on the waiting list. Again, only the first action from the order is selected here.

5.5.3 Validity assessment

The data gathered here has some validity issues. The first one being that a patient having a DBC finish in 2019 does not mean they are also completely finished with their care trajectory, yet we do take the trajectory from the patient as if it is a complete trajectory. It is possible the patient is still in treatment and needs more actions after their DBC that ended in 2019. However, the database does not have filters for patients finished with their treatment, and thus this cut-off moment and the resulting issue that patients in reality might still be in treatment after the cut-off was always going to exist. We introduce a probability for a patient becoming chronic in Section 5.6, which takes care of some of the error resulting from the cut-off since patients with a care trajectory that is actually too short then have a probability of having to return each year for a consultation.

Furthermore, not all consultations and surgeries from the original care trajectories can be linked to consultation codes from the calendar database or urgencies from the OR database, since some data is simply missing from the databases. For the OR urgencies, this is not a major issue as not all surgeries require an urgency. However, for the consultations, we do require a consultation type to correctly schedule an appointment or place a patient on the waiting list. Therefore, we set a default consultation type if no consultation code is attached to a consultation based on the action code in the sub-question concerned with consultation types.

Finally, although this is more of an issue connected to how we model individual treatments, some actions from the care trajectory are ignored. For example, as described in the example care trajectory earlier, the action "419040" is ignored from their first consultation order. For consultations, we assume that only one code can be leading. For example, we assume that the "419040" action is actually included in the "190060" action. For some cases this will be in accordance with the real-world system, for example when a patient receives their first consultation with a specific specialist, the code "190060" is always recorded, the "419040" then means the consultation was for a second opinion from a specialist, and we assume the consultation time remains the same. In the sixth order of the care trajectory given earlier, some surgery codes are ignored, as we take the first code from the order: "039860" and ignore "339868B" and "336132". We will explain in Section 5.7 how this is dealt with, but in short, the data on surgery times will include these orders where multiple treatments were performed in a single surgery.

5.6 How many patients per diagnosis are chronic patients?

As briefly mentioned earlier, eventually during validation of the model we realised that we had not included chronic patients and patients seemed to be leaving the hospital too quickly and the occupancy of the outpatient clinic was too low. As our care trajectories from Section 5.5 at that point only extended over a period of 3 years, we decided first to add a probability that would make patients chronic patients that would have to return yearly for a consultation. This insight came late during the modelling process and thus was not included in the project plan. In this section, we will describe how we gathered the rates of chronic patients per diagnosis, discuss its implementation into the model and assess the validity of the data and the implementation.

5.6.1 Data gathering

For this sub-question, we counted the number of patients per diagnosis that returned for a consultation performed by the speciality in more than 3 years from 2014 to 2020. These do not have to be in consecutive years. This definition for chronic patients was given by the business controllers and applied to 843 out of 23,323 patients found in 47 diagnoses. A part of the results is shown in Table 5-5, and the full results are given in Appendix E.

Table 5-5: Chronic patients per diagnosis (n = 23,323, T = 2014 to 2020, source = care-cube).

Diagnosis code	**Total patients**	**Chronic patients**	**Probability**
003	1	0	0
009	3	0	0
010	541	15	0.027726433
011	850	78	0.091764706
012	131	5	0.038167939
013	23	0	0
014	169	7	0.041420118
...	…	…	…
121	96	1	0.010416667
Total	**23,323**	**843**	

Upon being assigned a care trajectory in the model, we again get a random number between 0 and 1 from a uniform random number generator, if this is smaller than the probability of being a chronic patient, we assign the patient as chronic. If their care trajectory ends, we place the patient on the outpatient waiting list for a consultation with an urgency of a year, they then return after a year for the consultation. This repeats indefinitely.

5.6.2 Validity assessment

The data gathered itself here is assumed to be correct, whether the implementation is valid is up for discussion. For the speciality, we know that a lot of patients must return periodically each year, technically indefinitely, however, there is always a possibility they do stop treatments or coming back. This is ignored in the model. Furthermore, some of these patients return for a yearly consultation and must go back into a full treatment process which is also not possible in the model, they simply only keep coming back for the consultations. For this reason, we chose to extend the care trajectories from 3 to 6 years.

5.7 What are the treatment times per action and the required length of stay in the clinic after surgical treatments?

When routing a patient through the system based on their care trajectory, we need to know the cycle time of the actions they are about to receive. Furthermore, for surgeries, we also need to know the recovery time in the clinical ward. In this section we will discuss how this data was gathered and implemented. And, as always, we will discuss the validity of the data and implementation.

In the project plan, we expected to get the treatment times based on the care trajectory, however, we disconnected the treatment times from diagnoses as we assume the duration of a treatment is not related to the diagnosis of the patient.

5.7.1 Data gathering

Like the care trajectories, the data we required is split over several tables which we had to cross-reference. We first compiled a list of all actions performed by the speciality from 2017 through 2019 from the financial production database. However, this time paid no attention to the patients' diagnoses or status of the DBCs. For outpatient clinic data we again used the calendar database, listing all appointments for the speciality, their patient numbers, dates, and their plan times. Actual treatment times are unfortunately not available for the outpatient clinic. For OR data we used the OR database from the care-cube, again listing all surgeries performed by the speciality, their patient numbers, action codes, dates, and actual treatment times. Finally, for clinic data we used the admission database, listing all admissions for patients in treatment with the speciality, their patient numbers, dates, and admission times.

Using VBA again, we go through the entire action list row by row, first searching through the OR table and comparing patient number, action code and date to check whether it is a surgical treatment. If the action is found there, we then search through the action table again for the type of admission – either day admission or normal admission – and then search the admission table for the same patient number and date for the admission time. If the action is not found in the OR table, we go through the outpatient clinic table and again compare patient number and date for the action and get the plan time if they are found in the table. If either a plan time or treatment time is found, we copy the relevant data to a new table. As the OR database only contains one action per surgery and the calendar table only contains one row per appointment, some rows in the action table are ignored, even though multiple actions can be performed within one surgery and one appointment.

Once all the data is compiled, we can then calculate average treatment times and standard deviation in treatment times for surgical actions and average admission times and standard deviation in admission times for both normal and day admissions. The results can be found in Appendix F.

If only one surgery of a certain type was performed, we obviously cannot calculate variability. If such a surgery is performed in the model, we simply set the treatment time as constant with the treatment time found. For surgeries that we *can* calculate variability for, we assume the treatment times and clinic admission times are normally distributed. Furthermore, we keep track of the minimum treatment time and clinic admission time per surgery and type of admission and set that as the lower bound in the model (as sometimes the model pulled a negative treatment time from the distribution, which is impossible). The upper bound is set at 2 standard deviations above the average treatment times and admission times.

For outpatient clinic actions, we did attempt to get some sort of variability in time by using the plan times to calculate variability as normal, or by creating a distribution of plan times as absolute values, however, neither methods end up getting used. We took the mode of the plan times per action as input for the treatment times in the model. Plan times are made down to a precision 5 minutes, to still introduce some variability in treatment times, we set standard deviation in treatment time at 2 minutes 30 seconds for all outpatient clinic actions. We assume that we can take the plan time and the 2-and-a-half-minute standard deviation as parameters for a normal distribution of treatment times for the outpatient clinic in the model.

Once we expanded the care trajectories from 2017 through 2019 to 2014 to 2019, we were missing some data on actions only performed in the period from 2014 to 2016, and not after. Thus, the process described above was repeated only for those missing actions using data from 2014 to 2016 as well.

The OR, clinic and outpatient clinic are all simulated using station components. The OR is modelled as a parallel station, where both the patient and specialist have to be at the station for it to start working and they leave simultaneously based on the treatment time distribution of the treatment performed. The outpatient clinic is also a parallel station that we modify based on whether a specialist has to be present for the treatment performed, if not, a specialist does not need to be at the station for it to start working on the patient. Clinic beds are modelled as single stations, as work is only performed on the patient.

5.7.2 Validity assessment

A big validity issue for this data is that some actions are ignored from the big action list we start with. Not all actions found in the financial production database can be found in the other tables for clinic, OR and outpatient clinic because data is sometimes missing. Furthermore, for surgeries and outpatient clinic appointments, multiple actions are performed in one appointment or surgery, and the treatment times or plan times we get from the OR and calendar tables contain all those actions in a single treatment. However, if you remember from the care trajectories, we also model only one action per treatment, as we assume that extra actions performed in those treatments are included with the treatment times we use.

Yet, because of this, we cannot prove statistically that the treatment times are normally distributed for surgeries. At least, that is what we will attribute it to. If we were able to get the treatment times for individual actions per surgery, they would probably be normally distributed. However, this data simply is not available. An alternative to using a normal distribution would be to take all the treatment times per surgeries and give them a uniform probability, however, some surgeries have very few data points and we want to use as much randomness as possible. Another option would be to link treatment times to the care trajectories, as initially envisioned in the research design. We chose to do otherwise as the decoupling of treatment times and care trajectories also introduces more randomness into the model.

The treatment times for the outpatient clinic also have some validity issues. We do not take actual treatment times, as they are not available, and create a distribution using the modus of planning times as a mean and a standard deviation of 2 minutes and 30 seconds. Nevertheless, actions performed at the outpatient clinic are extremely routine procedures and thus variability in treatment time is assumed to be low. Using such a distribution was also agreed upon with the project supervisor and business controller.

5.8 What are the consultation types and their properties?

For consultations, the data gathered in Section 5.7 is not sufficient, as we also need to identify whether a specialist should be present and whether a patient should be placed on the waiting list for their consultation and for how long, which is not contained within the action code. Data gathering for this sub-question was done rather quickly using the calendar database and was not complicated. Thus, we will not pay a lot of attention to how it was done or whether the data itself is valid.

The database contains 71 types of consultations. Some types explicitly mention in their definition that the consultation is with a nurse or without a specialist, so we can easily label those as a consultation without a specialist. Any consultations labelled as "control" consultations in the database are those for which a patient is placed on the waiting list. Unfortunately, there was no data available in the database on the urgency for those appointments, thus, we set the urgency at a constant 3 months for all consultations. In reality it can vary somewhat, but 3 months is the standard for a control consultation.

For patients in the model that have a care trajectory with consultations without a consultation code attached, we set a default setting based on the action code they are be routed to. For repeat consultations, we set this to a consultation that the patient is placed on the waiting list for. For first consultations they are planned immediately. Whether or not a specialist should be present is contained in the action code, as a consultation with a nurse has a different code than one with a specialist.

5.9 What are the specialities of the specialists?

When a patient enters the system, the model must assign a specialist to the patient. Some treatments can only be performed by a single specialist. We therefore need to identify these treatments, to ensure that patients are assigned to the correct specialist. Like in Section 5.8, data gathering was done rather quick and dirty as the results are not of great importance to the model. Thus, we will not pay too much attention to how it was done and whether it is valid. To get the data, we used a document that describes some of the work procedures of the speciality at the hospital. In that document a list of possible treatments is given per specialist. We simply looked through the treatments performed by the speciality in the database, found the action codes related to the possible treatments per specialist given in the document, and imported these action codes into the model.

5.10 What is the OR blueprint and the resulting OR capacity for the speciality?

For the performing and scheduling of OR treatments, we need to research the OR capacity allocated to the speciality such that we know how many treatments can be performed. We will briefly describe how the data was gathered and discuss its validity and implementation in this section.

To calculate the OR capacity for the speciality, we take an OR blueprint from the hospital - that shows what specialities can use which ORs per day over the course of a month - from June 2020 as a baseline. For the speciality, the allocation was as seen in Table 5-6.

Table 5-6:OR blueprint for the speciality of June 2020.

Day	**Week 1**	**Week 2**	**Week 3**	**Week 4**
Monday	x	OR1	OR1	OR1
Tuesday	x	x	x	x
Wednesday	OR1	OR1	OR1	OR1
Thursday	OR1	x	x	x
Friday	OR1	OR1	OR1	OR1
Saturday	x	x	x	x
Sunday	x	x	x	x

Observe that the speciality is allocated three OR shifts a week in a single OR. A shift in the OR starts at 8:00 in the morning and finishes at 16:00. In this time, the speciality can technically plan as many appointments as they want, although planners do take some factors into consideration to optimise the schedule like the amount of clinic beds expected to be occupied on the day. As described in the OR waiting list queue discipline in Table 4-2 however, we ignore schedule optimisation.

Although the OR blueprint in reality will fluctuate slightly throughout the year, the speciality being allocated 3 shifts a week is standard. Thus, we do not model any fluctuations in the OR blueprint and take the June 2020 blueprint as static.

We then also must consider reduction weeks and other factors that take away some of the capacity from the OR. Throughout the year, the hospital has 10 vacation weeks. In those weeks, the OR runs at 70% capacity, or about two thirds of capacity. Thus, we simplify this reduction into removing one shift out of three for 10 weeks of the year. Furthermore, 10% of the capacity from the blueprint cannot be used because of an occasional lack of supporting staff. Thus, if we have 3 * 52 = 156 shifts a week, and remove 10%, we are left with 140 shifts. Then, we remove the 10 shifts from vacation weeks and 130 shifts remain. We can then divide by 13 to get 10 shifts every 4 weeks. The two shifts lost were removed from a Monday and Friday, on which days the least number of specialists work the OR – see Section 5.12 – and so the resulting OR blueprint used in the model can be seen in Table 5-7.

Table 5-7: OR blueprint for the speciality used in model.

Day	**Week 1**	**Week 2**	**Week 3**	**Week 4**
Monday	x	x	OR1	OR1
Tuesday	x	x	x	x
Wednesday	OR1	OR1	OR1	OR1
Thursday	OR1	x	x	x
Friday	OR1	OR1	x	OR1
Saturday	x	x	x	x
Sunday	x	x	x	x

5.10.1 Validity assessment

The two possible validity issues for capacity are not using a varying OR blueprint and the removal of shifts for reduction weeks. Using a static OR blueprint was a simplification we made and believe is valid as 3 shifts a week is standard for the speciality anyways, as already mentioned. Furthermore, removing some shifts based on the reduction weeks might be overly simplistic, yet we believe it is a valid simplification to make.

5.11 What is the outpatient clinic roster and the resulting outpatient clinic capacity for the speciality?

Similarly to the OR, we must identify how many treatment rooms the speciality has in the outpatient clinic, what the shifts are, etc. In this section we will discuss how we gathered the data required to set the capacity for the outpatient clinic in the model and assess the validity.

Information on the capacity for the speciality in the outpatient clinic is contained in the outpatient clinic roster, which, if you remember from the component list in Section 4.2, contains detailed information on how many consultations of what type each specialist can perform in days they work in the outpatient clinic. An example of a portion of a roster is given in Table 5-8.

Table 5-8: Example of an outpatient clinic roster.

Time	**Consultation code**	**Amount**	**Duration**
8:15	N, NS, SO	1	15 minutes
8:30	C, CCMH, CNO	4	15 minutes
9:30	N, NS, SO	1	15 minutes
9:45	ECO, TC, TCH	6	5 minutes
…	…	…	…

Table 5-8 can be read as follows: on the day this roster is planned for a planner can plan one consultation of type N, NS or SO at 8:15, then 4 successive consultations of type C, CCMH or CNO at 8:30, etc. These rosters are renewed each week for each specialist and are known for 14 weeks ahead. As they are different per specialist and per week, and would be relatively complicated to implement and code into the model because of the specific codes *and* times, we simplify the outpatient clinic shifts per specialist into open shifts that can be filled with any consultation type at any time in the model.

We do use the start and end times of the shifts seen in the roster. Shifts are divided into morning and afternoon shifts, with the morning shift typically starting at 8:15 and ending at 11:45, and the afternoon shift typically starting at 13:00 and ending at 15:30. Both shifts also have a 15-minute break within them. In the model, we simply remove these 15-minute breaks from the end of the shifts.

To get an indication of the amount of treatment rooms available to the speciality, we used a document showing a map of the outpatient clinic from above that shows what rooms are allocated to what specialisms for each shift of the week, what specialists are assigned to the rooms, and if the rooms are set up for specific treatments that shift. In Table 5-9, “Sp” denotes any specialist assigned to the room - we show their ID used in the model - and “Tr” denotes any treatment assigned to the room.

Table 5-9: Outpatient clinic rooms for the speciality, assigned specialists and treatments.

Day - shift	**Room 1**	**Room 2**	**Room 3**	**Room 4**	**Room 5**	**Room 6**	**Room 7**	**Room 8**
Monday morning	Tr 339866			Sp 1	AIOS 1		X	X
Monday afternoon	Tr 339866			Sp 1	AIOS 1		X	X
Tuesday morning	Tr 339869	Tr 339160	Sp 3	Sp 1	Sp 2	AIOS 2	X	X
Tuesday afternoon	Tr 339869	Tr 339160	Sp 3	AIOS 3	Sp 2	AIOS 2		
Wednesday morning	X				X	X	X	X
Wednesday afternoon	X	Tr 339954		X	X	X	X	X
Thursday morning	Tr 339866			X	X	X	X	X
Thursday afternoon	Tr 339866	Sp 4			X	X	X	X
Friday morning	X	Tr 339160	Tr 339160	Tr 339489		X	X	X
Friday afternoon	X	Tr 336272		X	X	X	X	X

In the model, scheduling appointments for outpatient treatments is done similarly to the OR waiting list queue discipline given in Table 4-2, however, for each room, we look for patients that are either waiting on a consultation with the specialist assigned to the room or for patients waiting on the treatment assigned to the room. If no specific treatment or specialist is assigned to the room, the model looks for patients waiting on any other treatment or consultations that do not require the presence of a specialist, like consultations with a nurse.

