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MASTER THESIS

Developing Hospital@home Services at Rijnstate

Author
Eva J. P. Soontiëns

Supervisors University of Twente
Prof. Dr. W. H. van Harten
Prof. Dr. Ir. E. W. Hans

Supervisors Rijnstate
Dr. P. Joustra

Industrial Engineering and Management
Faculty of Behavioural, Management and Social Sciences

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Management summary

Context

Recently, Rijnstate started developing their 'Virtueel Zorgcentrum' (VZC). The VZC is a virtual care and monitoring centre used to monitor patients in their home situation (Rijnstate, 2020). It is not yet known how the hospital care at home can best be organised. A master thesis has been conducted by Stoker (2019), which laid the foundation for the development of the hospital care at home at Rijnstate. It remains unclear whether the care at home can best be provided by Rijnstate alone, or if external (home care) organizations should be involved to obtain the required capacity. Rijnstate would like to investigate how hospital care at home can be organized as effectively as possible in order to keep the care demand towards hospitals manageable, to promote the efficiency of care provision and to increase patient satisfaction.

Goal

To (1) perform a benchmark of hospital@home services and the link with hospital control centres in a number of large (STZ) hospitals, and to (2) develop a quantitative model that can prospectively assess and compare the previously defined service designs and can be used for the further development of the Rijnstate@home services in terms of capacity management.

Approach

The research consists of two parts, both contributing to the development of the model and Rijnstate's @home services. First, a comparison of hospital@home services within the mProve network is made following the benchmarking method of Van Hoorn et al. (2006). This benchmark provides insight into the current developments of this new type of care provision in the Netherlands and creates a solid foundation for the second part. After performing a literature search, we find that simulation is the most appropriate modelling technique. In the second part of the research, the simulation model is created following the steps for a simulation study as described by Law (2014).

Results

The most important findings of the benchmark are:

- No variety exists in the service design used by the benchmarking partners for the provision of virtual care, meaning that the way virtual care is delivered to the patient is organized in the same way. When a patient is monitored at home, he or she should visit the hospital when a complication occurs and is treated at a certain specialty.
- The different characteristics of the patient groups and initiatives make it harder to compare services across hospitals.

- Although the path of development of the provision of care at home is different in each hospital, the goal of each hospital is to centralize initiatives in the long term.
- Combining different hospital@home services in an unexplored area in most hospitals.
- The amount of available (quantitative) data is not very extensive. Measuring and showing results can be a great incentive for people to devote more time to the initiatives for providing hospital care at home.

The most important findings of the conducted experiments are:

- The decision on the number of nurses should be based on the utilization as well as the waiting time in queues prior to the involved server. The simulation model can assist the user in making this trade-off.
- Nurses should have multiple tasks, since the utilization rate is very low when solely treating patients with complications. When a larger scale is reached, the issue of the low utilization rate will be no object.
- Including only outpatient groups requires less time for patient admission, since less unique patients are admitted. The utilization of nurses is higher because the number of outpatients included at the same time is greater than when inpatients are included.
- The performance of the system depends on the arrival rate and length of stay of the individual patient groups. This emphasizes the importance of the choice of input parameters. When the arrival rate or length of stay of one of the patient groups has been estimated incorrectly, this significantly changes the output.

Conclusion

The benchmark has been performed amongst the hospitals in the mProve network. The field truly is still in the development phase in most hospitals, resulting in a small amount of available data. No uniform pattern or definition of patient groups is found. This also results in a discrepancy in required resources. The large variety of goals and initiatives can also be used to our advantage. In this way, we can compare which type of care delivers the best quality of care, financial advantage, positive patient experience, and employee satisfaction, if more data becomes available in the future. The simulation model can be used for the intended purposes. The model is validated together with stakeholders and the experiments yielded the expected results. At this point the input data is not reliable enough to make detailed analyses. It is possible to compare scenarios and designs, but choices for parameters (such as the number of nurses) cannot be accepted directly. The experiments give insight into the impact of the number of patients and the patientmix, for example the difference between virtual care for inpatients and outpatients. Furthermore, they provide information about the considerations to make when choosing parameters and the influence of input data on the results.

Discussion

The two main issues experienced during this research were the lack of data and the discrepancy between different definitions. A large amount of the input data is based on expert opinions and data from other processes. When the input data is retrieved from the reality, this will increase the reliability of the model and enable the user to perform more detailed analysis. In particular the data related to the patient groups. It became clear from the sensitivity analysis that this input data directly affects the output of the model. The need for uniform definitions and parameters resulted from both the benchmark and the simulation model. Making a direct comparison between hospitals is hard, since the patientmix within the initiatives is different across hospitals. Finding rules of thumb, such as the number of patients per nurse, is not possible because of this. The impact of including different patient groups in the service is also visible in the experiment results. To increase the comparability of hospitals, the mProve network should aim to develop a universal definition of virtual care and parameters that can be measured across all its hospitals.

Acknowledgements

I am grateful to all the people who have contributed to this report. I would like to thank Rijnstate for giving me the opportunity to perform this research at their hospital and to make use of their facilities. I would like to thank Paul Joustra, my supervisor from Rijnstate, in particular. His expertise about simulation and capacity management in the hospital environment helped me a lot. Without his constructive feedback the report would not have been what it is today. Furthermore, I would like to thank Wim van Harten and Erwin Hans, who have been my supervisors from the University of Twente. They guided me through the process and made sure I stayed on track. Aside from my supervisors, I would like to thank my collegues from the Rijnstate capacity management team for the warm welcome. I am looking forward to continue working with them in the future.

Eva Soontiëns
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Contents

List of Abbreviations

DEA	**D**ata **E**nvelopment **A**nalysis
DES	**D**iscrete **E**vent **S**imulation
DMU	**D**ecision **M**aking **U**nit
ED	**E**mergency **D**epartment
EPD	**E**lectronic **P**atient **D**ossier
HCC	**H**ospital **C**ontrol **C**entre
ILP	**I**nteger **L**inear **P**rogramming
KPI	**K**ey **P**erformance **I**ndicator
LOS	**L**ength **O**f **S**tay
NFU	**N**ederlandse **F**ederatie van **U**niversitair Medische Centra
OLS	**O**rdinary **L**east **S**quares
OPAT	**O**utpatient **P**arenteral **A**ntimicrobial **T**herapy
PPM	**P**artial **P**erformance **M**easures
SFA	**S**tochastic **F**rontier **A**nalysis
STZ	**S**amenwerkende **T**opklinische (opleidings)**Z**iekenhuizen
TFP	**T**otal **F**actor **P**roductivity
VC	**V**irtual **C**are
VZC	**V**irteel **Z**orgcentrum

Chapter 1

Introduction

This chapter provides an introduction to Rijnstate and the research context and motivation. Based on the problem description, a research goal and approach are determined.

1.1 Introduction to Rijnstate

Rijnstate is a hospital in the region of Arnhem, Rheden and De Liemers, that offers care at four locations in the Netherlands: Arnhem, Zevenaar, Velp and Arnhem-Zuid. Currently, around 5,000 employees are working at the hospital, to serve the 450,000 inhabitants of the catchment area. Rijnstate is one of the largest healthcare providers in the Netherlands and the largest employer in the region. The location in Arnhem is one of the 26 major training hospitals in the Netherlands and provides highly specialized medical care. These major training hospitals work together in the association of Samenwerkende Topklinische Ziekenhuizen (STZ). In addition, Rijnstate is part of the mProve network. Together with the five other hospitals in the network they share best practices and compare results (Rijnstate, n.d.). They work on projects that cannot be realized by each hospital individually.

In 2018 the Minister of Medical Care and Sport and other parties in specialty medical care signed the 'hoofdlijnenakkoord'. In this agreement, a number of topics were settled including care in the right place, reducing regulatory pressure and handling challenges in the labour market. The agreement is a combination of, on the one hand, limiting the growth of health expenses, and on the other hand, keeping care accessible for everyone (Ministerie van Volksgezondheid, Welzijn en Sport, 2018). It involves the limiting growth of specialized medical care expenses from 0.8% in 2019 to 0.0% in 2022 (Rijksoverheid, 2018). To prevent care becoming more expensive innovative ways of care, such as e-health, can be used.

1.2 Research context and motivation

Increasingly, hospitals provide care outside the traditional hospital walls and concepts like a 'virtual hospital' and 'hospital@home'-services are organized. According to Gupta Strategists, approximately 46% of hospital patients in the Netherlands could receive the care they need at home, rather than in the hospital itself (Gupta Strategists, 2016). Rijnstate aims to reduce the length of stay of patients by delivering more hospital care at home or by preventing hospital admission through the Rijnstate@home project (Stoker, 2019). The goal of this project is to provide care at home when possible, and at the hospital when needed. A master thesis has been conducted by Stoker (2019), which laid the foundation for the development of the hospital care at home at Rijnstate.