5.11.1 Validity assessment

Of course, not using the specific consultation codes and appointment times from the outpatient clinic roster is a noteworthy simplification. However, when comparing the number of consultations performed in a week in the model with the amount performed in reality – which we will do in Chapter 6 – the means are the same with a 5% level of confidence.

The amount of treatment rooms and their assigned treatments and specialists given in Table 5-9 are not actually of great importance, as consultations with specialists are by far the most performed action in the outpatient clinic in the model. It surely matters on what days the specialists can hold these consultations, but the specific room in which they are performed does not really matter so we will not discuss the validity of the data given in the table.

5.12 What are the specialists' schedules?

In this section, we will briefly discuss how many specialists and AIOSs work for the speciality and their schedules. The speciality, in 2020, employs 4 specialists. They all can receive patients for consultations and perform treatments in the OR. Furthermore, 3 specialists supervise AIOSs who can perform consultations for patients of the specialists if the specialist is also working in the outpatient clinic. We asked a specialist to give us an example of each of the specialists' schedules. Combining that with the information gathered in Table 5-9 we get the schedules for the specialists seen in Table 5-10.

Table 5-10: Weekly schedule per specialist (OPC = outpatient clinic, Sp = specialist).

Day - shift	**Sp 1**	**Sp 2**	**Sp 3**	**Sp 4**	**AIOS 1 for Sp 1**	**AIOS 2 for Sp 2**	**AIOS 3 for Sp 3**
Monday morning	OPC	OR	Break	Break	OPC		
Monday afternoon	OPC	OR	Break	Break	OPC		
Tuesday morning	OPC	OPC	OPC	Other		OPC	
Tuesday afternoon	Break	OPC	OPC	Other		OPC	OPC
Wednesday morning	OR	OR	Break	OR			
Wednesday afternoon	OR	OR	Break	OR			
Thursday morning	OR	OR	OR	OR			
Thursday afternoon	OR	OR	OR	OPC			
Friday morning	OR	OR	OR	Other			
Friday afternoon	OR	OR	OR	Other			

In the model, we reference this schedule when we want to schedule a patient in a treatment room to ensure the specialist is not on break and able to work in the OR outpatient clinic. AIOSs can only work in the outpatient clinic, and when the model is scheduling for an AIOS it searches for patients assigned to the specialist the AIOS works under.

We also want to model holiday or other reduction weeks for the specialists, as those can cause a reduction in capacity for the outpatient clinic or consultation time. We set this at an average of 7 weeks a year, based the average of 45 work weeks a year in The Netherlands (Gemiddelden, n.d.). Consequently, every week a specialist's schedule is renewed, there is a ±13% probability of the new week being a holiday week.

5.13 Overview of computer model

To conclude this chapter, we will give an overview of the computer model, describe its components, and show where the data gathered in this research question is used in the computer model. For an explanation of the types of components and their functions used in the computer model, refer to Section 5.1. Finally, we will map the components from the component list of the conceptual model to the components in the computer model.

Figure 5-2 shows the overview of the Discrete Event Simulation (DES) model in Tecnomatix Plant Simulation. We will discuss each of the coloured blocks in the model in detail, except for the bottom right teal block, as that contains the components for the new day treatments that will be discussed in Chapter 7. Components in the grey area are concerned with storing statistics, importing data, storing input data, renewing schedules each week or month, etc. In other words, they contain mostly components, variables and tables that support the main activities in the model. Not all of these components will be described in detail, however, in Section 5.13.2 we will briefly describe how statistics are stored in the model.

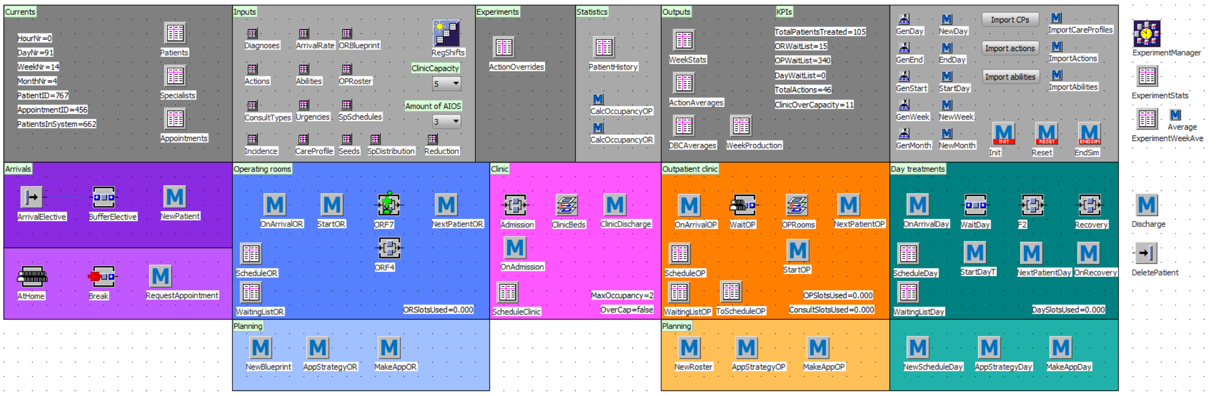

Figure 5-2: Overview of discrete event simulation model of the speciality.

5.13.1 MUs

In the computer model, we use 2 types of MUs. One for patients, and one for specialists. The specialists MU is also used for AIOSs. The icons for the MUs can be seen in Figure 5-3. If either MU is being processed in a station, the icons in the right column are shown, if they are not being processed, the icons in the left column are shown.

	Not processing	**Processing**
Patient		
Specialist		

Figure 5-3: MU icons.

Although we could have assigned attributes to the MUs, we found it more convenient to store data and attributes of the MUs, like the diagnosis for patients or the schedules of specialists, in two table objects. These are the "Specialists" table and "Patients" table.

5.13.2 Statistics

The model contains various tables that store various statistics. These tables and statistics should reflect the overall outputs of the model, which, to repeat from Section 4.1, are:

- Access times,
- Waiting list sizes,
- Production volume,
- Usage of capacity of the OR, clinical ward, and outpatient clinic.

The variables are defined in the theoretical framework in Chapter 2.

In the model, we have 5 tables that store various statistics. The first, "WeekStats", stores various statistics per week, like the total amount of treatments performed in a week or the number of patients on the waiting list for the OR that week. Secondly, we have the "ActionStats" table, that, for each action and consultation code, stores the number performed and average waiting time for the action. If the action is a surgery, it also stores the number of treatments performed as a day treatment and as a normal treatment. Thirdly, the "DBCStats" table stores the number of patients treated and number of actions performed, and average waiting time per action per diagnosis. Next, "WeekProduction" stores the number of individual actions and consultations performed each week. Finally, "PatientHistory" contains historical data on patient MUs. Once a patient leaves the system, their data from the "Patients" table is copied to the "PatientHistory" table.

5.13.3 Arrivals

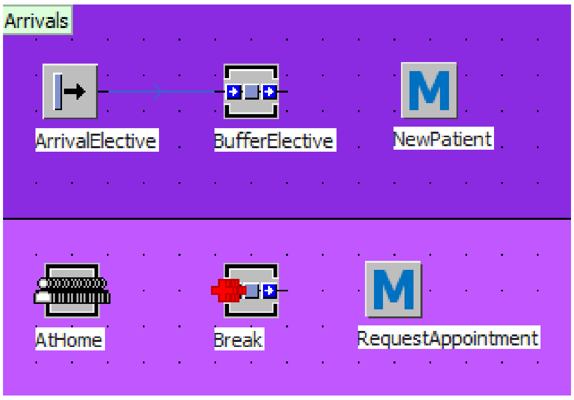

Figure 5-4: Arrivals in computer model.

In Figure 5-4 the Arrivals section of the model is shown. "ArrivalElective" is the source component that generates Patient MUs based on the arrival pattern given in Section 5.3. Patients are then moved to the "BufferElective" component in order to execute the "NewPatient" method, that assigns a diagnosis based on the incidence rates from Section 5.4, a care trajectory from the data generated in Section 5.5, decides whether the patient is chronic based on the data from Section 5.6, and assigns a specialist to the patient based on their abilities from Section 5.9 and the amount of time the specialist has for consultations each week as given in Section 5.11 and 5.12. This data is stored in the "Patients" table.

The "NewPatient" method then executes the "RequestAppointment" method, which requests appointments for patients as described in Section 5.5.2. The "RequestAppointment" method is also executed every time a patient finishes a treatment. The Patient is then moved to the "AtHome" buffer where they remain when they are on a waiting list or waiting on an appointment.

Finally, the "Break" component is a buffer where specialist MUs are moved to at the start of the working day (8:00) and wait in between performing treatments. If they are finished all their appointments for the day, specialists are moved back to "AtHome". Specialist MUs are not generated by a source object but by a method that is executed when starting the simulation.

5.13.4 Operating room

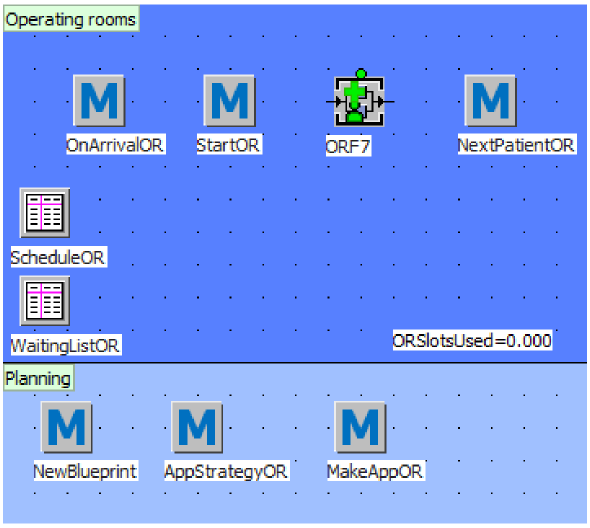

Figure 5-5: Operating rooms in computer model.

Figure 5-5 shows the OR in the computer model, that contains the components for performing surgical treatments. "ScheduleOR" contains the schedule for the OR, which is renewed each month by the "NewBlueprint" method, as the OR blueprint in the real-world system is also released each month (see Section 4.2.4). The method simply removes days of the schedule that have already passed and extends the schedule by 4 weeks. Thus, the schedule consists of 56 days, that are divided into "appointment slots" of 5 minutes long. The "AppStrategyOR" (where App is short for appointment) method is then executed, which loops over the days of the "ScheduleOR" table to find empty slots. Upon finding an empty slot, it searches through the "WaitingListOR" table for a patient with an urgency date within a month ahead who is waiting on a treatment that fits within the remaining time of the day. For example, if the first empty slot in the schedule found is at 14:00, "AppStrategyOR" searches for patients waiting on a treatment less than 2 hours long, as any longer would extend beyond the closing time of the OR. The method selects the first patient it finds.

Once “AppStrategyOR” finds an appropriate patient, it executes the “MakeAppOR” method that creates an appointment number for the patient and stores relevant data in an “Appointments” table, which is not pictured in Figure 5-5. The appointment number is then copied to the slots it is expected to fill in the “ScheduleOR” table, the schedule of the specialist of the patient contained in the “Specialists” table, and the schedule of the patient contained in the “Patients” table.

For example, if the appointment starts at 08:00, and the expected treatment time of the treatment the patient is waiting on is 1 hours and 32 minutes, all slots up until 09:35 are filled with the appointment number. We also add 4 slots for the 20 minutes change-over time to the expected treatment time. The expected treatment times per type of treatment were gathered in Section 5.7.

Then, the “MakeAppOR” method calls the “OnArrivalOR” method two hours before the appointment time. This means that if the “MakeAppOR” method is executed on Day 1 at 00:00 and the appointment it is scheduling is on Day 7 at 08:00, the model will execute the “OnArrivalOR” method on Day 7 at 06:00. The “OnArrivalOR” method then moves the patient to the “Admission” station of the clinic (which will be described in Section 5.13.5).

“StartOR” is the method that starts appointments for the OR and can be executed either when a patient has finished admission into the clinic or by “NextPatientOR”. “StartOR” gets the treatment the patient has an appointment for from the “Appointments” table and sets the processing time of the “ORF7” station using the treatment time distribution identified in Section 5.7. Then, the patient is moved into “ORF7”, and, if the next appointment of the patient’s specialist is the patient’s appointment, “StartOR” will also move the specialist into the OR.

“ORF7” is a parallel station that will only start processing MUs when a specialist and a patient MU are in the station. Upon finishing a treatment, “NextPatientOR” is executed, which moves the patient to their clinic bed and sets the resting time in the clinic based on their treatment and the clinic admission time distribution found in Section 5.7. “NextPatientOR” also moves the specialist to their next appointment or to the “Break” buffer, and then executes “StartOR” for the next appointment in the “ScheduleOR” table. Finally, “NextPatientOR” calculates how many slots were used for the treatment using the actual treatment time to calculate the occupancy for the OR and stores it in the “ORSlotsUsed” variable and stores various other statistics.

5.13.5 Clinic

In Figure 5-6 the clinic section of the computer model is shown. Patients are moved to the “Admission” station by “OnArrivalOR” 2 hours before their appointment time. Upon entering the “Admission” station, the “OnAdmission” method is executed that assigns an empty clinic bed to the patient. The occupancy of beds is stored in the “ScheduleClinic” table. “OnAdmission” also checks whether the appointment of the patient who arrived can start, and if so, executes the “StartOR” method for the appointment.

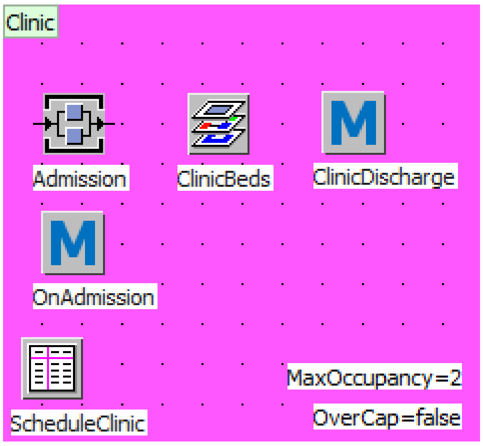

Figure 5-6: Clinic in computer model.

If the amount of clinic beds occupied exceeds the maximum number of beds planners allow the speciality to occupy (see Quantity property of Clinic beds in Table 4-2) the “OverCap” variable is set to true. The model checks whether the clinic has been over capacity each day and counts the days in the “WeekStats” table. Furthermore, we store the maximum bed occupancy each day and calculate the average maximum occupancy each week in the “WeekStats” table.

The “ClinicBeds” component in Figure 5-6 contains all the clinic bed stations shown in Figure 5-7. Once an OR treatment is finished, “NextPatientOR” sets the processing time of the clinic bed station the patient is assigned to based on the clinic admission time distribution of the treatment as identified in Section 5.7. If the treatment is performed as a day treatment, “NextPatientOR” will use the clinic admission time distribution for day treatment clinic admissions. The patient MU is then moved to the clinic bed station and the station will begin processing.

Figure 5-7: Clinic beds in computer model

When a patient is finished with resting in the clinic, the “ClinicDischarge” method is executed, which stores statistics on the clinic admission in the patients’ care history in the “Patients” table. It then executes the “RequestAppointment” method and moves the patient back home.

5.13.6 Outpatient clinic

Figure 5-8 shows the outpatient clinic in the computer model. It operates quite similarly to the OR. “ScheduleOP” contains schedules for all 8 treatment rooms which “NewRoster” renews weekly and extends up to 14 weeks ahead (see Section 4.2.4). Again, the days of the schedule are divided into 5-minute “appointment slots”. Then, the “AppStrategyOP” is executed. As the “WaitingListOP”, simply the waiting list for the outpatient clinic, can grow relatively long with patients with an urgency date too far ahead, the “AppStrategyOP” first copies patients that are within a week of their urgency date to the “ToScheduleOP” table. Then, like the OR appointment strategy, it loops over the days to find empty slots. Contrary to the OR, however, the outpatient clinic has multiple rooms with some restrictions as seen in Section 5.11. Thus, the “AppStrategyOP” loops over each of the rooms and searches for patients in “ToScheduleOP” waiting either on the action or for the specialist assigned to the room on that day. If such a patient is found, the “MakeAppOP” method is executed, which works exactly the same as the “MakeAppOR” method, except patients arrive half an hour before their appointment and the “MakeAppOP” method calls the “OnArrivalOP” method to do so.

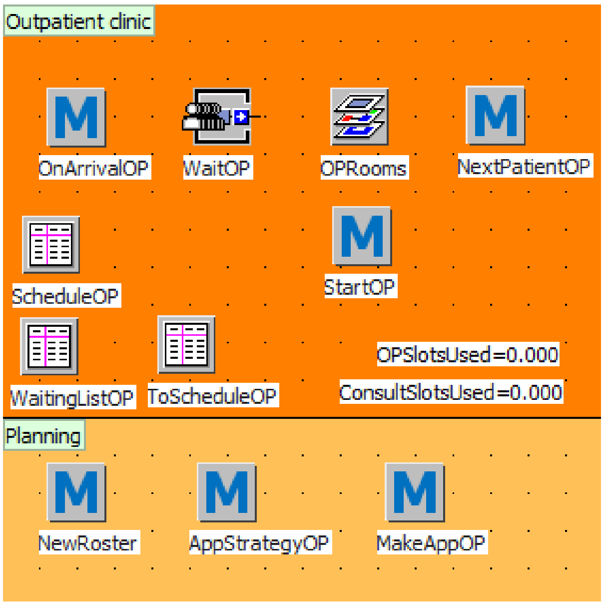

Figure 5-8: Outpatient clinic in computer model.

"OnArrivalOP" then moves the patient to the waiting room and, if possible, starts their appointment by executing "StartOP". "StartOP" moves patients to their treatment room, and, if the specialist is free, moves the specialist to the treatment room as well. The treatment rooms contained in "OPRooms" in Figure 5-8 are shown in Figure 5-9. Like the OR, the treatment rooms are parallel stations, and based on the action will start processing with either one or two MUs present. "StartOP" sets the treatment time and changes whether one or two MUs should be present based on the appointment it is about to start.

Upon finishing an appointment, "NextPatientOP" is executed which executes "RequestAppointment" for the patient, moves the patient back home, moves the specialist to their next appointment and executes "StartOP" for the next appointment scheduled for the treatment room.

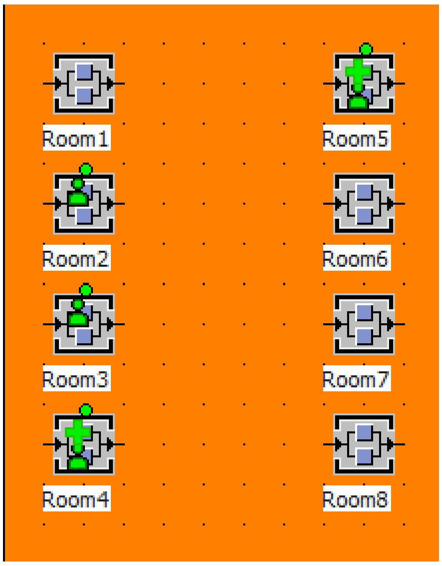

Figure 5-9: Outpatient clinic treatment rooms.

5.13.7 Component mapping from conceptual model to computer model

In this final section of this chapter, we will repeat the component list of the conceptual model as presented in Table 4-2, map the conceptual components to the components from the computer model given in the previous sections, and list the sub-questions used as input data per component. In doing so, model realisation will be finished.

Table 5-11: Component mapping from conceptual model to computer model.

Conceptual component	Detail	Computer model component – type	Input data – section
Entities:			
Patients	Quantity: individual patients	Patient – MU	
	Arrival pattern	ArrivalElective – Source	Arrival pattern – Section 5.3
	Attribute: diagnosis	NewPatient – Method (assigns diagnosis) Patients – Table (stores data)	Incidence rate – Section 5.4
	Routing: care trajectory	NewPatient – Method (assigns care trajectory) Patients – Table (stores data) RequestAppointment – Method (routes through care trajectory) AppStrategyOR/OP – Methods (schedules appointments) MakeAppOR/OP – Methods (makes appointments)	Care trajectories – Section 5.5
	Attribute: chronic/non-chronic	NewPatient – Method (assigns chronic attribute) Patients – Table (stores data)	Chronic patient rate – Section 5.6
	Attribute: specialist	NewPatient – Method (assigns specialist) Patients – Table (stores data)	Specialist abilities – Section 5.9 Outpatient clinic roster – Section 5.11

			Specialist schedules – Section 5.12
Specialists	Quantity	Specialist – MU	
	Arrival pattern	Specialist schedules – Table (holds empty schedules)	Specialist schedules – Section 5.12
	Routing: schedule	AppStrategyOR/OP – Methods (schedules appointments) MakeAppOR/OP – Methods (makes appointments) Specialists – Table (holds schedule filled with appointments)	
	Attribute: abilities/specialities	Specialists – Table (holds specialities)	Specialist abilities – Section 5.9
AIOS	Same components as specialists		
Activities:			
First/repeat consultation	Quantity: individual treatments	Room*X* – Parallel stations	
	Nature (X in Y out)	StartOP – Method (sets nature of activity)	
	Cycle time	Room*X* – Parallel stations StartOP – Method (sets cycle time)	Treatment time distributions – Section 5.7
	Resources	Outpatient clinic roster – Table	Outpatient clinic roster – Section 5.11
	Shifts	Outpatient clinic roster – Table	Outpatient clinic roster – Section 5.11
	Routing	OnArrivalOP – Method (moves patients to waiting room) StartOP – Method (moves patients and specialists into treatment room) NextPatientOP – Method (moves patients and specialists out of treatment room and starts next appointment) RequestAppointment – Method (requests next appointment for patient)	
Outpatient treatment	Same components as first/repeat consultations		
OR treatment	Quantity: individual treatments	ORF7 – Parallel station	
	Nature (X in Y out)	Always 2 in 2 out	
	Cycle time	ORF7 – Parallel station StartOR – Method (sets cycle time)	Treatment time distributions – Section 5.7
	Set-up/changeover	MakeAppOR – Method (sets 20 minutes changeover time)	
	Resources	OR blueprint – Table	OR blueprint – Section 5.10
	Shifts	OR blueprint – Table	OR blueprint – Section 5.10

	Routing	StartOR – Method (moves patients and specialists into treatment room) NextPatientOR – Method (moves patients and specialists out of treatment room and starts next appointment)	
Admission into clinic and clinical stay	Quantity: individual admission	Bed*X* – Single station	
	Nature (X in Y out)	Always 1 in 1 out	
	Cycle time	NextPatientOR – Method (sets cycle time)	Clinic admission time distributions – Section 5.7
	Routing	OnArrivalOR – Method (moves patients to admission) OnAdmission – Method (assigns clinic bed) StartOR – Method (moves patients out of admission into ORF7) NextPatientOR – Method (moves patients into clinic bed) ClinicDischarge – Method (moves patients out of clinic bed) RequestAppointment – Method (requests next appointment for patient)	
Resources:			
Outpatient clinic roster		Outpatient clinic roster – Table	Outpatient clinic roster – Section 5.11
OR blueprint		OR blueprint – Table	OR blueprint – Section 5.10
Queues:			
OR waiting list	Quantity: single	WaitingListOR – Table	
	Dwell time	Care trajectories – Table (holds urgency information)	Care trajectories – Section 5.5
	Queue discipline	AppStrategyOR – Method (selects patients from waiting list)	
	Routing	MakeAppOR – Method (schedules appointments and removes patients from waiting list)	
Outpatient waiting list	Quantity: single	WaitingListOP – Table	
	Dwell time	Consultation types – Table (holds urgency information)	Consultation types – Section 5.8
	Queue discipline	AppStrategyOP – Method (selects patients from waiting list)	
	Routing	MakeAppOP – Method (schedules appointments and removes patients from waiting list)	

6 Model validation

In this chapter, we will perform final validation of the computer model by addressing four types of model validation described in Section 3.3, which are:

- Conceptual model validation
- Data validation
- White-box validation
- Black-box validation

Experimentation validation will be performed in Chapter 7, as it involves the experiments which have not been discussed yet. Solution validation will not be performed as the implementation phase of the solution is not included in this study. Validation of a simulation model is something that should happen throughout the modelling process, and as such, some issues have already been addressed in Chapters 4 and 5. Furthermore, we should note that proving complete validity of a model is impossible, as the overall goal of a model is to provide an accurate enough representation of the real-world system for the model goals, and we can only validate the model with respect to its purpose (Robinson, 2014). To repeat, the overall objective of the model is:

> “To analyse the effects of shifting certain surgical treatments to a day-treatment for on the access times, waiting list sizes, production volume and usage of capacity of the OR, clinical ward and outpatient clinic for the speciality of the UMC Utrecht by modelling and simulating the patient treatment process.”

Thus, the aim of this chapter is to increase confidence in the model so that it can be used in decision-making for the new day-treatment clinic. In doing so, we will have answered the research question: *What are the model validation data?*

6.1 Conceptual model validation

Most of the issues surrounding conceptual model validation have already been addressed throughout Chapter 4. Here, we want to assess any assumptions or simplification made in the conceptual model described in Chapter 4 and 5 on the level of confidence we have that the assumption is correct and the level of impact on the results of the model if it is incorrect. We will do this for each component that assumptions or simplifications have been made for, starting with the model scope for inclusions and exclusions from the conceptual model, then moving to the level of detail per component. Note that we will not delve into detail on each assessment, as they are based on personal judgement, and is simply given to identify areas of concern. Furthermore, all assumptions and simplifications have been discussed with the project supervisor of the UMC and business controllers of the DHS, and some were also discussed with other staff of DHS and of the speciality, and they were all deemed acceptable.

In Table 6-1, we present all the assumptions and simplifications made for excluding or including of components and give the validity assessment.

Table 6-1: Conceptual model scope simplification and assumption confidence and impact level assessment.

Component		**Justification**	**Assessment**
Entities:			
Patients	Include	**Simplification:** emergency patients are excluded or modelled as elective patients. The only distinction ER patients have in the real-world system are the way they are admitted into the hospital, which is performed by another division of the hospital. Furthermore, the speciality has a relatively low amount of emergency patients, and their surgeries are performed in a different OR than the OR used for elective patients. Thus, the only effect on capacity ER patients have are the time specialists need to perform those surgeries. We deemed it acceptable to model these surgeries as normal surgeries.	**Confidence:** Medium **Impact:** Medium
Nurses**,** anaesthetic specialists, OR assistants, clinical specialists	Exclude	**Assumption:** supporting staffs are always available for the hours allocated to the speciality in the PAs and the resulting OR blueprint and outpatient clinic roster and thus cannot cause delays.	**Confidence:** Medium **Impact:** High
Activities:			
Repeat consultation	Include	**Simplification:** activities are like those for first consultations, and thus no real distinction is made in the model other than the planning method used.	**Confidence:** High **Impact:** Low
Admission into clinic and clinical stay	Include	**Simplification:** admission into the clinic and stay in clinic are seen as one activity since when a patient is being admitted a clinic bed is already reserved for them.	**Confidence:** High **Impact:** Low
Education/research	Exclude	**Assumption:** education and research have a lower priority than treating patients and are planned around treatments. Thus, they do not affect the process of treating patients and we exclude it from the model.	**Confidence:** High **Impact:** Medium
Resources:			
Production agreements	Exclude	**Simplification:** PAs are used to calculate capacity, yet the OR blueprint, clinic beds and outpatient clinic roster already hold the calculated capacity.	**Confidence:** High **Impact:** Low

Next, in Table 6-2, we assess all assumptions and simplifications made per component and their level of detail.

Table 6-2: Conceptual model level of detail simplification and assumption confidence and impact level assessment.

Component	Detail	Assumption(s)/Simplification(s)	Assessment
Entities:			
Patients	Arrival pattern	**Assumption:** we assume the arrival pattern of patients is Poisson distributed	**Confidence:** High **Impact:** Medium
	Attribute: diagnosis	**Simplification:** a patient can only have one diagnosis in the model, as someone in the real-world hospital with two diagnoses would receive separate treatments for the two diagnoses.	**Confidence:** High **Impact:** Low
	Routing: care trajectory	**Assumption:** we assume routing in the form of walking or transport through the hospital does not cause delays.	**Confidence:** Medium **Impact:** Low
Specialists	Routing: schedule	**Assumption:** we assume routing in the form of walking through the hospital does not cause delays.	**Confidence:** Medium **Impact:** Low
		Assumption: on average, specialists take 7 weeks off in a year.	**Confidence:** Medium **Impact:** Low
AIOS	Same assumption as specialists		
Activities:			
First/repeat consultation	Cycle time	**Assumption:** we assume treatment time is normally distributed using the mode of the historical plan times used for the action as the mean and 2 minutes 30 seconds as the standard deviation.	**Confidence:** Medium **Impact:** Low
	Set-up/changeover	**Assumption:** because of the simplicity of consultations, we assume the changeover time is negligible or assumed to be included in the treatment time.	**Confidence:** High **Impact:** Low
	Routing	**Simplification:** since for calculating occupancy of the outpatient clinic and production volume it does not matter whether the patient is physically at the hospital (the specialist is the leading factor here), consultations over the telephone and e-mail consultations are modelled the same as normal, in-person consultations. Patients arrive at the hospital as normal and are moved to the treatment room, etc.	**Confidence:** High **Impact:** Low
	Other: absenteeism/tardiness of patient	**Simplification:** we exclude no-shows and tardiness of patients in the model.	**Confidence:** Medium **Impact:** Medium
Outpatient treatment	Similar assumptions/simplifications as consultations		

OR treatment	Cycle time	**Assumption:** we assume treatment time is normally distributed, unless we can only find historical data on one session for a treatment, in which case we set the treatment time at constant for that time (see Section 5.7)	**Confidence:** High **Impact:** Medium
		Simplification: we only model one treatment per OR session, the cycle time should account for sessions in which multiple treatments are performed (see Section 5.7)	**Confidence:** Medium **Impact:** High
	Set-up/changeover	**Simplification:** change-over time is set to a static 20 minutes in the model, which is the same time planners use in between appointments for the speciality.	**Confidence:** Medium **Impact:** Medium
	Other: absenteeism/tardiness of patient	**Simplification:** we assume patients are never late for surgery. Furthermore, they arrive for admission to the clinic 2 hours in advance, so this is a rare occurrence anyways.	**Confidence:** High **Impact:** Low
Admission into clinic and clinical stay	Cycle time	**Simplification:** the time it takes to admit a patient to a bed is ignored, as the bed is already assigned to the patient at that point.	**Confidence:** High **Impact:** Low
		Assumption: we assume clinic admission time is normally distributed.	**Confidence:** High **Impact:** Medium
	Set-up/changeover	**Assumption:** there is no changeover time for admission. As soon as a patient is discharged, another patient will begin admission, and the bed can be assigned to the new patient.	**Confidence:** High **Impact:** Low
Resources:			
Clinic beds	Quantity	**Assumption:** since the clinic is shared with the rest of the hospital, we assume an infinite amount of clinic beds are available to the speciality, as we omit the other patients in the clinic from our model scope. However, OR-planners keep in mind that typically, the number of patients of the speciality admitted into the clinic should not exceed 5.	**Confidence:** Medium **Impact:** High
Outpatient clinic roster	Quantity	**Simplification:** in the real-world system, the roster holds detailed information on what type of consultations can be performed per specialist on the days they work in the outpatient clinic. We ignore the specific types of consultations and use only the times they are available from the roster.	**Confidence:** Medium **Impact:** Medium
OR blueprint	Quantity	**Simplification:** we remove 2 shifts from the blueprint for reduction weeks and ER patients.	**Confidence:** Medium **Impact:** Low

Queues:			
OR waiting list	Queue discipline	**Simplification:** no schedule optimisation is performed, meaning the model does not try to fit the most treatments in in one day, however, if it has reached an empty slot nearing the end of the day, it will continue searching through the waiting list for a patient with an expected treatment time short enough to fit them in.	**Confidence:** Medium **Impact:** Medium
		Simplification: because of the assumption made for clinic beds, the model does not consider how many clinic beds will be occupied that day when scheduling patients from the waiting list.	**Confidence:** Medium **Impact:** Medium
Outpatient waiting list	Mostly similar details to OR waiting list, except all patients on the outpatient waiting list have an urgency date and thus all have a minimum dwell time.		

6.2 Data validation

Data validation concerns ensuring that the data used for the model is accurate. Validity issues about input data have already been discussed in the relevant sections of Chapter 5 and thus we will not discuss data validation in this chapter.

6.3 White-Box validation

White-box validation means ensuring that the content of the model is true to the real world, meaning it is an indirect form of conceptual model validation. Furthermore, verification of the model, which means ensuring that the coded model is true to the conceptual model (Robinson, 2014), is also required. Like previous sections of this chapter, a lot of the validity issues have already been discussed in previous chapters, as white-box validation and verification should happen throughout the modelling process. We just want to mention again here that the conceptual model has been discussed in detail with the project supervisor, and specific components have been discussed with relevant staff (see Section 4.5.1). Moreover, the computer model has also been assessed by the project supervisor and business controllers of the DHS by going through the simulation step-by-step.

6.4 Black-Box validation

For black-box validation, we compare the simulation model to the real world. In other words, we compare outputs of the simulation to data from the real-world hospital to see if they are sufficiently similar. The outputs of the model are as follows:

- Access times,
- Production volume,
- Usage of capacity of the OR, clinical ward, and outpatient clinic.

As we do not have access to the waiting list of either the OR or outpatient clinic from the real-world hospital, we unfortunately cannot compare the outputs of the model with historical data. Furthermore, we modelled the clinical ward as having infinite capacity meaning results from the model will not be similar to historical data of the hospital. Thus, we will only compare the production volume, or the number of patients leaving the system each week, and the number of OR treatments and consultations performed in the model with data from the real-world hospital.

Before we can start comparisons, we need to identify some properties of the simulation to obtain accurate results. We have a non-terminating simulation, meaning it does not have a natural end point. The hospital in the simulation could in theory run infinitely. Combined with the fact that our input data does not change over time, this will mean that our output will reach a steady-state, where the output varies according to some fixed distribution (Robinson, 2014).