A problem that emerged in the research is that a variety of terms is used in literature to describe hospital care at home (Stoker, 2019). To make comparison of initiatives possible, the term 'hospital care at home' is defined by Stoker to include four categories of healthcare services:

1. **Admission avoidance**: Preventing hospital admission of elderly or patients with a chronic disease, persons who are at a high risk of hospital admission.
2. **Early discharge**: Shorten the period of hospitalization for patients after they have had surgery.
3. **Supported discharge**: Support patients at home to make the transition from hospital care to the home situation without care smaller. Patients are not sent home earlier.
4. **Home hospitalization**: Providing care to patients at home, that would usually be given at the hospital. Examples are immunotherapy or dialysis at home.

The goal of the thesis was to provide insight in how to organize hospital care at home and to describe alternative designs with their facilitators and barriers. By means of a decision tree, seven alternative service delivery scenarios were described by Stoker (2019). Several considerations need to be made when selecting a scenario, concerning the cooperation with external organizations, if the patient will visit the hospital or staff visits the patient, the combination of in-house an @home activities, and the combination of medical specialties. Appendix A depicts the decision tree with the service designs.

There are multiple initiatives within the Rijnstate@home project, which can be roughly spilt into two branches. The first one being the medication- and treatment@home program. In May 2021 a mobile medical team of oncology nurses started with administering oncolytics (chemotherapy and immunotherapy for cancer patients) at home (Rijnstate, 2021). They began with home administration of two drugs for patients who live within a radius of 25 kilometres from the hospital. The drugs include pembrolizumab for people with lung and bladder cancer and zoledronic acid to prevent bone problems.

Another type of care that has been moved to the home situation is Outpatient Parenteral Antimicrobial Therapy (OPAT), which is the long-term treatment with antibiotics through an IV. The OPAT team is a multidisciplinary team of infectiologists, pharmacists, and nurse specialists. They educate patients about the antibiotics and possible side effects, and are in close contact with the home care organisation that is administering the antibiotics. Because of this initiative, the length of stay of these patients in the hospital can be shortened.

Recently, Rijnstate started developing a second branch: the 'Virtueel Zorgcentrum' (VZC). The VZC is a virtual care and monitoring centre used to monitor patients in their home situation (Rijnstate, 2020). At the moment, clinical COVID and COPD patients, who meet predefined criteria, can be monitored at home using an oximeter. In the upcoming period, several other patient groups will be added to the VZC. The goal and monitoring devices are adjusted to the needs of each patient group. Appendix B depicts an overview of patient groups that Rijnstate intends to include in the VZC.

Rijnstate cooperates with Philips to investigate the use of a biosensor (Healthdot) to safely monitor patients at home. The new sensor can be combined with existing data platforms. In this way, Philips wants to support the transition from care in the hospital to the home situation. The Healthdot sensor measures a patient's respiratory rate, heart rate, activity and body position. The vital signs are measured by the sensor every five minutes for 14 days and send to one or more data platforms. Rijnstate intends to use the Healthdot when monitoring bariatric patients at home in the Vitalys@home project.

1.3 Problem description

It is not yet known how the hospital care at home can best be organised. It remains unclear whether the care at home can best be provided by Rijnstate alone, or if external (home care) organizations should be involved to obtain the required capacity. Rijnstate would like to investigate how hospital care at home can be organized as effectively as possible in order to keep the care demand towards hospitals manageable, to promote the efficiency of care provision and to increase patient satisfaction. Multiple designs of the @home services have been qualitatively explored. However, a (preferably prospective) qualitative assessment is yet to be performed. The assignment Rijnstate proposes for this master thesis is to perform a benchmark of hospital@home initiatives and the link with hospital control centres (HCCs) in a number of large (STZ) hospitals, preferably in the mProve network. The goal of the benchmark should be to identify the current situation regarding the hospital@home services. More specific, to find out how the services are organised, e.g. which patient groups are included, and if there is a link with a hospital control centre. Further, to perform a first pilot in optimizing the Rijnstate@home services in view of the interaction between the in-house and @home activities.

The hospital capacity is influenced in two ways by the provision of the @home activities. On the one hand, additional resources are needed to provide hospital care at home. More nurses are needed to treat the same number of patients, due to the travel time and the fact that a nurse can only treat one patient at a time. On the other hand, providing care and monitoring patients at home may result in a decreasing number of hospital admissions and a shorter length of stay, which may reduce the capacity and resources needed for the in-house activities. The interaction between these two changes is still unclear.

A question raised by Stoker (2019) is who should provide the care to the patient. According to the research, collaboration between departments is considered as an important factor for the success of the services. For the medication- and treatment@home services, patients can be visited by a general or specialized nurse. Some of these services can also be outsourced to external (home care) organisations. Within the VZC project, patients are currently not visited at home. They are monitored through the Engage application and contacted by phone. When the health of a patient deteriorates, the patient is either asked to travel to the hospital or picked up by an ambulance, depending on the severity of the complication. There are many possible configurations of these services, as described by Stoker (2019). To determine how departments can collaborate and which services can be performed by the same nurses, insight needs to be created in the required capacity for the service designs. Since the VZC is still in development, a solution needs to be created that provides insight into the current situation, but is also prepared for the analysis of future developments.

Within the medication- and treatment@home project, there is a lack of scheduling and routing of nurses and other resources. They experience the logistical challenge of getting a nurse and correct resources at the patient at the right time. Patients within the medication- and treatment@home program are visited according to a predetermined schedule, and their treatment can thus be planned. For providing certain types of medication and treatment at home, more nurses are needed than when the care would be provided in the hospital. In combination with the inefficient routing of nurses, this lead to an increase in needed capacity and higher costs of care. The fact that there are more nurses needed to provide the same type of care is not seen as a problem by Rijnstate, since they would like to invest in this new development. The inefficient use of capacity, by a lack of scheduling and routing, can be improved and is therefore included in the problem cluster.

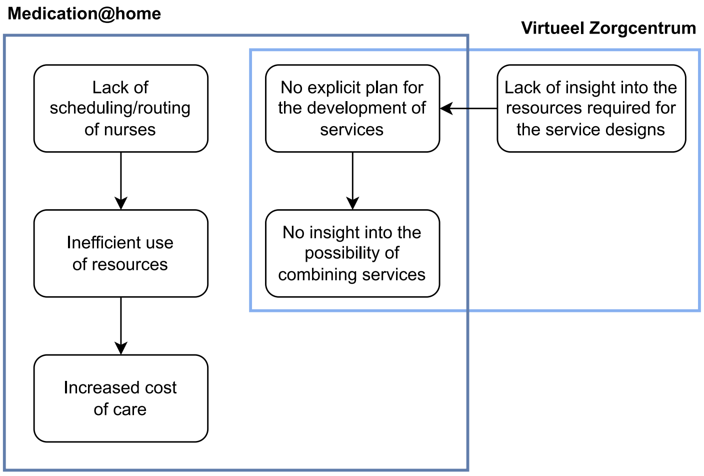


FIGURE 1.1: Problem cluster for the Rijnstate@home project.

The most important findings are combined into a problem cluster, which is depicted in Figure 1.1. There are four rules of thumb which can help to identify the core problem, as described by Heerkens and Van Winden (2017) in "Solving Managerial Problems Systematically":

1. *The problem cluster shows all problems you identified as such. You are convinced that there is a relationship with other problems.*
2. *Follow the chain of problems back to these problems which have no direct cause themselves.*
3. *If you cannot influence something, then it cannot become a core problem.*
4. *If more than one problem in the cluster remains, you should choose to fix the most important problem. The most important problem is whichever one whose solution would have the greatest impact effect at the lowest cost.*

When tracing the chain of problems back to the problems that have no direct cause themselves, there are two problems remaining. The lack of scheduling and routing of resources for the medication- and treatment@home services and the lack of insight into the required capacity for the service designs. Since both of these problems can be influenced, we should choose to solve the most important one.

The assignment as described by Rijnstate, to perform a first pilot in optimizing the Rijnstate@home services, is very broad. Optimizing the routing of the nurses of the medication- and treatment@home project may require a ILP model as proposed by Zwier (2021). Development and analysis of the possible service designs for the Virtueel Zorgcentrum will involve modelling through simulation. A combination of the two can be made, but is to extensive for the duration of this research. The core problem to solve at this point, is the lack of insight into the capacity required for the service designs. These insights can support Rijnstate in their decision about the most suitable service designs at each point during the development process of the @home services. When decisions have been made about the design and possible combination of services, the processes can be optimized. The goal of this explorative study will be:

To (1) perform a benchmark of hospital@home services and the link with hospital control centres in a number of large (STZ) hospitals, and to (2) develop a quantitative model that can prospectively assess and compare the previously defined service designs and can be used for the further development of the Rijnstate@home services in terms of capacity management.