We then need to assess the warm-up period to remove initialisation bias. Measuring outputs right from the start of the simulation would give unrealistic outputs, as we cannot assume that the hospital would have an empty waiting list at the beginning of the simulation. We could also have generated a starting condition, for example by filling the waiting list with patients before starting the simulation, but we decided to start with an empty system simply because it was easier.

We run into some issues with our simulation here, as some variables do not actually reach the steady state. The number of patients in the system, for example, keeps growing because of chronic patients, and the number of patients on the waiting list for the OR simply keeps growing because of a lack of capacity. In the real-world hospital, patients will sometimes simply get referred to another hospital if there is not enough capacity for them, chronic patients will also get referred to other healthcare providers, etc. Thus, for calculating the warm-up period, we used the number of patients leaving the system each week, or total production of the system as the variable to test initialisation bias. We assume that using the total production is a valid variable for the warm-up period, and that *most* variables are at least somewhat correlated to the total production.

Using the Marginal Square Error Rule (MSER) method of finding the warm-up period, where you use a formula to get the week in the simulation where deleting all data before it gives the smallest confidence interval of the mean of the weeks after (Robinson, 2014), and 10 replications of around 420 weeks' worth of input data, we get a warm-up period of 48 weeks. To implement this into the model, we only start measuring statistics in the 49th week of execution.

We then use two simple rules of thumb to get the number of replications required and the run-length of the simulation. The first being that at least three to five replications should be performed, we chose to perform 5 per experiment (Robinson, 2014). Referring to Section 5.1, five replications will mean five different streams of random numbers generated by the software. Then, the second rule of thumb is to set the run-length of the simulation at 10 times the warm-up period (Robinson, 2014), which for us is 480 weeks.

6.4.1 Data comparisons

Now that the warm-up period, run-length, and number of replications have been set, we can generate accurate results using the simulation and start comparing the outputs to data from the real-world hospital.

6.4.1.1 Number of patients treated

To compare the number of patients treated or leaving the hospital in the model with the real-world, we first need to compose some data as our definition of a patient is different than that of a patient in the real-world hospital, since we model patients as having a single diagnosis. Thus, we use a similar method as in Section 5.4.1, but now use the ending date of DBCs in 2019 and only count a DBC in a week if no new DBCs have been opened following it. Our results from the model contain data from far more than 52 weeks, rather we have 2,160 weeks. So, to compare the means relatively easily using an independent sample t-test, we randomly sample 52 weeks from the 2160, as for such a t-test the sample sizes have to be equal (Robinson, 2014).

Unfortunately, we cannot prove with statistical significance that the means of these two samples are equal, assuming unequal variances. The summary of the statistics can be seen in Table 6-3.

Table 6-3: Statistical summary of number of patients treated per week.

	Sample	N	Mean	Standard deviation
Number of patients treated per week	Hospital	52	60.8	8.7
	Model	52	47.1	10.3

We want to attribute this difference to how chronic patients are modelled in the system, as they return for a yearly consultation indefinitely. Furthermore, the data gathered from the hospital might not be entirely accurate, as some patients might still return for treatment and have a new DBC opened in the future. This difference will have to be considered when discussing the production volume from the model.

6.4.1.2 Number of OR treatments

For the number of OR treatments performed, we simply gather the amount of OR treatments performed per week in 2019, excluding any emergency surgeries, since we do not model ER patients. Comparing that to 52 random sampled weeks from the model using an independent sample t-test, we can prove with at least a 95% level of confidence that the means are equal. A summary of the statistics of the samples can be seen in Table 6-4.

Table 6-4: Statistical summary of number of OR treatments per week.

	Sample	N	Mean	Standard deviation
Number of OR treatments per week	Hospital	52	11.7	5.0
	Model	52	10.5	3.0

6.4.1.3 Number of consultations

We will now compare the number of consultations performed in the model against the number performed in the real-world hospital in 2019. We again sample 52 random weeks from the model output, and using an independent sample t-test, assuming unequal variances, we prove again with at least a 95% level of confidence that the means are equal. Table 6-5 shows the statistical summary.

Table 6-5: Statistical summary of number of consultations per week.

	Sample	N	Mean	Standard deviation
Number of consultations per week	Hospital	52	128.9	33.4
	Model	52	133.4	22.5

6.4.2 Other outputs

Again, we cannot compare the access times because we do not have access to the waiting list of the hospital. The occupancy of OR and outpatient clinic are heavily dependent on the number of treatments and consultations performed and thus we will not compare them to real-world data. As the capacity of the clinic has been simplified into being infinite (see clinic bed quantity assumption in Table 6-2), we also cannot compare the occupancy of the clinical ward in the model to the real-world hospital.

6.5 Conclusion

Now that the model validation process has been discussed, we can conclude the model coding phase for the current situation of the hospital. We can now move on to researching implementing the new day-treatment clinic and the new day-treatments as our experiments into the conceptual model and computer model and start the experimentation phase.

7 Experiment design

In this chapter, we will answer the research question: *What are the interventions that need to be made to the model for converting certain surgical treatments to day-treatments?* To do so, we perform the cycle of conceptual modelling and model coding again, now only focusing on the experiments we are implementing. Thus, our sub-questions are relatively similar to the research questions of Chapters 4, 5 and 6, as we first research the conceptual model of the new day-treatments, then identify and gather the required input data and finally perform experiment validation. The sub-questions are as follows:

1. What is the conceptual model of the new day-treatment process?
2. What is the required input data for implementing the new day-treatment process?
3. How valid are the experiments and their implementation?

Then, in Chapter 8, we will perform the experiments and discuss the results.

7.1 What is the conceptual model of the new day-treatment process?

For identifying the conceptual model of the new day-treatment process, we will first discuss the current process of day-treatments in the current conceptual model (as described in Chapter 4). Then, we will discuss what interventions to be made to the current components and what components need to be added. We will also describe the level of detail required for the components. Data for this sub-question was gathered through interviews with the medical specialist who designed the new day-treatment process, and a plan of action and business case for the new day-treatment process.

In the original conceptual model, day-treatments were included as normal OR treatments, as the only real difference in the hospital is that patients receiving a day-treatment do not rest as long in the clinical ward as patients receiving a normal surgery. For a day-treatment, patients will only need to rest in the clinic for a couple of hours, such that they can leave the hospital within the same day. Patients will go under full anaesthesia for a day-treatment in the current system. The day-treatments are performed by specialists in the regular OR.

7.1.1 New day-treatment process

For the new day-treatment process, the speciality is converting a treatment room from the outpatient clinic into a room for the day-treatments. This room, referred to as OR28, is currently used three days a week for two types of treatments (Room 1 in Table 5-9). The conversion should allow OR28 to be used five days a week for the treatments currently assigned to the room to be performed alongside the new day-treatments, which are to be performed under a local anaesthetic. A waiting area for OR28 should also be assigned.

If a patient receives a new day-treatment, depending on the time of treatment, they can either leave immediately or rest for a short period in a recovery section of OR28. Unlike admission into clinical ward, the recovery chairs are not assigned to patients before or during treatment, and patients will not have to be admitted like in the traditional clinic. A patient can be recovering while the next patient is receiving their treatment. Treatments are to be performed by specialists, with some supporting staff like anaesthetist and nurses.

7.1.2 Interventions to conceptual model

In Table 7-1, we present the interventions that should be made to the original conceptual model of Table 4-2.

Table 7-1: Interventions to conceptual model for new day-treatments.

Component	Detail	Justification/description
Activities:		
Add: Day-treatment	Quantity	The quantity of day-treatments will depend on the care trajectories of patients currently in the system. Limiting factors are the schedules of specialists and the availability of OR28.
	Nature (X in Y out)	2 in 2 out (one specialist and one patients)
	Cycle time	Treatment time distribution based on treatment performed. **Assumption:** we assume treatment time is normally distributed.
	Set-up/changeover	**Simplification:** change-over time is set to a static 20 minutes in the model, which is the same time planners use in between regular OR treatments for the speciality.
	Resources: OR28	Day-treatments are to be performed in OR28
	Shifts	Break periods are not applicable to day-treatments
	Routing	Patients arrive for their day-treatment 30 minutes in advance and wait in the waiting room. When their day-treatment can start, the patient and their specialist are moved to OR28. Upon finishing of a day-treatment, patients either rest in the recovery area of OR28 for a brief period or return home immediately. Specialists are moved to their next appointment or to the break room.
	Other: absenteeism/tardiness of patient	**Simplification:** we exclude no-shows and tardiness of patients in the model.
Add: Day-treatment recovery	Quantity	Some patients will need to rest after receiving a day-treatment, thus, the quantity of recoveries will depend on the number of day-treatments performed
	Nature (X in Y out)	1 in 1 out
	Cycle time	**Assumption:** the recovery time is assumed to be only a couple of hours. Thus, we assume a normal distribution with 2 hours as the mean recovery time, with a standard deviation of an hour. The minimum recovery time is set at 30 minutes, and the maximum at 4 hours. **Simplification:** the recovery time is equal for all types of treatments performed.
	Set-up/changeover	**Assumption:** there is a negligible amount of change-over time for recovery.
	Resources: recovery beds	Patients will rest in a recovery bed in OR28.
	Shifts	Breaks are not applicable.

	Routing	Patients enter recovery from their day-treatment in OR28, and upon finishing recovery are moved back home. They are then placed on the waiting list, are scheduled a new appointment, or are discharged from the hospital based on their care trajectory. Specialists are moved to their next appointment based on their schedule.
Resources:		
Outpatient clinic roster	Quantity	**Change:** we remove OR28 - Room 1 in Table 5-9 - from the outpatient clinic roster, as it can no longer be used as normal for the outpatient clinic.
Add: OR28	Quantity	OR28 will hold one treatment bed, a waiting room (assumed to have unlimited capacity), and some recovery beds.
	Where required	Day-treatments.
	Shifts	Same opening hours as the normal OR (08:00 – 16:00), open five days a week. **Simplification:** supporting staff for treatments in OR28 are excluded.
Add: Recovery beds	Quantity	**Assumption:** we use 3 recovery beds in the model.
	Where required	Day-treatment recovery.
	Shifts	Not applicable.
Queues:		
Add: Day-treatment waiting list	**Assumption:** similar details to OR waiting list from Table 4-2. No plan has been made for what the day-treatment waiting list will be like.	

These interventions should be implemented in the model in such a way that they can be activated or deactivated so experiments can be performed, and we can compare outputs of the model using the current situation and using the new day-treatments. We exclude supporting staff from the conceptual model of day-treatments

7.2 What is the required input data for implementing the new day-treatment process?

From the interventions to the conceptual model presented in Table 7-1, we can identify gaps in knowledge we need to fill with input data. We will set up some sub-questions to gather the required data and describe how the findings were implemented into the model. Finally, we will give an overview of the day-treatments in the Discrete Event Simulation model.

7.2.1 Data requirements

There are only a couple of input data requirements for model realisation, which are:

1. What surgeries can be moved from the regular OR to OR28?

To know the quantity of treatments that will be performed in OR28, we need to know exactly what treatments can be performed in the proposed day-treatment clinic.

2. What is, per treatment type, the expected percentage of treatments that can move to OR28, that will require recovery and that will not require recovery?

For each treatment, we need to know what the expected percentage of treatments can be performed in OR28 is, and whether some percentage of treatments will still need to be performed as normal. Furthermore, we need to know what percentage of those day-treatments will require a patient to rest in a recovery bed and what percentage of treatments will allow a patient to return home without recovery.

3. What are the expected treatment time distributions for the new day-treatments in OR28?

Finally, for accurately modelling the cycle time of the new day-treatments, we need to identify the expected treatment time distributions for each of the treatments.

We will now answer these sub-questions and describe how the results were implemented into the model.

7.2.2 What surgeries can be moved from the regular OR to OR28?

In this section we will identify all the surgeries of which the process can be shifted to that of the new day-treatments. Then, we will discuss the implementation into the computer model.

From the plan of approach and business case, we find 6 surgeries that can be moved to OR28. The surgeries, their action codes and action code description are shown in Table 7-2. Note that the action code descriptions have not been translated into English from Dutch.

Table 7-2: Surgeries able to be performed in OR28.

Action code
336193
336194A
336298A
339868B
336272
336790A
388130

Finally, the treatments the treatment room was already in use for still need to be performed in OR28 as well, which use the action codes seen in Table 7-3.

Table 7-3: Current treatments performed in OR28.

Action code
339866
339869A
339869K

Request appointment

In the computer model, we add a value to these actions that can be turned on or off. Then, the “RequestAppointment” method (Section 5.5.2) can check, per action, whether the action should be performed in OR28 or in the normal OR. As the “RequestAppointment” method only selects the first action from the current order – an order being multiple treatments a patient should receive on the same day – of a patients’ care trajectory, we check whether all actions in the current order can be performed in OR28. For example, if a patient should receive “336193” in combination with another surgery that is not performable in OR28, the treatment should not be performed in OR28. However, if a patient should receive “336193” in combination with “336272”, the treatment can be performed in OR28.

7.2.3 What is, per treatment type, the expected percentage of treatments that can move to OR28, that will require recovery and that will not require recovery?

Next, for each of the treatments identified in Section 7.2.2, we need to determine what percentage of the treatments can be performed in OR28 and what percentage should be performed as normal. Furthermore, we need to identify for what percentage of treatments performed in OR28 a patient will need to rest in a recovery bed.

specialist estimated the percentages as shown in Table 7-4.

Table 7-4: Percentages of treatments to OR28, with recovery and without recovery.

Action code	% to OR28	% with recovery	% without recovery
336193	100%	0%	100%
336194A	100%	0%	100%
336298A	100%	0%	100%
339868B	100%	10%	90%
336272	100%	5%	95%
336790A	20%	10%	90%
388130	100%	0%	100%
339866	-	0%	100%
339869A	-	0%	100%
339869K	-	0%	100%

Thus, most of the treatments are expected to be completely shifted to OR28 and performed as a day-treatment. Furthermore, the "339866", "339869A" and "339689K" actions are already performed in OR28 and should remain there.

336790A

The "336790A" surgery is a special case, as in the current system, about 20% of "336790A" surgeries performed are not successful. If so, a more complicated procedure must be performed that we will refer to as "336790T". Such "336790T" surgeries cannot be performed in OR28, as it requires the patient to be fully anaesthetised. Normally, as "336790A" are performed in the regular OR, the "336790T" can be performed within the same surgery. When a "336790A" treatment fails in OR28, however, a new request for an appointment will need to be made for a "336790T" surgery in the regular OR.

7.2.4 What are the expected treatment time distributions for the new day-treatments in OR28?

Finally, to finish gathering the input data, we need to get an estimate for the expected treatment times for each of the day-treatments in OR28. In this section, we will gather the treatment time distributions using the care-cube that contains historical data from the hospital.

We filtered data of the database that contains data on OR sessions first by surgeries performed by the speciality from 2017 through 2019 in the regular OR. Next, we filter for the action codes we identified in Table 7-2 as the main treatment performed in the surgery. Then, we can filter for surgeries performed under a local anaesthetic, which is how the new day-treatments are going to be performed, and compare them with surgeries performed under full anaesthesia. In doing so, we gather the treatment time distributions shown in Table 7-5.

Table 7-5: Treatment time distributions in minutes of proposed OR28 treatments, local versus full anaesthesia. (T = 2017 to 2019, source = care-cube)

	Local anaesthesia			**Full anaesthesia**		
Action code	Average	St. Dev.	n	Average	St. Dev.	n
336193	37.2	22.2	5	64.2	57.9	260
336194A	48.8	24.3	5	55.0	29.5	202
336298A	30.5	19.2	311	37.1	13.5	114
339868B	-	-	0	-	-	0
336272	40	-	1	72.9	57.1	9
336790A	67.5	31.7	15	71.4	19.9	99
388130	-	-	0	-	-	0

Notice that for both action "339868B" and "388130", no performed surgeries were found in the database. This likely means that the actions are never performed as the main action of a surgery, and always in conjunction with other actions. Referring back to the Request Appointment section on Page 6565, we can then assume that no patient will have these actions in their care trajectory without an action in the same order that cannot be performed in OR28. Thus, patients cannot receive these actions in OR28, and it is inconsequential that we do not have treatment time distributions for these actions.

Action codes "339866", "339869A" and "339869K" are performed as normal, and so we do not need to gather treatment time distributions and can use the distributions identified in Section 5.7. For action "336272" we use a constant treatment time of 40 minutes in the model. Finally, for "336790T", we use the distribution for a normal "336790A" surgery, as their treatment times are included with the distribution used for "336790A" surgeries.

7.2.5 Overview of computer model

As in Chapter 5, we will conclude this section on gathering input data for the experiments by giving an overview and description of the added components in the discrete event simulation (DES) model. Per component, we will note the input data used. For an explanation of the types of components and their functions used in the DES-software, see Section 5.1.

7.2.5.1 OR28

In Figure 7-1, the overview of OR28 implemented in the DES model is shown. It operates relatively similarly to the OR as described in Section 5.13.4. When the "RequestAppointment" (see Section 5.5.2 and Page 65) finds a patient that can receive a day-treatment, the method places the patient on the "WaitingListDay" table. Every week, the "NewScheduleDay" method first extends the "ScheduleDay" table by a week, for a total of 14 weeks ahead. Then, the "AppStrategyDay" method is performed, that selects the first open slot in "ScheduleDay", searches for patients on "WaitingListDay", and checks whether both "ScheduleDay" and the schedule of the patients' specialist is free for the expected treatment time of the patient. If a patient is found, the "MakeAppDay" method is executed, that notes the appointment in "ScheduleDay" and the specialists' schedule and executes "OnArrivalDay" 30 minutes before the starting time of the appointment.

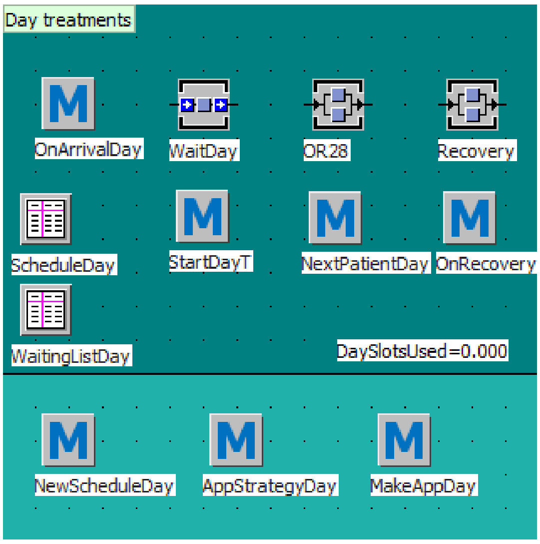

Figure 7-1: Overview of OR28 in computer simulation model.

“OnArrivalDay” moves the patient into the “WaitDay” buffer. Then, the “StartDayT” method is performed either by “OnArrivalDay” or “NextPatientDay” when the patient’s appointment can start. “StartDayT” sets the correct treatment time in the “OR28” parallel station based on the treatment time distributions found in Section 7.2.4, and moves the patient into “OR28”. If the patient’s specialist is free, “StartDayT” also moves the patient into “OR28”. “OR28” will start processing when both the patient and specialist are present in the station.

Upon finishing a treatment, “NextPatientDay” is executed. It moves the specialist to their next appointment or to the break room and executes “StartDayT” if there is another appointment scheduled in “OR28”. Furthermore, based on the distributions identified in Section 7.2.3, the patient is either moved to the “Recovery” station to rest, or is moved back home. The “Recovery” station is a parallel station, which will start processing individual patients as soon as they enter and does not require multiple MUs to be present.

If a patient receives a “336790A” treatment, there is a 20% chance “NextPatientDay” adds a TESE at the top of their care trajectory. “NextPatientDay” then executes “RequestAppointment” and the patient is placed on the waiting list or an appointment is scheduled for the next action in their care trajectory. Finally, if a patient is finished with recovery, “OnRecovery” is executed, which solely moves the patient back home.

7.2.5.2 Component mapping from interventions to conceptual model to computer model

We will now present a summary of the model realisation phase for the experiments by repeating the interventions to the conceptual model as presented in Table 7-1, map the conceptual components to the components used in the computer model as given in the previous sections, and list the input data used per component.

Table 7-6: Component mapping from changes to conceptual model to computer model.

Conceptual component	Detail	Computer model component – type	Input data – section
Activities:			
Add: Day-treatment	Quantity: individual treatments	OR28 – parallel station	
	Nature (X in Y out)	Always 2 in 2 out	
	Cycle time	OR28 – Parallel station StartDayT – Method (sets cycle time)	Expected treatment time distributions – Section 7.2.4
	Set-up/changeover	MakeAppDay – Method (sets 20 minutes changeover time)	
	Routing	StartDayT – Method (moves patients and specialists into treatment room) NextPatientDay – Method (moves patients and specialists out of treatment room and starts next appointment) RequestAppointment – Method (requests next appointment for patient)	
Add: Day-treatment recovery	Quantity: individual recoveries	Recovery – Parallel station	
	Nature (X in Y out)	1 in 1 out	

	Cycle time	Normally distributed with 2 hours as mean, 1 hour as standard deviation	
	Resources: recovery beds	Recover – Parallel station	
	Routing	NextPatientDay – Method (moves patients into Recovery) OnRecovery – Method (moves patients out Recovery)	Percentage of patients that require recovery per treatment – Section 7.2.3
Resources:			
Outpatient clinic roster	**Change:** quantity	At start of simulation, we switch to the changed roster if OR28 is open or switch to the normal roster if OR28 is closed	

7.3 Experiment validation

As we have performed another cycle of conceptual modelling and model coding, we want to focus again on the types of validation discussed in Chapter 6, with the exception of Black-Box validation, as no real-world data is available. Thus, in this section, we will discuss issues surrounding conceptual model validation, data validation and white-box validation in order to provide more confidence in the experiments and their results.

7.3.1 Conceptual model validation

Like in Section 6.1, we will present all the simplifications and assumptions made to the conceptual model of the new day-treatments and give an assessment on the level of confidence and level of impact of the assumption or simplification per component. Again, we will not discuss the assessments as they are based on personal judgement and simply serve to identify possible areas of concern. If no assumption or simplification has been made for a component, we exclude it from the list.

Table 7-7: Conceptual model of new day-treatments simplification and assumption confidence and impact level assessment.

Component	Detail	Justification/description	Assessment
Activities:			
Add: Day-treatment	Cycle time	**Assumption:** we assume treatment time is normally distributed.	**Confidence:** High **Impact:** Medium
		Assumption: per treatment type, we use the distribution of treatment times found in the care-cube for treatments performed under local anaesthesia in the regular OR.	**Confidence:** High **Impact:** Medium
	Set-up/changeover	**Simplification:** change-over time is set to a static 20 minutes in the model, which is the same time planners use in between regular OR treatments for the speciality.	**Confidence:** Medium **Impact:** Medium
	Other: absenteeism/tardiness of patient	**Simplification:** we exclude no-shows and tardiness of patients in the model.	**Confidence:** High **Impact:** Low

Add: Day-treatment recovery	Cycle time	**Assumption:** the recovery time is assumed to be only a couple of hours. Thus, we assume a normal distribution with 2 hours as the mean recovery time, with a standard deviation of an hour. The minimum recovery time is set at 30 minutes, and the maximum at 4 hours.	**Confidence:** Medium **Impact:** Low
		Simplification: the recovery time is equal for all types of treatments performed.	**Confidence:** Medium **Impact:** Low
	Set-up/changeover	**Assumption:** there is a negligible amount of change-over time for recovery.	**Confidence:** High **Impact:** Low
Resources:			
Add: OR28	Shifts	**Simplification:** supporting staff for treatments in OR28 are excluded.	**Confidence:** Medium **Impact:** Medium
Add: Recovery beds	Quantity	**Assumption:** we use 3 recovery beds in the model.	**Confidence:** High **Impact:** Low
Queues:			
Add: Day-treatment waiting list	**Assumption: s**imilar details to OR waiting list from Table 4-2. No plan has been made for what the day-treatment waiting list will be like.		**Confidence:** High **Impact:** Low

Note that all assumptions made are relatively similar to those made in the original conceptual model, have also been discussed with the project supervisor, and were all deemed acceptable.

7.3.2 Data validation

We have not yet discussed the validity of the input data used for the new day-treatments in Section 7.2. Most of the data, however, is rather straight-forward and comes from valid sources, like the specialist who oversees execution of the plan for OR28, and the care cube. Furthermore, no actual data on the process of the new day-treatments is available, as the OR28 simply is not in use yet, leaving no other choice than to base the input data on assumptions and expectations.

7.3.3 White-Box validation

White-Box validation, repeating from Section 6.3, is concerned with ensuring that the model content is corresponding to the real-world system. However, as the real-world system does not exist yet and we can only use expectations of the process to model it, we are somewhat unable to perform White-Box validation. Of course, we have discussed the process of the new day-treatments in the model with a specialist, who assessed the conceptual model and thought it reflected the expected process accurately enough. This is really the most we can do for White-Box validation.

Furthermore, verification also needs to be performed, meaning we should ensure that the conceptual model has been coded correctly. Both the conceptual model and DES model components for the new day-treatments are relatively similar to those of the original OR. Thus, most of the code and other components of the DES model of the original OR have been re-used for the new day-treatments. Moreover, the model has been tested in similar ways by describing the components to staff at the hospital and stepping through the simulation step-by-step.

7.3.4 Conclusion

With the validity of the experiments addressed, we can execute experiments and analyse the results of the simulation.

8 Experimentation and analysis of results

In this final chapter, we will set up and perform experiments with the newly added day-treatments as described in Chapter 7. Then, we will analyse each of the desired outputs of the model (Section 4.1) in order to answer the research question: *What are the effects of the new day-treatment process on access times, waiting list sizes, production volume and usage of treatment rooms for the speciality?* In doing so, we will have finished the research and achieved the overall research goal, the research goal being:

> "To analyse the effects of shifting certain surgical treatments to a day-treatment for on the access times, waiting list sizes, production volume and usage of capacity of the OR, clinical ward and outpatient clinic for the speciality of the UMC Utrecht by modelling and simulating the patient treatment process."

8.1 Experiments

To get results from the simulation, we use the Experiment Manager (see Section 5.1) to perform experiments. In this section, we will describe how we use the Experiment Manager and what experiments were performed.

The business case and plan of action for OR28 have some discrepancies, as the business case does not mention that the "336790A" surgery should also be performed in OR28. The plan of action was made in an earlier stage of the OR28 project, and although it is unclear why the business case does not mention the "336790A" surgeries and the plan of action does, we thought it would be interesting to compare the effects of performing all the new day-treatments in OR28 against performing all the new day-treatments but "336790A" in OR28. Of course, we should also compare performing the new day-treatments in OR28 to the normal, current situation.

Recalling to the Request Appointment section on Page 65, we implemented a switch for each of the new day-treatments given in Section 7.2.2 that sets whether they should be performed in OR28 or as normal. We use these switches in the Experiment Manager. Then, if day-treatments are performed in OR28, the model should also switch the outpatient clinic roster from normal to the roster where OR28 is removed. Furthermore, if OR28 is used for any new day-treatments, the "339866", "339869A" and "339689K" treatments should always be performed in OR28.

In Table 8-1, we show the experiments performed and the location used for the new day-treatments per experiment.

Table 8-1: Locations used for new day-treatments per experiment.

	Experiment	**336193, 336193A**	**336298A**	**336790A**	**339866, 339869A, 339689K**
1	Current situation	Normal	Normal	Normal	Normal
2	"336790A"as normal	OR28	OR28	Normal	OR28
3	All in OR28	OR28	OR28	OR28	OR28

We will now analyse the results for each of the outputs.

8.2 Access times and waiting list sizes

Access times are defined as the time a patient spends on a waiting list. In this section, we will discuss the effects of implementing the new day-treatments on access times, and on the waiting list size in terms of number of patients on the waiting list. We will discuss the OR waiting list and outpatient waiting list separately, and will focus mainly on the OR, as it is assumed that moving the day-treatments from the regular OR to the new OR28 will have the biggest effect on the waiting list for the OR and less of an effect on the outpatient clinic waiting list. Moreover, the time a patient spends on the waiting list of the outpatient clinic is usually desired, as patients on the outpatient clinic waiting list always have an urgency date, meaning their appointment should not be planned before a certain date.

8.2.1 OR access times

We cannot reveal the absolute access times for the speciality. Therefore, we will discuss changes in terms of percentages for the OR access times. We compare the distributions of access times of patients for the OR and the differences in means per experiment are shown in Table 8-2.

Table 8-2: Change in OR access times per experiment.

	Experiment	**Change in access times**
1	Current situation	0%
2	"336790A" as normal	- 28.3%
3	All in OR28	- 34.3%

Thus, on average, patients spend around 35% less time on the OR waiting list if all the new day-treatments are performed in OR28 in the model. With a 95% level of confidence, we can prove that the means of the distributions of access times of experiment 1 against 3 are significantly different. Furthermore, we can prove that the means of experiment 2 against 3 are significantly different. This provides a basis also arranging OR28 for "336790A" treatments.

8.2.2 OR waiting list size

As mentioned in the previous section, the OR waiting list grows over time, not reaching an equilibrium in the run-length of 480 weeks we determined in Section 6.4. This is true for all 3 experiments. Thus, in this section, we will show the progression of the waiting list size over time, discuss the differences, and compare the distributions of the difference in waiting list size per month.

In Figure 8-1, the average length of the OR waiting list at the end of the month over the 5 replications performed is shown. There is no axis for the number of patients as we cannot show the size of the waiting list because of confidentiality.

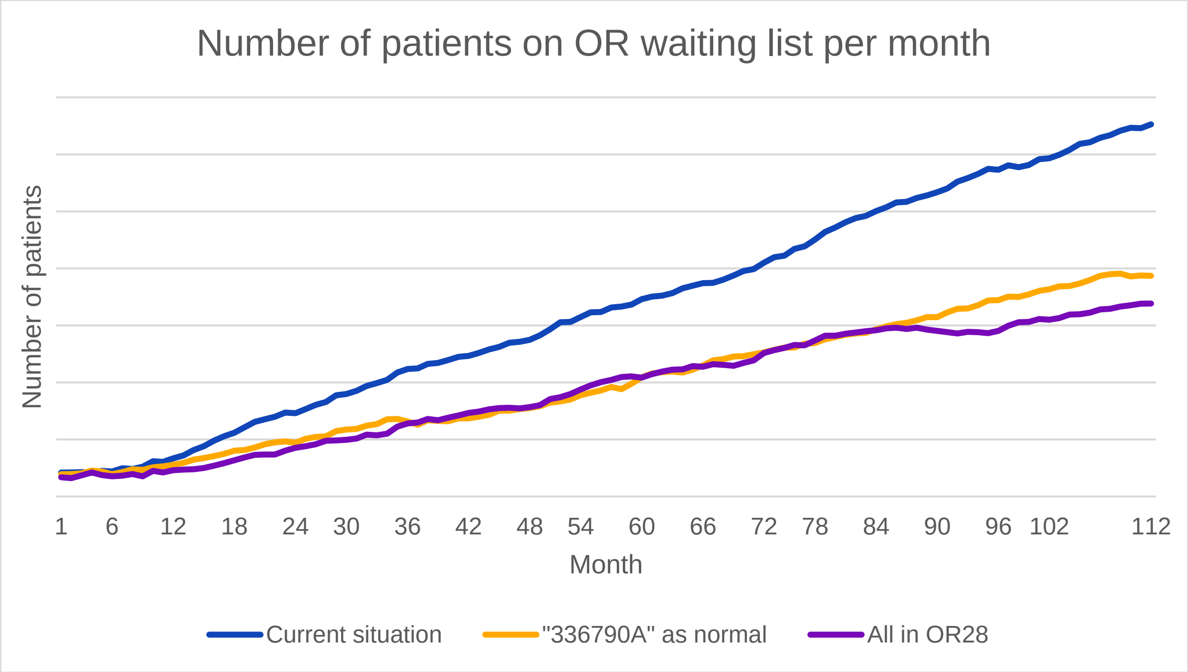

Figure 8-1: Number of patients on OR waiting list per month

Observe that the OR waiting list seems to grow significantly less fast upon implementing and using OR28. At the end of the simulation there are, on average, 48% less patients on the waiting list if all the possible new day-treatments are performed in OR28, and 40% less patients if "336790A" treatments are not performed in OR28. These are both quite significant reductions in the size of the waiting list.

Then, when comparing the rate of increase for the size of the waiting list, we get the changes in increase rate of the number of patients on the waiting list for the OR shown in Table 8-3 per experiment.

Table 8-3: Change in increase rate per month of number of patients on waiting list of the OR per experiment.

	Experiment	**Change in increase rate**
1	Current situation	0%
2	"336790A" as normal	- 43.0%
3	All in OR28	- 50.1%

With a 95% level of confidence, we can prove that the means of the distribution of increase rates of experiment 1 and 3 are statistically different. However, we cannot prove that the difference in means between experiment 2 and 3 are statistically different.

8.2.3 Outpatient clinic waiting list

We finally want to discuss the effect of OR28 on the outpatient clinic waiting list. As all patients on the waiting list must wait for a certain period because of their urgency rating, we will only discuss the number of patients that are unable to be scheduled around their urgency date. The change in mean of the number of non-schedulable patients per week is shown in Table 8-4.

Table 8-4: Change in number of non-schedulable patients of the outpatient clinic per week per experiment

	Experiment	**Change in number of non-schedulable patients**
1	Current situation	0%
2	"336790A" as normal	- 51.7%
3	All in OR28	- 35.4%

Both the differences in means between experiment 1 and 3 and between experiment 2 and 3 are statistically significant with a 95% level of confidence. As you can see, the average number of non-schedulable patients was actually lowest for experiment 2, where “336790A” treatments are not performed in OR28 and the other day-treatments are. We do not have an explanation for this, and this difference might be reduced if more replications are performed.

In the real hospital, the specialists and outpatient clinic are severely overwhelmed with the demand for consultations and the model does not seem to reflect that very accurately. Thus, the only conclusion we want to draw from these results is that implementing the new day-treatments does not increase the pressure on the outpatient clinic waiting list to a point where the outpatient clinic cannot keep up with demand for consultations and treatments. We theorised that because of the day-treatments, patients would progress through the system more quickly and as a result demand for consultations would increase, and this does not seem to be the case.

8.2.4 Access times conclusion

To summarise, the effects of implementing the new day-treatment clinic on access times and waiting lists are shown in Table 8-5.

Table 8-5: Effects of new day-treatment clinic on OR access times, OR waiting list size increase rate and number of non-schedulable patients for the outpatient clinic.