1.4 Scope

To create a starting point for the research, Rijnstate proposes to perform a benchmark of hospital@home services and the link with hospital control centres in a number of large (STZ) hospitals. Based on a short literature search, we define a 'hospital control centre', also often referred to as a 'hospital command centre', to be a central place that includes all data sources and brings together relevant information about supply and demand of capacity within the hospital. In the HCC real-time data and smart calculation models are used for predictive analyses and to support balanced decision making. Appendix C contains a summary of the search for a definition. The focus of the benchmark should be on the hospital@home services, in order to be relevant to this research. The presence and size of a HCC at the benchmarking partners will be taken into account, along with the link to the provision of hospital care at home. Other organisational details of the HCC will not be considered, since this will make the benchmark to extensive for the intended use. By 'hospital@home services' we mean the provision of hospital care at home (home hospitalization) and the monitoring and coaching of patients in the home situation to prevent (re)admission to the hospital or to provide early and/or supported discharge (Stoker, 2019). The service designs developed by Stoker (2019) concern the provision of 'virtual care', this includes the monitoring and coaching of patients in the home situation to prevent (re)admission to the hospital or to provide early and/or supported discharge. These are the services provided by the Virtueel Zorgcentrum at Rijnstate. The other part of the hospital@home services, the provision of hospital care at home (home hospitalization), corresponds to the medication- and treatment@home project.

Besides influencing the capacity of the hospital, providing more care at home might also impact the region's home care organisation and general practitioners. The influence on their capacity and processes is outside the scope of this research. Services that have already been moved to the home situation in previous years, such as the OPAT, are also not included since they are not part of the Rijnstate@home project.

1.5 Research model

This research consists of two parts, both contributing to the development of the Rijnstate@home project. The first goal is to perform a benchmark of hospital@home services and the link with hospital control centres in a number of large (STZ) hospitals. This benchmark will provide insight into the current developments of this new type of care provision in the Netherlands. The second goal is to provide insight into the capacity management of Rijnstate's hospital care at home and its influence on the in-house activities. The goals are divided into smaller problems by formulating several research questions for each goal. The subquestions and their research methods are as follows:

1 Perform a benchmark of hospital@home services and the link with hospital control centres in a number of large (STZ) hospitals

1.1 *Which benchmark method is most suitable for this research?*

The benchmark method proposed by Rijnstate is the method proposed by Van Lent, De Beer, & Van Harten (2010). To determine whether this is the most appropriate method for this research, it needs to be compared to other available benchmarking methods by means of a literature research. Appendix D contains the search strings and a detailed description of this research.

1.2 *What are relevant performance indicators for this benchmark?*

An important step in all benchmarking methods is to develop relevant and comparable indicators. To select relevant performance indicators, a literature research is performed. Appendix D contains the search strings and a detailed description of this research. Furthermore, expert opinion is used to derive indicators by consulting stakeholders on their view on appropriate indicators. After the performance indicators have been defined, a method needs to be formulated on how to measure them.

2 Develop a quantitative model that can prospectively assess and compare the previously defined service designs and can be used for the further development of the Rijnstate@home services in terms of capacity management

2.1 *What research has already been done concerning optimizing hospital@home services?*

To create a starting point for the modelling process, we need to identify what research has already been done in this field and what information is readily available. A literature research is performed to find existing research concerning hospital@home services and their optimization. Appendix D contains the search strings and a detailed description of this research.

2.2 *What is the current situation at Rijnstate concerning their hospital@home services?*

Before we can start modelling the various service delivery scenarios, the current situation regarding the Rijnstate@home project needs to be explored. The current situation at Rijnstate is analysed by talking to those involved in the development of the virtual care services and by reading all relevant documentation concerning the project. This will result in an overview and chart of the current processes.

2.3 *How can the previously formulated service delivery scenarios be modelled?*

Many methods exist that can be used to model the various service delivery scenarios. Subsequent to the analysis of the current situation, research into possible modelling techniques needs to be done using previous research resulting from Question 2.1 (if any) and knowledge from various IEM courses. Based on the available information and models that have or have not been created already, a suitable modelling approach needs to be selected. Section 4.1 contains the resulting modelling approach.

Chapter 2

Theoretical framework

In this chapter, the knowledge questions defined in Section 1.5 are answered based on existing literature. The first section contains information about benchmarking processes, methods, and indicators. The second section focuses on the modelling of hospital@home services. The third and final section includes the answers to our knowledge questions. Appendix D includes the search strings criteria for the literature selection.

2.1 Benchmarking

Benchmarking is a widely used management tool, and one of the methods found in the continuous quality improvement (CQI) toolbox (Mosel and Gift, 1994). Many articles have been written about the benchmarking process and various definitions are suggested. In this research, the definition Mosel and Gift (1994) propose in their article about collaborative benchmarking in healthcare is used:

Healthcare benchmarking is "a continual and collaborative discipline, which involves measuring and comparing the results of key processes with the best performers and adapting best practices to achieve breakthrough process improvements in support of healthier communities."

Various typologies have been developed in order to classify benchmarking models, each having its own pros and cons. There is no standard methodology to classify benchmarking models in the context of healthcare (Wind and Van Harten, 2017). Fong, Cheng, and Ho (1998) developed a scheme incorporating the nature of the referent other, content of the benchmark, and purpose of the relationship. Wind and Van Harten (2017) successfully used this scheme to classify benchmarking models in the context of healthcare benchmarking. This scheme, depicted in Table 2.1, will be used for this research.

For the benchmarking of the HCC and hospital@home services in hospitals throughout the Netherlands, we are working with benchmarking partners from the same industry. The comparison will not be between various departments within Rijnstate. To determine the nature of the referent other, we are left with the choice between competitor and industry benchmarking. Hospitals do not necessarily have to be competitors to participate in this study, hence we are performing an industry benchmark.

The benchmark is limited to the processes of the hospital control centre and the provision of hospital care at home. Therefore, the content of the benchmarking can be categorized as a process benchmark. The purpose of this research will be to explore the possibility of learning from other hospitals. The purpose of the benchmarking relationship is therefore not to gain superiority over others, but to collaborate with them by sharing knowledge. In

Classification	Type	Meaning
Nature of referent other	Internal	Comparing within one organization about the performance of similar business units or processes.
	Competitor	Comparing with direct competitors, catch up or even surpass their overall performance.
	Industry	Comparing with company in the same industry, including noncompetitors.
	Generic	Comparing with an organization which extends beyond industry boundaries.
	Global	Comparing with an organization where its geographical location extends beyond country.
Content of benchmarking	Process	Pertaining to discrete work processes and operating systems.
	Functional	Application of the process benchmarking that compares particular business functions at two or more organizations.
	Performance	Concerning outcome characteristics, quantifiable in terms of price, speed, reliability, etc.
	Strategic	Involving assessment of strategic rather than operational matters.
Purpose of the relationship	Competitive	Comparison for gaining superiority over others.
	Collaborative	Comparison for developing a learning atmosphere and sharing of knowledge.

TABLE 2.1: Classification scheme for benchmarking. Reprinted from "Benchmarking: a general reading for management practitioners" (p. 410) by Fong, S. W., Cheng, E. W., & Ho, D. C. (1998).

the following section, various benchmarking processes for healthcare found in literature are compared.

2.1.1 Processes

Benchmarking was first implemented by Xerox Corporation in 1982 as part of a new quality program. Nowadays, benchmarking is a widely applied technique in many industries. Multiple benchmarking processes are presented in literature (Van Lent, De Beer, and Van Harten, 2010)(Spendolini, 1992)(Van Hoorn et al., 2006). Even though they are applied across various industries, they all include some common characteristics and components. In 1992, Spendolini (1992) compared 24 benchmarking processes and found four common components (Van Lent, De Beer, and Van Harten, 2010). As a contribution to the NFU benchmarking OR project, Van Hoorn, Van Houdenhoven, Wullink, Hans, and Kazemier (2006) created a benchmarking process for the application in healthcare. Based on these two models and additional case studies, Van Lent et al. (2010) created a framework for international benchmarking of specialty hospitals. The steps added to the benchmarking process by Van Lent et al. (2010) are the forming of a benchmarking team, the identification phase of stakeholders, and the construction of a framework to structure the indicators. Furthermore, an evaluation of the implementation of the improvement plans is added to the process. This model is proposed by Rijnstate for this particular benchmark. Besides the application of the processes developed by Van Hoorn et al. (2006) and Van Lent et al. (2010), no benchmark processes specifically created for the application in healthcare have been found. Table 2.2 describes both benchmarking processes.

The processes of Van Hoorn et al. (2006) and Van Lent et al. (2010) are almost identical. The main advantage of the 13 steps process of Van Lent et al. (2010), is the additional step of structuring the performance indicators. This sixth step in the process ensures that indicators are relevant and comparable. The proposed model for this is the EFQM (European Foundation for Quality Management) model, considering strategic aspects, processes and outcomes (Van Lent, De Beer, and Van Harten, 2010). An advantage of the process of Van Hoorn et al. (2006), is that it involves less extensive research into stakeholders. Furthermore, forming a benchmarking team is not applicable to this research and also the implementation and evaluation of improvement plans are outside the scope. All things considered, the process of Van Lent et al. (2010) seems to extensive for the objective of the benchmark this research.

Therefore, the process of Van Hoorn et al. (2006) is preferred. Steps 1 to 7 of the process are included in this study. The processes by Van Hoorn et al. (2010), does not specify which method should be used for the analysis and comparison of the performance indicators. In the following section, various methods from literature are compared.

Van Hoorn's benchmarking process		Van Lent's benchmarking process	
Step	**Activity**	**Step**	**Activity**
1	Make a choice for a comparable process	1	Determine what to benchmark
		2	Form a benchmarking team
2	Select comparable benchmarking partners	3	Choose benchmarking partners
3	Describe and analyse process and contingency variables	4	Define and verify the main characteristics of the benchmarking partners
		5	Identify stakeholders
		6	Construct a framework to structure the indicators
4	Develop comparable performance indicators	7	Develop relevant and comparable indicators
5	Stakeholders choose performance indicators	8	Stakeholders select indicators
6	Measure the performance indicators unambiguous and integral	9	Measure the set of performance indicators
7	Analyse differences in performance	10	Analyse performance differences
8	Develop improvement plans	11	Develop improvement plans
9	Implementation of improvement plans	12	Implementation of improvement plans
		13	Evaluation of the implementation

TABLE 2.2: Benchmarking process of Van Hoorn et al. (2006) and Van Lent et al. (2010). Reprinted from "International benchmarking of specialty hospitals. A series of case studies on comprehensive cancer centres" (p. 2) by Van Lent, W. A. M., De Beer, R. D., and Van Harten, W. H. (2010).

2.1.2 Methods

Multiple methods can be used to perform the actual comparison of measurements. Von Hirschhausen and Cullmann (2005) made an arrangement of benchmarking methods and created a chart similar to Figure 2.1. First, a distinction is made between one- and multi-dimensional techniques. One-dimensional methods assess productivity by dividing one output by one input (Liebert, 2011). Multi-dimensional techniques can incorporate multiple effect between input and output factors. According to Liebert (2011), in order to receive an overall picture of the performance of a decision making unit (DMU), multi-dimensional methods should be favoured over one-dimensional methods.

Multi-dimensional techniques can then be divided into average and frontier approaches, and into non-parametric and parametric methods. Liebert (2011) favours three well-documented and often applied methods: Total Factor Productivity (TFP), Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA).

Merkert, Odeack, Brathen and Pagliari (2012) also conclude that partial performance measures (PPM) fail to produce representative efficiency measures when combining multiple inputs and outputs. They categorize multi-dimensional techniques as parametric and non-parametric when reviewing benchmarking methods. Merkert et al. (2012) mention ordinary least-squares regression analysis (OLS) and SFA as parametric methods TFP and DEA as non-parametric methods in their review. Table 2.3 depicts an overview of the methods with their characteristics, advantages, and disadvantages found in literature.

The methods mentioned in Table 2.3 are methods applied across all industries. To be able to select the most appropriate method for this research, we need to assess the applicability of each method to the healthcare sector. Benneyan, Sunnetci, and Ceyhan (2008) illustrate the

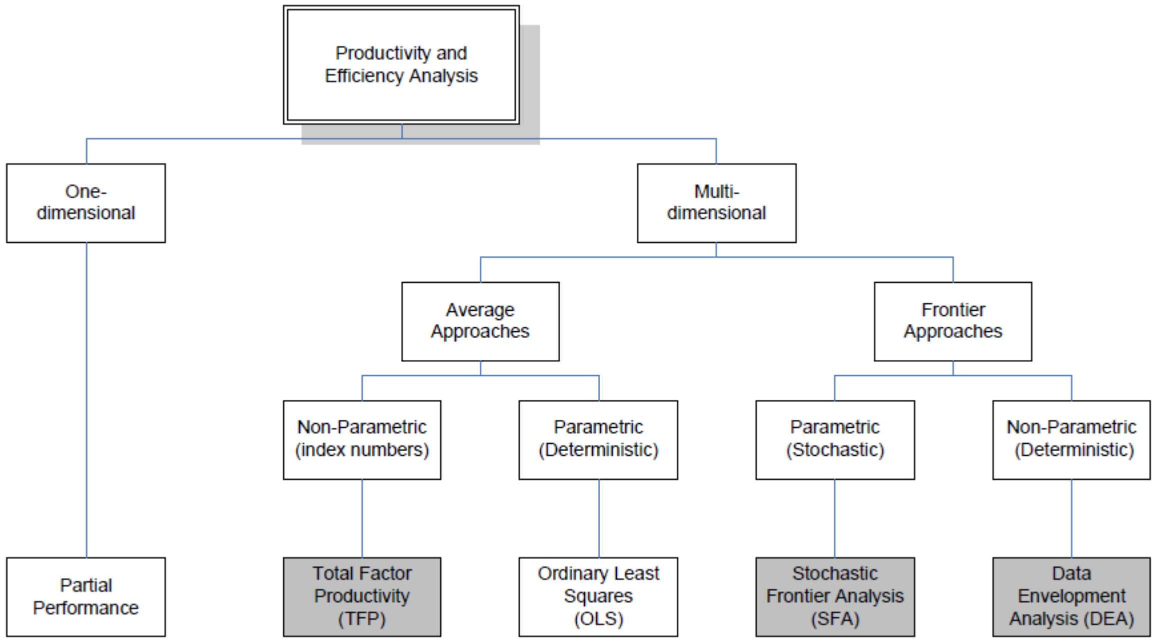


FIGURE 2.1: Quantitative benchmarking approaches. Reprinted from "Airport Benchmarking: An Efficiency Analysis of European Airports from an Economic and Managerial Perspective" (p. 20) by Liebert, V. P. (2011). Jacobs University.

use of DEA models in benchmarking healthcare systems. The approach is found to be useful when comparing systems that use multiple inputs to produce multiple outputs. Modified DEA approaches are proposed by Benneyan et al. (2008) to address common issues in benchmarking healthcare systems. Multiple studies successfully apply stochastic frontier analysis to determine the efficiency of healthcare systems (Rezaei et al., 2016)(Ogloblin, 2011)(Izon and Pardini, 2015). In the research of Kiadaliri, Jafari, and Gerdtham (2013) there is no significant difference between the efficiency scores obtained by DEA and SFA. The total productivity factor is used on multiple occasions for the measurement of productivity of healthcare services, sometimes in combination with DEA (Elmonshied and Fadlalla, 2019)(Yu et al., 2020)(Nghiem, Coelli, and Barber, 2011).

No applications were found of ordinary least-squares regression in the context of healthcare benchmarking. According to Liebert (2011), the TFP approach is most common in measuring price and quantity changes over time. The method assumes that all decision making units operate efficiently. This is unlikely for the hospital control centres and hospital@home services, since they are still in the development phase. Frontier methods, such as SFA and DEA, use an efficient frontier to identify the efficiency of individual DMUs relative to a set of other DMUs. DEA is a non-parametric approach, using linear programming to find the efficient frontier. SFA is a parametric approach, which hypothesizes a functional form and use the data of all DMUs to estimate the parameters of the function (Cordeiro et al., 2018). In this case, DEA is favoured over SFA because of the prior assumptions needed for SFA that may heavily influence results (Liebert, 2011). When using DEA, no assumptions have to be made about the specific form of the frontier or the probability density of input and output variables (Katharakis and Katostaras, 2013).