	Experiment	**OR access times**	**OR waiting list size increase rate**	**Outpatient clinic non-schedulable patients**
1	Current situation	0%	0%	0%
2	“336790A” as normal	- 28.3%	- 43.0%	- 51.7%
3	All in OR28	- 34.3%	- 50.1%	- 35.4%

The day-treatment clinic has a significant positive effect on the access times for the OR and the increase rate of the waiting list size of the OR. Furthermore, adding “336790A” surgeries to the treatments in OR28 reduces the OR access times and increase rate of the waiting list size of the OR even further. Implementing OR28 also seems to decrease pressure on the outpatient clinic and reduces the number of patients that are unable to be scheduled around their urgency date.

Although the OR28 was hoped to stop the increase of the OR waiting list size altogether, it seems not to have a great impact on the waiting list. However, the 50% slower growth of the waiting list is still a substantial improvement. To further decrease the increase rate of the OR waiting list, it might be beneficial to split OR treatments that have actions that can and cannot be performed in OR28. In the model, we still use care trajectories that are based on treatments in the normal OR, and, for example, if a patient must receive both a “336193” and another action that is not performable in OR28, the patient will receive both actions in a single OR treatment. We did not test the effect of splitting up this treatment into a separate “336193” in OR28 and another OR treatment in the model.

8.3 Production volume

We will now discuss the effect of implementing the OR28 and new day-treatments on the overall production volume of the model hospital. Then, we will discuss how much is produced – i.e., how many treatments are performed – in OR28 and how much time that saves in the regular OR.

8.3.1 Overall production volume

We will first compare the average number of patients treated each week, or number of patients leaving the system. The distributions per experiment of number of patients treated per week are shown in Table 8-6.

Table 8-6: Statistical summary of number of patients treated per week per experiment.

	Experiment	**Mean**	**Standard deviation**
1	Current situation	47.4	8.9
2	“336790A” as normal	49.4 (+ 2.0)	9.1
3	All in OR28	49.5 (+ 2.1)	9.1

Observe that the increase in number of patients treated each week upon implementing the new day-treatments is not incredibly high. However, the difference in means between experiment 1 and 3 is statistically significant with a 95% level of confidence. The difference in means between experiment 2 and 3 is not.

The number of patients treated would probably increase further if we increased number of patients entering the system in the arrival pattern of patients in the model (see Section 5.3), as the arrival pattern is based on historical data of the hospital and thus is based on only using the regular OR. However, there presumably is a trade-off between accepting more patients, resulting in an increase in production volume, and the decrease in access times and waiting list size increase rate. This trade-off could be explored by performing a sensitivity analysis in future research yet was not performed in this study as the arrival pattern or patient demand is not an input of the model (see Section 4.1).

8.3.2 Production in OR28

Using the number of treatments performed in OR28 per treatment type, we can calculate how much time is saved in the regular OR by opening OR28. Table 8-7 shows these calculations.

Table 8-7: Time saved in regular OR by performing treatments in OR28.

Treatment	**Average number performed in OR28 per experiment**	**Treatment time in regular OR in hours**	**Total time saved in hours**	**Time saved per week in hours**
336193	232.3	1.0	238.7	0.6
336194A	17.6	0.9	16.0	0.04
336298A	468.8	0.5	247.4	0.6
336790A	8.4	1.2	10.0	0.02
		Total:	**557.8 hours**	**1.3 hours**

Over the course of 432 weeks, a total of 512 OR hours are saved by opening OR28, which translates to a little over an hour saved each week in the regular OR.

8.4 Usage of treatment rooms

The usage of capacity of the treatment rooms, meaning the percentage of time a treatment room is in use versus the time it *could* theoretically be in use, is the final output we will discuss in this section. We will go over the effects of implementing OR28 on the usage of capacity of the OR, outpatient clinic and clinical ward separately. Furthermore, we will discuss the usage of OR28 itself.

8.4.1 Usage of OR

Theoretically speaking, the usage of OR should not decrease upon using OR28 and performing the new day-treatments. The waiting list of the OR still increases indefinitely (see Section 8.2.2), meaning capacity of the OR still is not high enough to keep up with demand. However, the usage of the OR does decrease slightly when OR28 is opened. The distributions of both planned and real usage per week are shown in Table 8-8. With planned usage, we mean the percentage of time treatments are scheduled in the OR versus the total time treatments *could* be planned in the OR, and the real usage meaning the percentage of time treatments are actually performed versus the total time treatments *could* be performed in the OR.

Table 8-8: Planned and real usage of OR per week per experiment.

	Experiment	**Planned usage mean**	**Planned usage standard deviation**	**Real usage mean**	**Real usage standard deviation**
1	Current situation	92.5%	10.3%	71.4%	17.3%
2	“336790A” as normal	91.8% (- 0.7%)	10.8%	71.0% (- 0.4%)	17.5%
3	All in OR28	90.5% (- 2.0%)	12.4%	70.0% (- 1.4%)	17.9%

For both planned and real usage of the OR, the difference in means between experiments 1 and 3 are statistically significant with a 95% level of confidence. The differences between experiments 2 and 3 are not. The differences are so slight, however, that we wonder whether they are relevant, and if they would persist if more replications of the simulation are performed.

8.4.2 Usage of clinical ward

In this section we will discuss the “usage” of the clinical ward. In the model, the clinical ward technically has an infinite capacity (see Clinic Beds resource in Table 4-2). Thus, we cannot calculate usage in the regular meaning of the word, as there is no theoretical capacity to compare the actual usage to. As the number of patients the speciality has admitted to the clinic typically should not exceed 5 patients, we counted the number of days in a week where this does occur. The distributions of the number of days per week where the speciality has more than 5 patients admitted into the clinic are shown in Table 8-9.

Table 8-9: Number of days per week that the speciality has over 5 patients admitted into the clinic per experiment.

	Experiment	**Mean**	**Standard deviation**
1	Current situation	1.48	0.90
2	“336790A” as normal	1.32 (- 0.16)	0.90
3	All in OR28	1.30 (- 0.18)	0.90

The difference between experiment 1 and 3 is slight, yet statistically significant with a 95% level of confidence. The difference between experiment 2 and 3 is not.

We also measured the maximum number of patients the speciality has admitted into the clinic each day and take an average per week. The distributions of the average number of patients admitted into clinic per week are shown in Table 8-10.

Table 8-10: Average number of patients admitted into the clinic per week.

	Experiment	**Mean**	**Standard deviation**
1	Current situation	2.17	0.80
2	"336790A" as normal	2.06 (- 0.12)	0.77
3	All in OR28	2.03 (- 0.14)	0.79

Again, the difference between experiment 1 and 3 is slight but statistically significant, and the difference between experiment 2 and 3 is not statistically significant.

Like the usage of the OR, we have doubts whether these differences would persist if more replications were performed. However, it is reassuring that the usage of the clinic did not increase upon shifting the OR treatments to day-treatments. These OR treatments in the current system typically do not require a patient to rest in the clinic for very long. Thus, moving the treatments to OR28 could have resulted in more treatments being performed in the regular OR that would require patients to rest in the clinic for longer. This does not seem to happen.

8.4.3 Usage of outpatient clinic

We will now discuss the effects of implementing the new day-treatments on the usage of the outpatient clinic. We separate the outpatient clinic into usage of the overall outpatient clinic with all the treatment rooms given in Table 5-9 and usage of consultation time available with specialists or AIOSs.

The usage of the outpatient clinic as a whole increases slightly, which is to be expected as OR28 is one of the outpatient clinic treatment rooms, meaning the capacity of the outpatient clinic is lowered. The distributions of usage of the outpatient clinic per week are shown in Table 8-11.

Table 8-11: Planned and real usage of outpatient clinic per week per experiment.

	Experiment	**Planned usage mean**	**Planned usage standard deviation**	**Real usage mean**	**Real usage standard deviation**
1	Current situation	21.3%	3.2%	21.3%	3.2%
2	"336790A" as normal	24.7% (+ 3.4%)	3.7%	24.7% (+ 3.4%)	3.7%
3	All in OR28	24.7% (+ 3.4%)	3.6%	24.7% (+ 3.4%)	3.6%

The difference between experiments 1 and 3 is statistically significant with a 95% level of confidence, the difference between experiments 2 and 3 is not.

Then, the usage of consultation time decreases slightly upon implementing the new day-treatments. In Table 8-12 the distributions of usage of consultation time per week are shown.

Table 8-12: Planned and real usage of consultation time per week per experiment.

	Experiment	**Planned usage mean**	**Planned usage standard deviation**	**Real usage mean**	**Real usage standard deviation**
1	Current situation	84.5%	14.1%	84.4%	14.2%
2	"336790A" as normal	84.1% (- 0.4%)	14.0%	84.1% (- 0.3%)	14.0%
3	All in OR28	83.7% (- 0.8%)	13.7%	83.7% (- 0.7%)	13.8%

However, none of the differences in means between the experiments are statistically significant.

The usage of the outpatient clinic and consultation time are not affected excessively, removing even more of the worry expressed in Section 8.2.3. The opening of OR28 does not seem to cause patients to move through the system faster to the point that the outpatient clinic cannot keep up with the increase in demand.

8.4.4 Usage of OR28

Finally, we will discuss the usage of the new day-treatment clinic, or OR28. The distributions of usage of OR28 per week per experiment can be seen in Table 8-13.

Table 8-13: Planned and real usage of OR28 per week per experiment.

	Experiment	**Planned usage mean**	**Planned usage standard deviation**	**Real usage mean**	**Real usage standard deviation**
2	"336790A" as normal	24.9%	11.1%	18.2%	8.1%
3	All in OR28	25.3%	11.4%	18.6%	8.3%

Observe the sizeable amount of unused capacity of OR28. This means it could be interesting to explore what other treatments could be performed in OR28. The "336193", "336194A" and "336298A" treatments currently set to be performed in OR28 were chosen because they were minimally invasive surgeries that are performed often. The "336790A" treatments are of lesser volume yet do have a significant effect on the OR access times (see Section 8.2.1) when they are performed in OR28. Furthermore, although not statistically significant, performing "336790A" treatments in OR28 alongside the other treatments does improve most other outputs slightly as well. Thus, identifying other minimally invasive treatments that are not necessarily performed often that could be performed in OR28 and what their effect on the outputs of the model would be could be beneficial.

9 Conclusion and discussion

9.1 Conclusion

The overall research goal has been achieved, which is as follows:

> "To analyse the effects of shifting certain surgical treatments to a day-treatment for on the access times, waiting list sizes, production volume and usage of capacity of the OR, clinical ward and outpatient clinic for the speciality of the UMC Utrecht by modelling and simulating the patient treatment process."

We modelled and simulated the patient treatment process of the speciality using a discrete event simulation software package (Tecnomatix Plant Simulation) and found that shifting certain surgical treatments to a day-treatment and implementing a new day-treatment clinic for the speciality had an overall positive effect on waiting times, production volume and usage of capacity.

This was done by answering five research questions.

1. *"What is the conceptual model of the patient treatment process of the speciality of the UMC Utrecht in the current situation?"*

First, we analysed the current patient treatment process and gathered contextual data (Chapter 4). From this contextual data we built the conceptual model by first defining the objective of the model, which is the overall research goal, and the inputs and outputs (Section 184.1). Then, we compiled all necessary components in the model (Table 4-1) and their required level of detail (Table 4-2) to achieve the objective and calculate the outputs.

2. *What is the input data?*

Next, we identified gaps in knowledge that required input data to convert the conceptual model into a discrete-event simulation model. We gathered this data, coded the model, and implemented the findings (Chapter 5).

3. *What are the model validation data?*

We then performed model validation (Chapter 6). We assessed any assumptions and simplifications made during modelling (Table 6-1 and Table 6-2) on their level of confidence and level of impact. Furthermore, we gathered validation data from the real-world hospital to compare to results from the simulation (Section 6.4). Here, we also determined the warm-up period, run-length and number of replications to perform for the simulation.

4. *What are the interventions that need to be to the model for converting certain surgical treatments to day-treatments?*

We designed the interventions and experiments through repeating the first three research questions for the process of the new day-treatments (Chapter 7). We found that an outpatient clinic treatment room, named OR28, would be converted to a day-treatment room and recovery centre (Section 7.1.1), where 3 types of surgical treatments were going to be performed (Section 7.2.2).

5. *What are the effects of the new day-treatment process on access times, waiting list sizes, production volume and usage of treatment rooms for the speciality?*

Finally, we performed the experiments and gathered results. We found a decrease in access times (Section 8.2.1), a decrease in waiting list sizes (Sections 8.2.2 and 8.2.3), an increase in production volume (Section 8.3) and a decrease in usage of treatment rooms (Section 8.4).

9.2 Discussion

Here, we will reflect on and discuss the results of the study as a whole. Individual variables have already been discussed in the previous Chapter 8, and most concerns surrounding validity of individual components or parts of the research have already been addressed in the relevant chapters and sections. Thus, this section is slightly repetitive and will refer to previous sections frequently.

Overall, the implementation of OR28 has a positive effect on the access times, production volume and usage of capacity. Furthermore, arranging OR28 for "336790A" treatments as well as "336193", "336194A" and "336298A" treatments has a statistically significant positive effect on the access times of the OR, and non-significant, yet positive effects on other variables. Thus, opening OR28 for all the treatments mentioned is a good decision for the speciality for the variables examined in this study.

The financial business case for opening OR28 was outside the scope of our study. Opening and arranging the treatment room for these new treatments is obviously going to require an investment, and it is interesting to study whether or when this investment would reach its break-even point. The findings of this report regarding the logistical performance of the redesigned system will help develop this business case.

Furthermore, more improvement in the variables measured could possibly be gained by:

- Splitting of surgeries containing multiple treatments into a day-treatment and surgery as described in Section 8.2.4,
- Identifying the trade-off between accepting more patients and the reduction in access times and OR waiting list growth as described in Section 8.3.1,
- Arranging OR28 for other minimally invasive, low-volume treatments not described in the business case or plan of action for OR28 as described in Section 8.4.4.

It is interesting to explore these ideas in future research.

Our model is generic, so it is able to perform the same analyses for other specialities of the UMC. Changing the input data (Chapter 5) might be sufficient to replicate the study for other specialities similar to the speciality.

We cannot prove complete validity of the model, however, the entire purpose of the model is to be a *sufficiently* accurate representation of reality with respect to its purpose (Robinson, 2014). With the various types of validation performed – see Section 4.5.1, the validity assessment sections of Chapter 5, Chapter 6 and Section 7.3 – the purpose of the model has been achieved. Furthermore, reliability issues have been addressed in Section 6.4 by setting an appropriate warm-up period, run-length and number of replications to perform per experiment.

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Appendix A – Preliminary conceptual model of the speciality's processes

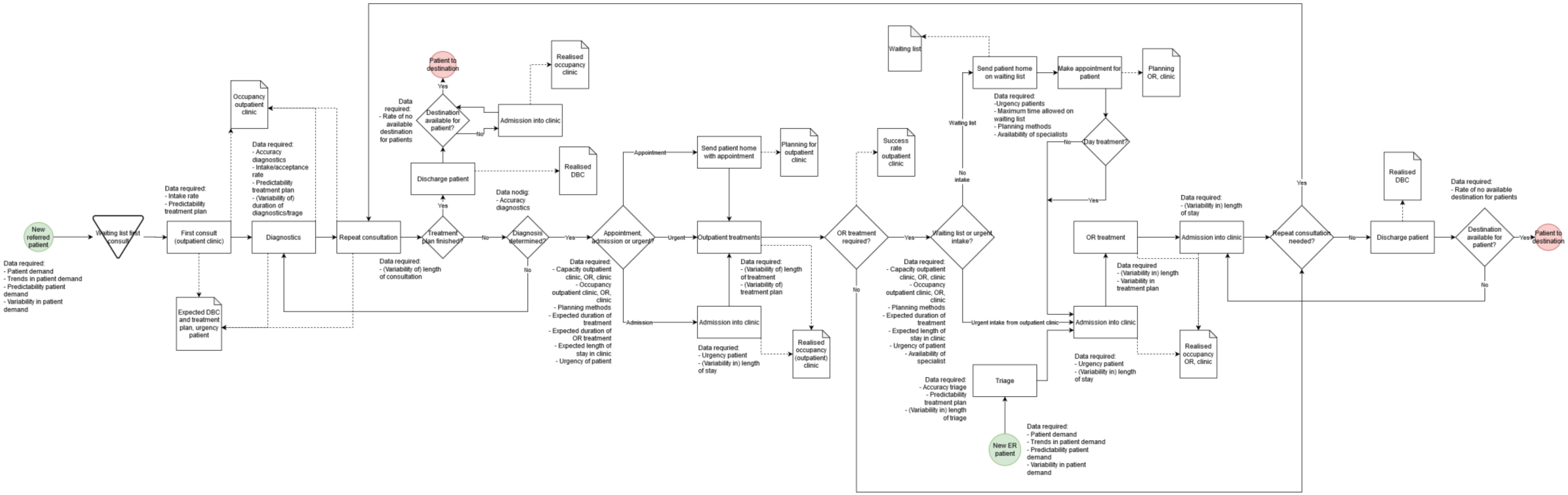

Figure A-1: Preliminary conceptual model of the speciality's processes.

Appendix B – Removed research question

What are the effects of the new day-treatment clinic or admission lounge on waiting times, production volume and usage of treatment rooms for the speciality?