When performing data envelopment analysis, performance data for the input and output is generally based on a set of quantitative data. Qualitative data is more difficult to incorporate and harder to mathematically manipulate when calculate the efficiency measures in DEA (Kao and Lin, 2011). Multiple methods are proposed in literature to extent the DEA

Method	Dimensions	Approach	Parametric	Advantages	Disadvantages
PPM	One	N/A	N/A	- Relatively easy to compute, understand and interpret (Merkert et al., 2012)	- Less effective in providing a robust assessment of overall performance (Merkert et al., 2012) - Fail to capture substitution effects between input factors (Liebert, 2011)(IBNET, n.d.)
TFP	Multi	Average	No	- Can combine multiple input measures (Merkert et al., 2012) - Can provide meaningful results with only two observations (Liebert, 2011)	- Assumes that all DMUs operate efficiently (Liebert, 2011) - Cannot be decomposed into different types of efficiencies (IBNET, n.d.)
OLS	Multi	Average	Yes	- Distinguishes between different variables' roles in affecting output (IBNET, n.d.) - Coefficients can be interpreted in terms of cost drivers or how inputs contribute to output (IBNET, n.d.)	- Large data set is necessary in order to obtain reliable results (IBNET, n.d.) - The regression results are sensitive to model specification and interpretation of the error term (IBNET, n.d.)
SFA	Multi	Frontier	Yes	- Does not purely explain inefficiency as mis-management (Liebert, 2011) (Bogetoft and Otto, 2010) - Accounts for data noise such as data errors and omitted variables (Liebert, 2011)	- Prior assumptions may heavily affect results (Liebert, 2011) - Sensitive to small sample sizes (Liebert, 2011) - Functional relationship needs to be specified (Liebert, 2011) - The separation of noise and inefficiency relies on strong assumptions (IBNET, n.d.)
DEA	Multi	Frontier	No	- Requires fewer assumptions and a smaller sample size than the SFA method (Merkert et al., 2012) - Superior when multiple inputs and outputs are considered, and the best weights are not immediately transparent (Benneyan et al., 2008) - Provides explicit, real peer-units (Bogetoft and Otto, 2010)	- Results are potentially sensitive to the selected inputs and outputs (IBNET, n.d.) - When there is no relationship between factors, DEA views each company as unique and fully efficient (IBNET, n.d.) - Sensitive to outliers (Liebert, 2011)

TABLE 2.3: Overview of benchmarking methods and their characteristics.

and represent the qualitative data. The common idea in these studies is to convert the qualitative data using ordinal and interval data (Saljooghi and Giski, 2013)(Kao and Lin, 2011). Since most of the hospital@home services are still in the development phase, we assume that not much quantitative data is available yet. Converting all data into quantitative measures is computationally intensive and might yield less reliable results than a DEA with quantitative data would (Saljooghi and Giski, 2013). The goal of the benchmark in this research is be to identify the current situation regarding the hospital@home services. Ranking hospitals by determining efficiency measures is not essential to attain this.

The PPM method is relatively easy to compute, but is less effective when providing an overall assessment. Partial indicators fail to incorporate relationships among input factors. PPM approaches usually analyse the relationship of two simple measures, resulting in a measure of productivity (IBNET, n.d.). The only case in which this method should be used, is if data for overall measures is not available (Liebert, 2011). In this case, PPM might be useful when analysing quantitative variables, if there is a small amount of data available. For the remaining variables, a comparison will be made based on the qualitative data. The next section elaborates on some methods that can be used to compare the qualitative indicators.

2.1.3 Performance indicators

Khalifa and Khalid (2015) performed a study about the development of strategic healthcare performance indicators. Organizations develop key performance indicators (KPIs) for monitoring, measuring, and managing the performance of healthcare systems to ensure effectiveness, efficiency, equity, and quality (Khalifa and Khalid, 2015). In a benchmark, these performance indicators can be used to evaluate the performance of a healthcare system against set standard or values of other systems. Khalifa and Khalid (2015) suggest a classification of performance indicators into performance levels (strategic, tactical, operational), performance dimensions (safety, effectiveness, efficiency, timeliness, patient centeredness, equity), and system components (structure, processes, and outcomes), as illustrated in Figure 3 below. Von Eiff (2015) makes the distinction between various areas of performance indicators based on the areas of an input-output model. KPIs should represent the real core business of an institution (Von Eiff, 2015), Von Eiff (2015) aims to uncover the performance of these core processes by dividing KPIs into key performance resources, key performance processes, and key performance results.

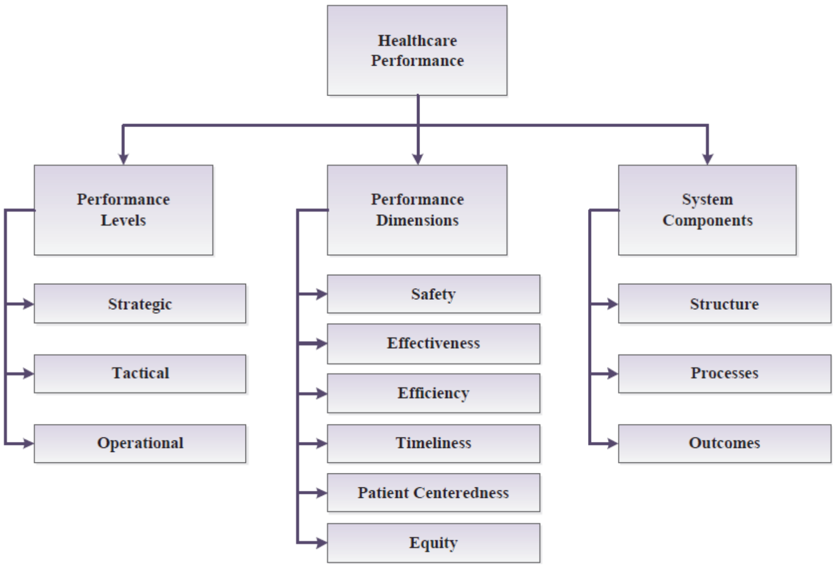


FIGURE 2.2: Classification of healthcare performance indicators. Reprinted from "Developing Strategic Health Care Key Performance Indicators: A Case Study on a Tertiary Care Hospital" (p. 461) by Khalifa, M., and Khalid, P. (2015). Procedia Computer Science, 63, 459-466.

In their paper about the application of benchmarking in healthcare, Torkki and Lillrank (2013) state that performance should be captured through "empirical, demonstrated and documented key performance indicators (KPI)". These indicators can consists of results, technologies, resources, and organizational arrangements. According to them, KPIs need to be defined on multiple levels of abstraction to be able to make a relevant comparison. Furthermore, the relation between the KPIs needs to be explained (Torkki and Lillrank, 2013). Van Veen-Berkx, De Korne, Olivier, Bal, and Kazemier (2016) add that benchmarking indicators should be SMART (specific, measurable, attainable, relevant, and time-bound) and based on reliable and comparable data.

Jester, Titchener, Doyle-Blunden, and Caldwell (2015) performed a literature review related to hospital at home schemes and applied their findings to the conceptual model of Donabedian (1988). The result of their study is a robust, practical and comprehensive evaluation framework for hospital at home services. The framework consists of evaluation objectives and corresponding methods for each component of Donabedian's model: structure, process, and outcome. It enables the user to implement practical, evidence based evaluation strategies that include the perspective of all stakeholders.

Besides the frameworks found in literature, there are many other studies assessing the development of hospital performance indicators (Ioan, Nestian, and Tiţă, 2012)(Carini et al., 2020)(Tyagi and Singh, 2017). The common aspect of these studies is that they classify performance indicators into various dimensions (and subdimensions). When comparing the studies of Ioan et al. (2012), Carini et al. (2020), and Tyagi and Singh (2017), we find six common dimensions for hospital performance: efficiency, clinical effectiveness, patient-centeredness, safety, responsive governance, and staff orientation.

The Donabedian model, used in the frameworks of both Khalifa and Khalid (2015) and Jester et al. (2015), is the most used model when assessing the quality of care and examining health services. It is a flexible framework that can be applied in many healthcare settings. For the purpose of this research, it is important that all components of the hospital control centre and hospital@home services are covered in the benchmark. Donabedian's framework, illustrated in Figure 2.3, will enable us in doing this.

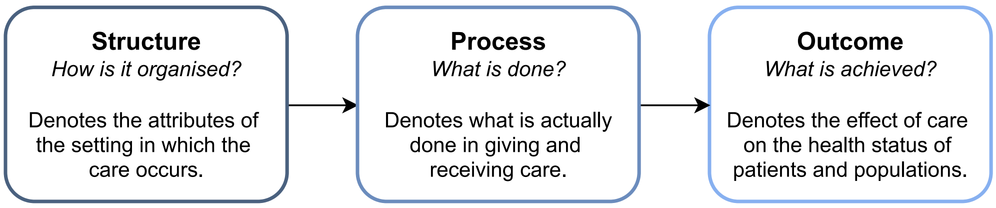


FIGURE 2.3: Graphical representation of Donabedian's model.

2.2 Modelling hospital@home services

Multiple modelling methods can be used in the context of healthcare optimization. Appendix E includes a summary of commonly used operations research methods, for the reader who is less familiar with this subject. To make a comparison between various scenarios and service designs, simulation is the most commonly used method in healthcare. This research will probably involve a considerable amount of uncertainty and also simplifying assumptions. A simulation model can incorporate all of this. It is "a technique that imitates the operations of a real-world system as it evolves over time" (Winston and Goldberg, 2004). Therefore, it can be used to create an environment in which future developments of the Rijnstate@home project can be analysed. A more detailed explanation of why simulation is the desired method for this research is included in Appendix E.

The book of Law (2014), classifies simulation models along three dimensions:

- Deterministic vs. Stochastic Simulation Models
- Static vs. Dynamic Simulation Models
- Continuous vs. Discrete Simulation Models

To compare the various service designs, we need a model that is stochastic instead of deterministic, meaning that the model will involve probabilistic (random) components. This is required because of the stochastic nature of the input components. For example, the deterioration of health of patients monitored at home is probabilistic.

Stochastic models can then be divided into static and dynamic models. Static models represent the system at a particular point in time, whereas dynamic models represent the system as it evolves over time (Law, 2014). According to Pidd (2004), the term 'static' is used because there is very little dynamic interaction in the models. The time dimension in static models is handled via a time-slicing approach with little complex logic. Dynamic models on the other hand, include dynamic and complex interactions of entities. Models that are both stochastic and static are often referred to as Monte Carlo simulations. Stochastic and dynamic models can be further classified into continuous and discrete models.

In stochastic, dynamic, and discrete models the variables can only change at a discrete set of points over time. This makes it possible to follow and track individual entities within a system. For example, individual patients and hospital staff can be tracked and have their own characteristics (Fard, Roper, and Hess, 2016). If the group of patients could be considered as a whole, the system could be described by a continuous model (Law, 2014). Since the characteristics and actions related to individual patients are important, our simulation model needs to be discrete.

The chosen simulation methods needs to be stochastic and discrete. The remaining decision is whether we need a static model or a dynamic model. The monitoring and coaching of patients is a process in which the passage of time plays a role. Furthermore, we need to model dynamic interactions between the entities in the system, such as patients requesting assistance at the same point in time and queues of patients waiting for consult. Therefore, the simulation model also needs to be dynamic and imitate the system as it progresses through time (Robinson, 2004).

A model that meets all the requirements is the discrete event simulation (DES) model. DES models are frequently used in the healthcare industry, for example to compare different scenarios and optimize resource allocation plans (Fard, Roper, and Hess, 2016). According to Robinson (Robinson, 2004), a number of methods have been proposed to carry out discrete event simulation: the event-based, activity-based, process-based, and three-phase approach. A detailed description of these methods is provided by Pidd (2004).

The three-phase approach is based on the fact that there are two ways in which a activity can start within a DES. When operations have a start and finishing time that can be predicted, they are classified as Bs. Operations that cannot be directly scheduled and classified as Bs, are regarded as Cs. The occurrence of Cs depends on the states of other entities in the model. The first of the three phases is to move to the next chronological event. In the second phase, the Bs are executed that must occur at that time. The third phase is to check for each C if the conditions for its occurrence are satisfied. If they are, the action is executed (Pidd, 2004).

The activity-based approach consists of activities, which are similar to the Cs of the three-phase approach. The Bs of the three-phase approach also become activities, but a condition for its occurrence is added that checks whether the time has advanced far enough for the activity to be executed (Pidd, 2004). The approach consists of two phases: moving the simulation clock to the time of the next event, and checking for each activity if the conditions for is occurrence are satisfied (Pidd, 2004). Because at each event time all activities need to be checked, the activity-based models need more time to run.

An event-based model consists of event routines, which are sets of statements describing the logical consequences that result from an event (Pidd, 2004). The event in this approach is a state change that occurs at a given instant of time. The event-based approach was popular during the first years of discrete event simulation. After this, process-based approaches were favoured over the event-based approach (Pidd, 2004). Process-based models are build using the whole process of an entity as building blocks (Pidd, 2004). These processes are the sequences of operations that an entity must go through. Each entity class has one or more of its own processes. The life of an entity is defined by its progress through its process (Pidd, 2004).

Pidd (2004) states that the activity-based and event-based approach can be omitted when selecting a suitable simulation method. The process-based and three-phase approach both avoid computer programs that are slow and avoid the need to think through all possible logical consequences of an event (Pidd, 2004). There is one important difference between these two approaches, concerning the avoidance of a deadlock in which an entity needs a resource or other entity that must be free before it is able to proceed (Pidd, 2004). The three-phase approach this is solved by repeatedly scanning the Cs in the third phase. In process-based approaches, this must be managed during the development of each process template.

2.3 Conclusion

Healthcare benchmarking is "a continual and collaborative discipline, which involves measuring and comparing the results of key processes with the best performers and adapting best practices to achieve breakthrough process improvements in support of healthier communities." (Mosel and Gift, 1994). The selected benchmarking process for this research is Step 1 to 7 of the method of Van Hoorn et al. (2006).

1. Make a choice for a comparable process
2. Select comparable benchmarking partners
3. Describe and analyse process and contingency variables
4. Develop comparable performance indicators
5. Stakeholders choose performance indicators
6. Measure the performance indicators unambiguous and integral
7. Analyse differences in performance

The Donabedian model, depicted in Figure 2.3, is used to select a set of performance indicators for the benchmark. This model is used in the frameworks of both Khalifa and Khalid (2015) and Jester et al. (2015), and is the most used model when assessing the quality of care and examining health services. It is a flexible framework that can be applied in many healthcare settings.

To make a comparison between various scenarios and service designs, simulation is the most commonly used method in healthcare. This research involves a considerable amount of uncertainty and also simplifying assumptions. A simulation model can incorporate all of this. It is "a technique that imitates the operations of a real-world system as it evolves over time" (Winston and Goldberg, 2004). Discrete event simulation (DES) is the most suitable approach for this study because it is stochastic, discrete, and dynamic. DES models are frequently used in the healthcare industry, for example to compare different scenarios and optimize resource allocation plans (Fard, Roper, and Hess, 2016).

Chapter 3

Benchmarking

This chapter includes a comparison of hospital@home services following the benchmarking method of Van Hoorn et al. (2006). The first section describes the processes that are compared (step 1). The second section includes the selection and description of benchmarking partners (step 2 and 3). The third and fourth section describe the selection and measuring of indicators (step 4, 5, and 6). The final sections include the analysis of the collected data (step 7). The remaining steps of the benchmarking method of Van Hoorn et al. (2006), developing and implementing improvement plans, are not within the scope of this thesis.

3.1 Process description

According to Van Hoorn et al. (2006), promoting comparability starts with choosing a process that is comparable. They promote the comparison of smaller operational processes instead of institutions as a whole. In this thesis, three types of services are included in the comparison of hospitals: virtual care, medication- and treatment@home, and hospital control centres. Besides comparing the different services across several hospitals, we are also interested in the connection between these services. We define the services as follows:

- **Virtual care**: the monitoring and coaching of patients in the home situation to prevent (re)admission to the hospital or to provide early and/or supported discharge.
- **Medication- and treatment@home**: the provision of hospital care at home (home hospitalization). In this thesis we will focus on medication@home, therefore we will refer to medication- and treatment@home as medication@home for the remainder of this thesis.
- **Hospital control centre (HCC)**: a central place that includes all data sources and brings together relevant information about supply and demand of capacity within the hospital. In the HCC real-time data and smart calculation models are used for predictive analyses and to support balanced decision making.

3.2 Benchmarking partners

It is important to choose comparable partners in order to realize improvements. Van Hoorn et al. (2006) recommend selecting a limited number of benchmarking partners. Rijnstate is part of the mProve network. Together with six other hospitals they share best practices and compare results. Because of this existing collaboration regarding information sharing, the mProve hospitals are selected as benchmarking partners.

The following hospitals are part of the network:

- Albert Schweitzer Ziekenhuis (*Dordrecht, Zwijndrecht*)
- Isala (*Zwolle, Meppel*)
- Jeroen Bosch Ziekenhuis (*'s-Hertogenbosch*)
- Máxima Medisch Centrum (*Veldhoven, Eindhoven*)
- Noordwest Ziekenhuisgroep (*Alkmaar, Den Helder*)
- Rijnstate (*Arnhem, Zevenaar*)
- Zuyderland Medisch Centrum (*Heerlen, Sittard-Geleen*)

Table 3.1 contains characteristics of the mProve hospitals. For the comparison of the processes described in Section 3.1, other processes of the hospitals do not need to be comparable. In general, all hospitals of the mProve network are classified as 'large' by the BDO hospital benchmark (BDO, 2020). Every mProve hospital has some type of virtual care initiative. Furthermore, four of the seven hospitals have a hospital control centre. Based on the characteristics described in Table 3.1, no evident differences between the hospitals can be identified.