The fifth research question is concerned with the new day-treatment clinic that the speciality wants to implement into their processes as was described in Section 1.1.2. Like with research question 4, the cycle of conceptual modelling and model coding is performed again. This question was divided into three sub-questions.

1. How do you calculate required capacity for the new day-treatment clinic?

In order to design the new day-treatment clinic, for example calculating the optimal parameters like the required amount of beds, treatment rooms and staffing, a systematic literature review will be performed to find the methods of designing such a clinic. Most of the preliminary data for implementing the day-treatment clinics into the conceptual model will already have been gathered in the previous research question. The function of this sub-question is then to find the methods of calculating or gathering the input data. However, if anything that could be used as preliminary data does come up during the literature review this data should be assessed as well.

The systematic literature protocol to be used will now be set up. First the key theoretical concepts will be defined, then inclusion and exclusion criteria for selecting literature will be given, a conceptual matrix will be set up and the search strategy to be used will be described.

Key concepts

- *Day-treatments:* non-surgical procedures to be performed in the outpatient clinic, where a patient is admitted, treated, and discharged within the same day. At the UMC Utrecht, a day-treatment is always a treatment to be performed in the outpatient clinic, and thus are non-surgical procedures. Although new day-treatments are analysed in the previous research question, the speciality already has some day-treatments in place. The patient currently gets admitted into the clinical ward, which is normally reserved for patients staying for longer than a day before or after treatment. The day-treatments are typically minimally invasive procedures. Since this question is only focused on capacity of the clinic, not necessarily its function, this term can be left out of the search string.
- *Day-treatment clinic:* the new proposed clinic where patients receiving a day-treatment get admitted, treated, and discharged instead of in the normal clinical ward. A broader synonym for the day-treatment clinic would just be “clinic”, similar terms might be transit lounge or admission lounge (Singh, 2017; Veneklaas, 2019).
- *Capacity:* the total amount that can be produced (Cambridge Dictionary, n.d.), for the new clinic, this likely means the amount of beds and staffing.

Criteria

To be included in the study, the subject area of the literature or journal must be business or management related. Thus, the plethora of pharmacological and medical studies found when the term clinic or treatment is searched are excluded. Since the question only focuses on capacity of the clinic, including only business and management articles is justified.

Conceptual Matrix

From the constructs, a conceptual matrix is now set up.

Table B-1: Conceptual matrix for systematic literature review.

Constructs	**Related terms**	**Broader terms**	**Narrower terms**
Day-treatment clinic	Transit lounge, Admission lounge	Outpatient clinic, clinical ward, clinic	
Capacity	Dimensions, management		Number of beds, number of staff

Search string

For making the search string, the CIMO search strategy was used to turn the conceptual matrix into a search string.

Table B-2: Search string table for systematic literature review.

CIMO	**Constructs**	**Related terms**	**Broader terms**	**Narrower terms**
Context	Day-treatment clinic	Transit lounge, Admission lounge	Outpatient clinic, clinical ward, clinic	
Intervention	Calculation	Dimensioning		
Mechanism	Capacity	Dimensions	Management	Number of beds, number of staff
Outcomes	Expansion	New		

SCOPUS was selected as the search database since it is multidisciplinary. This research question is related to medical studies in that it concerns a hospital clinic yet also is related to business or management studies since it concerns capacity calculation. Thus, using PubMed or any other purely medicine related databases might result in fewer search results since business journals are not in those databases.

Once methods for calculating the capacity for the day-treatment clinic have been found, the input data can be calculated with the following 2 sub-questions.

2. What is the required capacity of the new day-treatment clinic?

Here the methods found in the previous sub-question should be applied for the new day-treatment clinic.

3. What are the effects of implementing the new day-treatment clinic on the required capacity for the current clinical ward, outpatient clinic and OR for the speciality?

Any changes that can be made in the required capacity for other parts of the speciality should be analysed here.

Then, the new changes can be implemented and coded into the model. Now, the model technically contains 3 systems, which are the current real-world system, and the two theoretical system, one with only the new day-treatments implemented and one with a day-treatment clinic implemented as well.

Appendix C – Visual BPMN Model

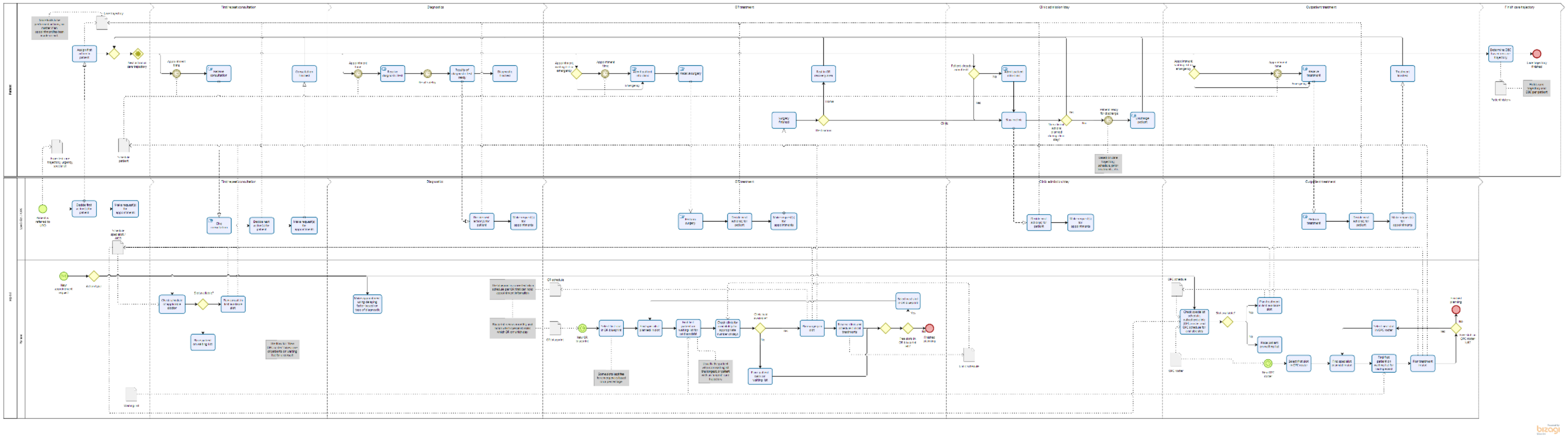

Figure C-1: Visual BPMN Model of the speciality's patient treatment process.

Appendix D – Diagnosis incidence rates

Table D-1: Diagnosis incidence rates (n = 15,8033, T = 2017 to 2019, source = care-cube).

Diagnosis code	Patients	Probability	Cumulative probability
003	1	6.31592E-05	6.31592E-05
009	405	0.025579486	0.025642645
010	473	0.029874313	0.055516958
011	553	0.034927051	0.090444009
012X	0	0	0.090444009
012	91	0.005747489	0.096191499
013	19	0.001200025	0.097391524
014	108	0.006821196	0.10421272
015X	0	0	0.10421272
015	107	0.006758037	0.110970757
016	4	0.000252637	0.111223394
018	393	0.024821575	0.136044969
019	93	0.005873808	0.141918777
020	46	0.002905324	0.144824102
0202	2	0.000126318	0.14495042
021	276	0.017431946	0.162382366
022	5	0.000315796	0.162698162
023	66	0.004168509	0.166866671
0233	1	6.31592E-05	0.16692983
026	3	0.000189478	0.167119308
027	4	0.000252637	0.167371945
028	92	0.005810649	0.173182593
0299	0	0	0.173182593
030	611	0.038590286	0.211772879
031	108	0.006821196	0.218594076
032	394	0.024884734	0.24347881
033	307	0.019389882	0.262868692
034	306	0.019326723	0.282195415
035	651	0.041116655	0.32331207
036	9	0.000568433	0.323880503
037	1022	0.064548727	0.38842923
038	247	0.015600328	0.404029559
040	815	0.051474768	0.455504326
041	594	0.037516579	0.493020906
042X	0	0	0.493020906
042	100	0.006315922	0.499336828
043	31	0.001957936	0.501294764
044	480	0.030316428	0.531611192
045	15	0.000947388	0.53255858
048	150	0.009473884	0.542032464

050	45	0.002842165	0.544874629
0502	1	6.31592E-05	0.544937788
052	25	0.001578981	0.546516769
053	53	0.003347439	0.549864208
0531	1	6.31592E-05	0.549927367
054	210	0.013263437	0.563190804
056	74	0.004673783	0.567864587
058	104	0.006568559	0.574433146
060	110	0.006947515	0.581380661
0601	2	0.000126318	0.581506979
061	30	0.001894777	0.583401756
062	140	0.008842291	0.592244047
063	36	0.002273732	0.594517779
064	31	0.001957936	0.596475715
065	116	0.00732647	0.603802185
066	166	0.010484431	0.614286617
067	2	0.000126318	0.614412935
068	385	0.024316301	0.638729236
069	17	0.001073707	0.639802943
070	22	0.001389503	0.641192446
071	465	0.029369039	0.670561486
072	10	0.000631592	0.671193078
073	37	0.002336891	0.673529969
074	3	0.000189478	0.673719447
075	62	0.003915872	0.677635319
076X	0	0	0.677635319
076	77	0.00486326	0.682498579
077	65	0.00410535	0.686603929
0803	1	6.31592E-05	0.686667088
082	24	0.001515821	0.688182909
083	154	0.009726521	0.69790943
084	8	0.000505274	0.698414703
085	55	0.003473757	0.701888461
086	5	0.000315796	0.702204257
090	21	0.001326344	0.703530601
092	1	6.31592E-05	0.70359376
093	612	0.038653445	0.742247205
094	155	0.00978968	0.752036885
096	26	0.00164214	0.753679025
097	7	0.000442115	0.754121139
098	2912	0.183919661	0.938040801
099	673	0.042506158	0.980546959
101	14	0.000884229	0.981431188
101X	0	0	0.981431188

101X	0	0	0.981431188
102	8	0.000505274	0.981936462
103	3	0.000189478	0.982125939
104	2	0.000126318	0.982252258
108	2	0.000126318	0.982378576
1140	1	6.31592E-05	0.982441736
1199	1	6.31592E-05	0.982504895
120	66	0.004168509	0.986673404
1201	0	0	0.986673404
121	80	0.005052738	0.991726142
124	1	6.31592E-05	0.991789301
1240	1	6.31592E-05	0.99185246
1241	0	0	0.99185246
130	1	6.31592E-05	0.991915619
1301	0	0	0.991915619
1303	1	6.31592E-05	0.991978779
133	1	6.31592E-05	0.992041938
1365	1	6.31592E-05	0.992105097
1396	1	6.31592E-05	0.992168256
1401	1	6.31592E-05	0.992231415
1402	0	0	0.992231415
1403	1	6.31592E-05	0.992294575
163	1	6.31592E-05	0.992357734
170	14	0.000884229	0.993241963
1701	0	0	0.993241963
192	2	0.000126318	0.993368281
204	0	0	0.993368281
2105	1	6.31592E-05	0.993431441
2120	0	0	0.993431441
222	4	0.000252637	0.993684078
223	0	0	0.993684078
247	1	6.31592E-05	0.993747237
2525	1	6.31592E-05	0.993810396
2550	1	6.31592E-05	0.993873555
2550	0	0	0.993873555
2565	1	6.31592E-05	0.993936714
271	0	0	0.993936714
293	0	0	0.993936714
2940	1	6.31592E-05	0.993999874
299	1	6.31592E-05	0.994063033
301	2	0.000126318	0.994189351
301	0	0	0.994189351
301	0	0	0.994189351
3019	1	6.31592E-05	0.994252511

302	2	0.000126318	0.994378829
303	1	6.31592E-05	0.994441988
311	2	0.000126318	0.994568307
319	3	0.000189478	0.994757784
3210	0	0	0.994757784
323	1	6.31592E-05	0.994820944
324	1	6.31592E-05	0.994884103
328	1	6.31592E-05	0.994947262
331	2	0.000126318	0.99507358
3314	0	0	0.99507358
333	1	6.31592E-05	0.99513674
347	2	0.000126318	0.995263058
349	1	6.31592E-05	0.995326217
36	1	6.31592E-05	0.995389377
367	0	0	0.995389377
401	1	6.31592E-05	0.995452536
403	2	0.000126318	0.995578854
406	2	0.000126318	0.995705173
418	2	0.000126318	0.995831491
419	1	6.31592E-05	0.99589465
421	2	0.000126318	0.996020969
441	1	6.31592E-05	0.996084128
449	1	6.31592E-05	0.996147287
452	1	6.31592E-05	0.996210447
501	1	6.31592E-05	0.996273606
506	1	6.31592E-05	0.996336765
608	1	6.31592E-05	0.996399924
709	1	6.31592E-05	0.996463083
732	0	0	0.996463083
741	1	6.31592E-05	0.996526243
753	2	0.000126318	0.996652561
754	4	0.000252637	0.996905198
757	1	6.31592E-05	0.996968357
781	0	0	0.996968357
7907	1	6.31592E-05	0.997031516
799	0	0	0.997031516
801	0	0	0.997031516
802	1	6.31592E-05	0.997094676
811	2	0.000126318	0.997220994
823	1	6.31592E-05	0.997284153
831	9	0.000568433	0.997852586
832	1	6.31592E-05	0.997915746
8906	1	6.31592E-05	0.997978905
964	1	6.31592E-05	0.998042064

9901	2	0.000126318	0.998168382
9905	0	0	0.998168382
B13	1	6.31592E-05	0.998231542
B41	1	6.31592E-05	0.998294701
F11	6	0.000378955	0.998673656
F12	11	0.000694751	0.999368408
G11	1	6.31592E-05	0.999431567
G17	1	6.31592E-05	0.999494726
M11	2	0.000126318	0.999621045
M12	1	6.31592E-05	0.999684204
M13	5	0.000315796	1
Sum	**15833**	**1**	

Appendix E – Probability of chronic patients

Table E-1: Probability of chronic patients per diagnosis (n = 23,323, T = 2014 to 2019, source = care-cube)

Diagnosis	Total patients	Chronic patients	Probability
003	1	0	0
009	3	0	0
010	541	15	0.027726433
011	850	78	0.091764706
012X	131	5	0.038167939
012	23	0	0
013	169	7	0.041420118
014	145	1	0.006896552
015X	4	0	0
015	507	18	0.035502959
016	133	5	0.037593985
018	60	0	0
019	442	10	0.022624434
020	4	0	0
0202	96	3	0.03125
021	1	0	0
022	7	0	0
023	4	0	0
0233	119	1	0.008403361
026	765	22	0.02875817
027	140	10	0.071428571
028	748	9	0.012032086
0299	401	18	0.044887781
030	502	17	0.033864542
031	1051	34	0.032350143
032	15	2	0.133333333
033	1478	216	0.146143437
034	455	4	0.008791209
035	918	17	0.018518519
036	914	27	0.029540481
037	1	0	0
038	154	4	0.025974026
040	67	0	0
041	685	41	0.059854015
042X	12	0	0
042	157	2	0.012738854
043	52	7	0.134615385
044	1	0	0
045	1	0	0
048	34	0	0

050	75	0	0
0502	1	0	0
052	333	7	0.021021021
053	118	0	0
0531	136	1	0.007352941
054	130	12	0.092307692
056	2	0	0
058	39	0	0
060	193	3	0.015544041
0601	44	1	0.022727273
061	44	0	0
062	170	0	0
063	170	0	0
064	2	0	0
065	608	8	0.013157895
066	16	0	0
067	28	1	0.035714286
068	751	75	0.099866844
069	17	0	0
070	46	0	0
071	6	0	0
072	90	1	0.011111111
073	14	0	0
074	110	2	0.018181818
075	123	4	0.032520325
076X	1	0	0
076	38	0	0
077	204	5	0.024509804
0803	7	0	0
082	68	15	0.220588235
083	7	1	0.142857143
084	35	2	0.057142857
085	1	0	0
086	1089	18	0.016528926
090	176	0	0
092	36	0	0
093	10	1	0.1
094	3903	92	0.023571612
096	906	8	0.008830022
097	119	0	0
098	16	4	0.25
099	10	0	0
101	2	0	0
101X	3	0	0

101X	2	0	0
102	71	0	0
103	1	0	0
104	12	0	0
108	88	7	0.079545455
1140	96	1	0.010416667
1199	1	0	0
120	2	0	0
1201	1	0	0
121	1	0	0
124	7	0	0
1240	1	0	0
1241	2	0	0
130	15	0	0
1301	27	0	0
1303	5	0	0
133	3	0	0
1365	8	0	0
1396	17	0	0
1401	1	0	0
1402	4	0	0
1403	1	0	0
163	3	0	0
170	6	0	0
1701	1	0	0
192	1	0	0
204	1	0	0
2105	1	0	0
2120	6	0	0
222	11	0	0
223	134	0	0
247	1	0	0
2525	1	0	0
2550	6	0	0
2550	2	0	0
2565	1	0	0
271	2	0	0
293	17	0	0
2940	1	0	0
299	38	0	0
301	2	0	0
301	21	0	0
301	2	0	0
3019	44	0	0