Hospital	HCC	VC	Size	Day Admissions	Clinical Admissions	Staff + Specialists	ORs	Beds
Albert Schweitzer Ziekenhuis	X	X	Large	23890	22529	3315	14	675
Isala		X	Large	35364	47083	7131	25	1245
Jeroen Bosch Ziekenhuis		X	Large	27,160	25580	4260	16	630
Máxima Medisch Centrum		X	Large	14,854	19435	3208	18	614
Noordwest Ziekenhuisgroep	X	X	Large	28527	38047	4840	25	770
Rijnstate	X	X	Large	25229	29983	5318	22	766
Zuyderland Medisch Centrum	X	X	Large	36098	35389	4971	21	980
			Average	27303	31149	4744	20	864

TABLE 3.1: Characteristics of the mProve hospitals (T = 2021), where HCC = Hospital Control Centre, VC = Virtual Care, OR = Operating Room

3.3 Indicators

To cover all components of the hospital@home services and HCCs in this benchmark, the Donabedian framework is used to develop relevant indicators. The model distinguishes between three types of indicators: structure, process, and outcome. In a system with multiple stakeholders, it is important to involve all of them in the selection of indicators. This promotes their involvement in the processes and ensures that relevant outcomes are compared (Van Hoorn et al., 2006). Table 3.2 contains the indicators selected by four stakeholders of Rijnstate and the VZC. The selection is made out of a longlist of possible indicators and placed in the Donabedian model.

	Structure	Process
Virtual care	- Presence of initiative - Amount of FTE included - Centralization of initiatives - Systems used - Collaboration with external organisation	- Patient groups - Types of virtual care - Number of patients at home - Total number of patients - Service designs used
Medication@home	- Presence of initiative - Centralization of initiatives - Connection with virtual care	- Patient groups - Number of patients at home - Total number of patients - Planning responsibility - Planning tools
Hospital control centre	- Presence of initiative - Systems used - Connection with virtual care - Connection with medication@home	
Outcome		
- Number of patients with early discharge - Number of hospital readmissions (during monitoring at home) - Number of patients discharged from home monitoring - Number of hospital visits prevented by home hospitalization		

TABLE 3.2: Selection of relevant indicators placed in the Donabedian model

3.4 Method

The list presented in Section 3.3 is a combination of quantitative and qualitative indicators. All data is gathered by conducting interviews. The interviewees are involved in the virtual care, medication@home, and hospital control centres in the mProve hospitals. In some hospitals, all data can be gathered in one interview, while for others multiple interviews need to be conducted due to the decentralization of the initiatives. An interview form is created before the interviews as a common thread in the conversation. At the end of the interview, the form should be as complete as possible. After the interview is conducted, the interviewee receives the form to verify the data and provide additions where necessary.

3.5 Analysis

This section includes the results of the interviews conducted with the mProve hospitals. Each of the initiatives is presented in a separate subsection. The final subsection includes the output indicators since these are overarching all initiatives.

3.5.1 Virtual care initiatives

Presence of virtual care initiatives

Virtual care initiatives are present in every mProve hospital. Some hospitals only work with e-coaches, while others also provide remote patient management. It is important to distinguish between these two types because they result in a different overall workload. Remote patient management requires more frequent contact with the patient than e-coaching does.

Centralization of initiatives

Centralization of initiatives concerns whether the virtual care is organised from a central department in the hospital or separately within each department. In three of the seven hospitals (Isala, Jeroen Bosch, and Rijnstate), virtual care is organised from a central place in the hospital. The other hospitals have virtual care initiatives across different departments. An argument for decentralization mentioned in the interviews is that decentralization in the early stages of the initiative may increase the engagement of the individual departments when centralizing later on. Stoker (2019) also mentions that by starting working separately and collaborating later on problems are more easily noticed. The advantage of centralization of initiatives is that it prevents departments from inventing the same service twice and that scale is created earlier. Centralization of initiatives is a long term goal of most hospitals.

Systems used for facilitating virtual care

A wide variety of systems is used for the facilitation of virtual care across hospitals. Some hospitals have a different system for each patient group. A disadvantage of this is that the nurses have to switch between multiple applications while managing patients (when virtual care is centralized). When virtual care is not yet centralized, a variety of systems may complicate this. Applications that can combine the input from different monitoring systems are in development. Noordwest Ziekenhuisgroep uses the EPD and patient portal to communicate with patients and provide e-coaching.

Collaboration with external organisations

Hospitals are in close contact with general practitioners about the patients that are monitored at home. The local home care organisations often support the patients that go home with additional oxygen. The most striking difference between hospitals, resulting from this indicator, is their vision of the burden on general practitioners. Some hospitals see the home monitoring as an unburdening of general practitioners, while others see it mainly as a relief for the hospital. The location of the hospital in the Netherlands might influence this. Stoker (2019) mentions that "an advantage of working with an external organisation is the reduction of time to implement the program. But, working with multiple partners makes coordination and communication more difficult".

Patient groups and their types of virtual care

Both inpatients and outpatients are included in the virtual care. The most common patient groups across the mProve hospitals are:

- COPD: included in 6 of the 7 hospitals.
- COVID: included in 4 of the 7 hospitals.
- (Chronic) heart failure: included in 4 of the 7 hospitals.
- (Pregnancy) diabetes: included in 4 of the 7 hospitals.
- IBD: included in 4 of the 7 hospitals.
- Asthma: included in 3 of the 7 hospitals.

When distinguishing between remote patient management and e-coaching, we find that COVID, COPD, asthma, and heart failure patients are most often included in remote patient management. Diabetes and IBD patients are most often included in e-coaches.

Number of included patients per group

The number of patients included in the virtual care initiatives varies considerably across hospitals and patient groups. E-coaching is generally easier to scale than remote patient management since it is often less labour intensive. Especially the Zuyderland hospital has included a large number of patients in their e-coaches, around 2,800 patients are included at the moment of interviewing. The remote patient management initiatives have reached a considerable scale, of around 100-200 patients per group, in the Albert Schweitzer Ziekenhuis and Isala hospital.

Total number of patients per group

The total number of patients in a patient group is the number of patients that could be included in the virtual care initiative. This number is unknown to most hospitals, presumably because there are no objective inclusion criteria, which makes it harder to select suitable patients from a database.

Service designs used

The first service design, where the patient is treated at the hospital by a nurse of a certain specialty, is used in every hospital. The third service design, where the patient is treated at the hospital by a specialized nurse of the hospital@home program, is used for COVID patients in the Isala hospital. At the moment of interviewing, none of the other service designs is being used in practice. Stoker (2019) provides an overview of the considerations to be made when selecting service designs.

3.5.2 Medication@home

No information is available about the medication@home initiatives of the Jeroen Bosch hospital. The information in this section is based on interviews of the remaining six hospitals. Furthermore, the administration of intravenous antibiotics is outside the scope of this research, since this is not a new development in the field.

Presence of medication@home

Medication@home is present in five of the six interviewed hospitals. The Albert Schweitzer Ziekenhuis is currently developing their medication@home program and will start with immunotherapy at home. The Noordwest Ziekenhuisgroep organizes the medication@home in close cooperation with a home care organization. The medication is administrated by the home care organization.

Centralization of initiatives

The medication@home is decentralized in all hospitals except for Rijnstate. Here, medication@home is part of the Rijnstate@home project. Because of the different needs of patient groups it is understandable that initiaves are not centralized yet in most hospitals. However, the centralization of medication@home provides a larger scale which allows for optimization of schedules and routes.

Connection with virtual care

In Rijnstate, the administration of medication@home is done by nurses of the Rijnstate@home project, which also work for the Virtueel Zorgcentrum. These nurses do not work for both services simultaneously. This is the only connection between the virtual care initiatives and medication@home resulting from the interviews.

Patient groups

In terms of the medication@home, patient groups are sometimes defined by a medical condition and sometimes by medication type, which makes the comparison more difficult. The most common patients are oncology patients. In addition, some hospitals included palliative medication and medication for patients with asthma, heart failure of rheumatism.

Number of patients

The number of patients included per patient group is unknown to most hospitals. This might be due to the decentralization of initiatives. Centralization of the medication@home initiatives would simplify the monitoring of the process. The Isala hospital has reached the largest scale for their medication@home initiatives, they serve hundreds of patients at home each year.

Planning and scheduling

The employee scheduling and planning of the patient visits are organized differently in each hospital. In some cases the planner of a department to which the initiative belongs is responsible. In other cases, the planning and scheduling are done by the transfer office. In Rijnstate, the medication@home initiatives are centralized and the planning is made at the Virtueel Zorgcentrum. At the Noordwest Ziekenhuisgroep, the administration of medication is done by a home care organization. Naturally, they are also responsible for the planning.