302	95	0	0
303	12	0	0
311	5	0	0
319	237	0	0
3210	1	0	0
323	2	0	0
324	129	0	0
328	1	0	0
331	11	0	0
3314	1	0	0
333	2	0	0
347	21	0	0
349	1	0	0
36	2	0	0
367	53	0	0
401	11	0	0
403	1	0	0
406	1	0	0
418	9	0	0
419	4	0	0
421	4	0	0
441	1	0	0
449	18	0	0
452	1	0	0
501	4	0	0
506	1	0	0
608	2	0	0
709	1	0	0
732	18	0	0
741	1	0	0
753	60	0	0
754	2	0	0
757	3	0	0
781	1	0	0
7907	4	0	0
799	2	0	0
801	2	0	0
802	2	0	0
811	6	0	0
823	3	0	0
831	1	0	0
832	1	0	0
8906	2	0	0
964	4	0	0

9901	1	0	0
9905	14	0	0
B13	3	0	0
B41	1	0	0
F11	28	0	0
F12	2	0	0
G11	1	0	0
G17	1	0	0
M11	3	0	0
M12	129	0	0
M13	17	0	0
003	1	0	0
009	6	0	0
010	8	0	0
011	2	0	0
012X	2	0	0
012	1	0	0
013	4	0	0

Appendix F – Treatment times per action and clinic times per surgeries (dd:hh:mm:ss)

Table F-1: Treatment time distributions per action and clinic time distributions per surgeries. (n1 = 35,250, T1 = 2017 to 2019, n2 = 186, T2 = 2014 to 2016, source = care-cube)

Action code	**Action type**	**Average treatment time time**	**Standard deviation**	**Median plan time**	**Average clinic admission**	**Standard deviation clinic admission**	**Average day clinic admisison**	**Standard deviation day clinic admission**	**Minimum treatment time**	**Minimum clinic admission**	**Minimum day clinic admisison**
036033	Surgery	3:37:00			4:07:11:00						
036040	Surgery	3:24:50	58:44		4:11:53:36	2:17:37:20			2:28:00	8:15:00	
036053	Surgery	3:07:00			8:23:00						
036131	Surgery	5:24:00			14:06:33:00						
036202	Surgery	1:14:10	44:19		9:32:00	8:50:19	2:47:00		29:00	3:17:00	
036222	Surgery	58:30	16:45		1:20:29:00	1:06:08:05	8:43:00		37:00	22:36:00	
036235	Surgery	50:40	11:35		1:19:48:20	1:05:44:00			40:00	1:01:35:00	
036261	Surgery	2:51:00			5:10:43:00						
036411	Surgery	52:00	33:35		1:03:51:40	14:26	8:51:00	1:24:51	29:00	1:03:35:00	7:51:00
036670	Surgery	1:21:00					4:30:00				
036842	Surgery	1:42:00			2:10:00:00						
036843	Surgery	1:56:50	44:07		2:20:48:20	1:15:30:08			1:08:00	2:03:14:00	
039860	Surgery	59:18	34:22		1:17:34:06	2:03:09:10	7:48:53	2:51:26	14:00		2:00:00
190013	Consult	14:43	5:28	15:00							
190060	Consult	14:18	7:43	15:00							
333741	Surgery	1:21:00	1:24						1:20:00		
333743	Surgery	4:05:00									
335511	Surgery	50:00									
335602	Surgery	1:24:00			14:29:00						
336040J	Surgery	3:50:20	35:34		6:04:27:00	1:10:21:55			3:19:00	5:04:09:00	
336052	Surgery	3:37:00	8:29		6:17:41:30	19:51:28			3:31:00	6:03:39:00	

336092	Surgery	1:23:00			4:20:24:00						
336095	Surgery	3:23:27	51:18		2:17:02:00	1:20:12:13			1:46:00		
336130	Surgery	4:11:27	1:04:18		6:18:16:00	6:21:49:04			2:46:00	3:14:00	
336132	Surgery	29:40	7:02		1:04:46:00		4:45:42	2:02:05	20:00		2:53:00
336132A	Surgery	34:30	7:46				3:20:00		29:00		
336150B	Surgery	2:47:27	53:08		5:01:04:16	3:14:04:31			1:36:00		
336150E	Surgery	2:57:18	1:39:15		5:01:31:00	5:16:06:12			1:28:00	7:14:00	
336151	Surgery	3:33:15	42:42		5:03:00:40	4:00:44:30			2:48:00	1:01:32:00	
336152	Surgery	3:50:00			4:05:30:00						
336168	Surgery	2:33:49	56:43		5:08:36:49	4:12:41:09			1:18:00	10:30:00	
336169	Surgery	3:06:00			8:15:15:00						
336170	Outpatient	15:54	10:58	15:00							
336170B	Surgery	4:03:00							4:03:00		
336172E	Surgery	2:13:16	55:39		1:23:08:44	1:07:21:12			1:09:00	22:36:00	
336173	Surgery	2:25:20	1:21:46		4:12:54:00	4:17:18:07			1:00:00	1:04:47:00	
336174	Outpatient	15:00		15:00							
336175	Surgery	1:29:00	1:28:13		4:08:39:00		9:08:00				
336181	Surgery	2:34:00			5:07:10:00						
336192C	Surgery	1:01:25	27:41		1:05:23:48	12:28:41				20:09:00	
336193	Surgery	1:01:38	53:00		1:22:55:12	3:03:10:21	6:42:15	2:27:04			3:40:00
336194A	Surgery	54:24	34:23		1:14:19:50	1:11:32:30	6:59:52	1:49:43			4:36:00
336196A	Surgery	1:04:12	19:16		1:21:39:00	9:41:14	8:02:00		36:00	1:14:48:00	
336196B	Surgery	52:00					7:49:00				
336197	Surgery	2:05:00	48:14		7:14:37:13	10:00:36:20			49:00	5:18:00	
336200	Surgery	35:18	14:20		1:04:31:00	18:23:29	4:24:08	2:31:01		10:00:00	2:04:00
336202C	Surgery	1:45:06	34:47		1:23:35:18	1:01:22:17			1:10:00	1:01:15:00	
336202E	Surgery	6:57:45	7:05:32		3:05:01:00	2:12:44:00				1:00:00:00	
336203	Surgery	1:31:21	41:10		2:23:30:22	3:01:34:18	7:57:00			10:17:00	
336210	Surgery	58:00			12:02:00						

336210A	Surgery	14:00					3:15:00				
336221	Surgery	1:24:20	1:03:43		5:18:34:00	3:12:17:13	10:45:00		38:00	3:06:58:00	
336223	Surgery	1:11:06	32:51		3:05:55:21	7:11:58:19	8:31:00		39:00	22:56:00	
336229	Surgery	1:27:15	35:47		1:03:22:30	1:28:23			51:00	1:02:20:00	
336230	Surgery	3:56:00	1:53:08		6:17:19:30	4:20:26:55			2:36:00	3:06:59:00	
336231	Surgery	1:46:00			2:04:12:00						
336240	Surgery	1:51:00			12:07:49:00						
336252	Surgery	5:29:48	1:09:54		6:03:16:30	5:14:10:04			4:18:00	1:27:00	
336262	Surgery	1:09:52	37:33		1:04:53:30	14:58:09	5:11:30			3:15:00	2:23:00
336262B	Surgery	1:19:00	37:16		1:22:52:45	22:15:55			41:00	1:01:30:00	
336263	Surgery	2:06:42	1:57:21		2:07:26:00	3:02:38:48	8:00:00		45:00	2:39:00	
336264	Surgery	1:01:40	1:01:41		7:10:30:00		7:58:00				
336272	Surgery	53:26	20:58		2:07:22:45	2:05:18:57	10:55:00	4:24:27	31:00		7:48:00
336272A	Outpatient	16:18	6:07	15:00							
336280	Surgery	51:30	23:54		1:08:19:26	18:28:03	9:43:30	2:34:51	25:00	23:35:00	7:54:00
336291	Surgery	1:18:00	5:17		1:11:11:40	16:38:51			1:14:00	1:01:25:00	
336298A	Surgery	31:40	11:51		1:16:46:58	2:17:04:04	5:35:28	2:58:06	11:00		2:00:00
336310	Surgery	4:04:15	33:59		10:21:14:07	11:03:24:34			3:25:00	10:00:00	
336320	Surgery	3:02:00	46:40						2:29:00		
336340	Surgery	2:07:00			5:03:07:00						
336349	Surgery	1:02:00					3:38:00				
336349A	Surgery	3:13:45	1:06:30		4:21:12:05	4:10:39:36			1:50:00		
336361	Surgery	2:03:18	22:54		3:03:28:18	1:14:31:18			1:29:00	1:00:30:00	
336361B	Surgery	56:24	14:56		1:06:52:00	2:52:05	13:35:00	3:53:20	44:00	1:03:41:00	10:50:00
336401	Surgery	1:16:00			1:05:13:00						
336409	Surgery	2:48:00			2:07:30:00						
336410	Surgery	55:30	24:44		1:03:33:00	38:11			38:00	1:03:06:00	
336420	Surgery	2:11:42	58:53		2:14:47:46	2:01:13:08	6:24:00		54:00	1:32:00	
336420A	Surgery	28:00			1:07:34:00						

336421	Surgery	1:03:30	16:15		4:03:51:00	2:23:43:27			52:00	2:01:08:00	
336422	Surgery	1:12:00	25:27		1:00:05:00		9:04:00		54:00		
336429	Surgery	1:13:00	42:24		1:06:44:00	6:09:11			40:00	1:00:42:00	
336429A	Surgery	1:11:00			1:05:23:00						
336440	Surgery	2:53:42	40:58		3:19:23:11	1:08:17:57			2:03:00	1:02:00	
336444E	Surgery	4:14:00			3:09:40:00						
336445	Surgery	1:34:24	19:30		1:13:29:05	12:25:15			1:01:00	22:58:00	
336449	Surgery	1:29:15	44:19		1:04:35:00	1:10:12			57:00	1:02:56:00	
336450	Surgery	3:08:19	1:09:02		3:05:05:37	1:09:45:20			1:11:00	10:42:00	
336471	Surgery	1:56:00			4:01:25:00						
336478A	Surgery	1:26:00	46:40		1:05:05:00				53:00		
336479	Outpatient	22:18	12:31	15:00							
336479A	Surgery	49:22	19:45		2:03:21:10	5:05:18:14	9:00:17	1:54:42		23:23:00	7:43:00
336480	Surgery	48:30	2:07		1:02:13:30	4:02:32			47:00	23:22:00	
336492	Surgery	40:30	43:21		17:47:30					1:11:35:00	
336493	Surgery	43:30	3:32		1:08:07:30	37:28			41:00	1:07:41:00	
336496	Outpatient	15:00		15:00							
336496B	Surgery	42:30	26:09		1:18:21:30	15:05:48			24:00	1:07:41:00	
336496C	Surgery	1:04:46	1:10:23		1:05:39:09	10:08:01	8:54:45	1:00:15		22:40:00	8:57:00
336499G	Surgery	1:20:40	11:55		1:04:05:30	13:26	10:30:00		1:07:00	1:03:56:00	
336499K	Surgery	3:12:00			3:08:35:00						
336502	Surgery	1:17:00	41:38		14:36:15	15:16:07			38:00		
336520	Surgery	1:23:41	25:58		1:23:47:37	16:45:06			18:00	6:08:00	
336581B	Outpatient	30:00		30:00							
336596	Surgery	1:01:00			2:03:00:00						
336610K	Surgery	1:03:54	26:43		1:01:25:40	3:36:09	10:02:30	3:32:03		22:04:00	7:18:00
336620	Surgery	2:07:00					11:33:00				
336634	Surgery	3:26:00			1:04:00:00						
336661	Outpatient	5:00		5:00							

336670U	Surgery	2:04:00	28:58		1:00:30:08	2:51:50	9:35:24	1:51:48	1:18:00	19:17:00	7:01:00
336680	Surgery	1:35:00	18:51		1:05:05:00		8:08:20	2:02:36	1:07:00		5:36:00
336680A	Surgery	1:11:45	6:30		1:02:49:00		11:41:20	3:59:53	1:03:00		9:00:00
336681	Surgery	39:00			3:05:45:00						
336683	Surgery	1:30:00	18:40		3:03:27:30	3:21:28:03			1:13:00	9:22:00	
336690	Surgery	1:35:00			1:03:59:00						
336690A	Surgery	1:02:20	13:48		1:01:39:20	1:12:04	9:19:40	3:34:52	48:00	1:00:17:00	5:53:00
336692	Surgery	49:00			19:44:00						
336693A	Surgery	47:00	2:49				6:40:00	4:00:24	45:00		3:50:00
336700	Surgery	2:56:00					10:59:00				
336710	Surgery	31:30	16:15				12:01:00		20:00		
336720	Surgery	35:30	11:15		1:00:15:00		4:26:33	1:52:28	24:00		2:05:00
336740	Surgery	1:01:48	18:06		1:11:41:00	14:38:59	7:25:00		42:00	1:00:30:00	
336751	Surgery	1:15:00					10:50:00				
336763	Surgery	2:55:00	28:17						2:35:00		
336790	Surgery	2:09:32	24:31		1:02:18:00		9:00:39	2:05:34	1:11:00		3:42:00
336790A	Surgery	1:11:10	22:00		1:05:19:07	3:07:23	8:23:25	2:41:56	27:00	1:02:47:00	2:02:00
336803	Surgery	25:00	9:00				7:19:00		16:00		
336805	Surgery	35:00									
336806A	Surgery	27:00									
336807	Surgery	41:00									
336810A	Surgery	44:33	19:23		23:50:00	1:12:07	6:00:00	56:52	20:00	22:59:00	4:40:00
336810B	Surgery	36:00			22:47:00						
336811	Surgery	51:00			2:11:31:00						
336820	Surgery	56:31	15:05		1:00:22:00	55:51	4:41:30	2:35:00	35:00	23:43:00	2:03:00
336843A	Surgery	46:40	14:34		1:00:50:00	1:41:49			33:00	23:38:00	
336843D	Surgery	50:00	21:12		22:54:00		3:28:00		35:00		
336846A	Surgery	1:20:27	23:27		2:05:45:38	12:41:03			56:00	1:05:15:00	
336880	Surgery	33:55	13:24		1:01:35:00	3:04:39	8:26:00	1:40:31	9:00	22:51:00	6:48:00

336891	Surgery	1:15:00			3:06:51:00						
337319	Surgery	30:00			1:01:02:00						
337334D	Surgery	2:36:30	33:01		3:17:07:20	2:11:01:04			1:53:00		
337352	Surgery	1:51:42	33:45		2:23:52:00	1:07:05:35			1:20:00	1:06:02:00	
338905	Surgery	55:12	47:36		7:01:05:40	8:03:28:40				1:00:59:00	
338919H	Surgery	44:00	6:14		1:04:54:00		8:47:00		39:00		
339160	Outpatient	27:02	7:32	25:00							
339161D	Surgery	1:53:30	45:52		1:15:08:22	1:06:16:51	8:30:20	2:03:42			5:39:00
339163	Outpatient	5:00		5:00							
339166	Surgery	58:30	9:28		1:16:11:30	1:02:38:06			47:00	1:00:49:00	
339360	Surgery	1:06:04	57:45		2:16:20:10		3:19:00			1:26:00	
339370	Surgery	52:00			1:05:13:00						
339486A	Outpatient	25:41	7:14	30:00							
339488A	Outpatient	16:10	10:13	15:00							
339488C	Outpatient	16:48	4:32	15:00							
339489	Outpatient	13:56	7:11	15:00							
339866	Outpatient	17:22	5:59	15:00							
339869A	Outpatient	1:13:53	24:34	1:00:00							
339869K	Outpatient	1:07:29	17:35	1:00:00							
339872	Outpatient	18:45	7:30	15:00							
339880	Outpatient	5:47	4:17	5:00							
339880A	Outpatient	28:13	8:08	30:00							
339900B	Surgery	47:42	11:45				5:18:46	1:59:38	36:00		2:19:00
339954B	Outpatient	5:00		5:00							
339956	Outpatient	5:00		5:00							
339996Z	Outpatient	6:30	6:42	5:00							
339997C	Outpatient	16:16	3:46	15:00							
415000D	Consult	15:00	2:30	15:00							
415099A	Outpatient	5:06	45	5:00							

415099D	Outpatient	5:00		5:00								
419040	Outpatient	20:24	12:24	15:00								
980996	Consult	4:20:00		4:20:00								
980996A	Consult	22:39	19:01	15:00								
980996B	Consult	16:55	8:41	15:00								
980996T	Consult	8:18	7:32	5:00								
984300	Consult	5:49	3:17	5:00								
190090	Clinical											
190218	Clinical											
190021	Clinical											
987777A	Clinical											
987777	Clinical											
336173B	Outpatient	15:00	0	15:00								
336190	Outpatient	5:00	0	5:00								
336260	Outpatient	21:47	25:38	5:00								
336581A	Outpatient	30:00	0	30:00								
336899D	Outpatient	15:00	0	15:00								
338900H	Outpatient	20:00	0	20:00								
338945	Outpatient	5:00	0	5:00								
339160G	Outpatient	22:30	10:36	30:00								
339164	Outpatient	5:00	0	5:00								
339483H	Outpatient	5:00	0	5:00								
339492B	Outpatient	16:00	24:35	5:00								
339758	Outpatient	10:00	7:04	5:00								
339830F	Outpatient	5:00	0	5:00								
339959	Outpatient	2:12:30	3:00:18	4:20:00								
339979G	Outpatient	5:44	2:39	5:00								