Planning tools

The planning is done manually in almost every hospital. Sometimes, the planning is based on historical data. The Isala hospital incorporates a workforce scheduling system. Overall, this part of the medication@home seems to be little developed yet.

3.5.3 Hospital control centres

Presence of the HCC

Hospital control centres are present in four of the seven mProve hospitals. The COVID-19 pandemic, which started in 2020, stimulated the development of the HCCs. Real-time data of the patient flow support the rapid decision making demanded by the pandemic.

Systems used in the HCC

The most frequently used software in HCCs are Tableau, HiX, and PowerBI.

Connection with virtual care

The connection between virtual care and the HCC has been made in the Zuyderland hospital and the Albert Schweitzer Ziekenhuis. The ASZ includes virtual care in the dashboards of their centre. At the Zuyderland hospital, the control centre is also used to experiment with new initiatives, for example incorporating new e-coaches.

Connection with medication@home

At the time of interviewing, no connection has been made between the medication@home and the HCC. The Albert Schweitzer Ziekenhuis is planning on adding the medication@home patients to their HCC dashboards when the immunotherapy at home starts.

3.5.4 Outcomes

Four indicators were created to measure the outcome of the initiatives. The number of discharged patients from home monitoring is the easiest to measure of the four indicators. Almost every hospital has this information. Information about the number of patients with early discharge and the number of hospital readmissions during home monitoring is only known at the Isala hospital. Here, the patients are discharged 3 to 5 days earlier due to the home monitoring. Also, the number of repeating visits has decreased by 15%. The number of readmissions is hard to measure in areas were multiple hospitals are located. Patients that are monitored by one hospital can be (re)admitted by a neighbouring hospital. The Máxima Medisch Centrum and Isala hospital measured the influence on hospital visits and both found a significant reduction of hospital visits resulting from virtual care and medication@home.

3.6 Conclusion

The goal of the benchmark is to provide insight into the current developments regarding hospital@home services and their link with hospital control centres in the Netherlands. The field truly is still in the development phase in most hospitals, resulting in a small amount of available data. The first service design, where the patient is treated at the hospital by a nurse of a certain specialty, is used in every hospital. If more variety exists in the used service designs, findings about them can serve as input for the second part of this study. This does not imply that this benchmark is purposeless. Exploring the field of virtual care by conducting interviews leads to a better understanding of the service, which is very useful when translating it into a simulation model.

The different characteristics of the patient groups and initiatives make it harder to compare services across hospitals. Patients using the remote patient management service often require more time and resources than patients using the e-coaches. Besides this, hospitals treat patients of the same patient group differently, based on the opinion of their physicians. COPD patients in hospital A may be called by a nurse daily, while in hospital B the nurses call COPD patients once per week. No uniform pattern or definition of patient groups is found. This also results in a discrepancy in required resources. Next to the variety among patient groups, the goal of virtual care varies across hospitals. For example, some hospitals see home monitoring as an unburdening of general practitioners, while others see it mainly as a relief for the hospital. The different objectives result in a different focus while developing the virtual care services. The large variety of goals and initiatives can also be used to our advantage. In this way, we can compare which type of care delivers the best quality of care, financial advantage, positive patient experience, and employee satisfaction, if more data becomes available in the future.

Although the path of development of hospital@home services is different in each hospital, the goal of each hospital is to centralize initiatives in the long term. An argument for decentralization mentioned in the interviews is that decentralization in the early stages of the initiative may increase the engagement of the individual departments when centralizing later on. The advantage of earlier centralization of initiatives is that it prevents departments from inventing the same service twice.

Combining different hospital@home services in an unexplored area in most hospitals. The only connection found between medication@home and virtual care is the administration of medication@home by nurses of the Rijnstate@home project, which also work for the Virtueel Zorgcentrum. However, these nurses do not work for both services simultaneously. The incorporation of virtual care and medication@home in the hospital control centres is slightly more developed. The Zuyderland hospital and Albert Schweitzer Ziekenhuis have already taken steps in this.

A wide variety of systems is used for the facilitation of virtual care across hospitals. Some hospitals have a different system for each patient group. Applications that can combine the input from different monitoring systems are in development. Such systems will promote the development of virtual care and enable the centralization of services.

When reflecting on the maturity of the processes at different hospitals, we have to distinquish between the different initiatives and indicators. In our opinion, the number of patients and groups included can be used as a measure for maturity of the process, provided that the processes and groups are comparable. Remote patient management cannot be compared to e-coaching processes. Also, centralization of initiatives often indicates maturity of the process. From the interviews, the virtual care processes seem to be most developed at the Jeroen Bosch Ziekenhuis. The Zuyderland hospital has reached a large scale with their e-coaches. Isala hospital and the Albert Schweitzer Ziekenhuis have included a relatively large number of patients in their remote patient management program. Rijnstate has centralized all their hospital@home initiatives in their Virtueel Zorgcentrum, this allows them to more easily connect alternatives. The medication at home processes are the most developed at the Isala hospital, they have reached the largest scale. Concerning the hospital control centres, we found that the HCC of the Noordwest Ziekenhuisgroep is the most advanced. Table 3.3 provides a summary of the conclusions.

3.7 Further research

In general, the amount of available data was not very extensive. Stoker (2019) mentions that a "problem was sceptical physicians, physicians did send too few patients to the service". Measuring and showing the results of the hospital@home projects can be a great incentive for physicians to devote time to them.

In the mProve hospitals, the connection between virtual care and medication@home has not been made yet. Especially the virtual care initiatives may benefit from cooperation, for example when a medication@home nurse can visit home monitored patients in their neighbourhood. The medication@home services will benefit most from a structural solution to the routing problem.

Another finding is the different view on the burden on general practitioners. Some hospitals see home monitoring as an unburdening of general practitioners, while others see it mainly as a relief for the hospital. An interesting area of research would be the perception of the general practitioners in different regions on this matter.

Section	Indicator	Main findings
1. Virtual care initiatives	Presence	Virtual care is present in every mProve hospital. A distinction needs to be made between e-coaching and remote patient management.
	Centralization	In three of the seven hospitals virtual care is centralized. Centralization of initiatives is a long term goal of most hospitals.
	External collaboration	The vision of the burden on general practitioners differs across hospitals. Some hospitals see the home monitoring as an unburdening of general practitioners, while others see it mainly as a relief for the hospital.
	Patient groups	Many different patient groups are included in the virtual care of mProve hospitals. Different characteristics of patient groups make comparision more difficult.
	Service designs	The first service design, where the patient is treated at the hospital by a nurse of a certain specialty, is used in every hospital.
2. Medication@home	Presence	Medication@home is present or in development in all the mProve hospitals.
	Centralization	Rijnstate is the only hospital where medication@home is centralized.
	Patient groups	Patient groups are sometimes defined by a medical condition and sometimes by medication type, which makes comparison of initiatives more difficult.
	Number of patients	The exact number of included patients is unknown to most hospitals. Isala hospital has reached the largest scale for their medication@home initiatives.
3. Hospital control centres	Presence	Four of the seven mProve hospitals have some type of hospital control centre (HCC). The HCC is the most developed at the Noordwest Noordwest Ziekenhuisgroep. The COVID-19 pandemic stimulated the development of HCCs in multiple hospitals.
	Connection	Zuyderland hospital and the Albert Schweitzer Ziekenhuis have made the connection between virtual care and the HCC. No connection has been made between the HCC and medication@home.
4. Outcomes	Outcomes	The amount of available (quantitative) data is not very extensive. Measuring and showing results can be a great incentive for people to devote more time to the hospital@home initiatives.

TABLE 3.3: Summary of the most important findings from the mProve benchmark on hospital@home initiatives.

Chapter 4

Simulation model

This chapter includes a description of the model development and the execution of experiments. Section 4.1 describes the modelling approach using the steps of Law (2014). Section 4.2 consists of a description of the conceptual model. In Section 4.3 the available data is analysed and estimates are created for missing data. Section 4.4, 4.5, and 4.6 include the simulation set-up, implementation and verification, and validation of the model respectively. The final section (4.7) contains the performed experiments.

4.1 Modelling approach

After performing the literature search, as described in Section 2.2, we conclude that simulation is the most appropriate modelling technique for this research. This section includes a breakdown of the steps that need to be taken when developing the model.

4.1.1 Process Steps

Law (2014) describes the steps to be taken in a simulation study as follows:

1. Formulate a problem and plan the study.
2. Collect data and define a model.
3. Is the assumptions document valid?
4. Construct a computer program and verify.
5. Make pilot runs.
6. Is the programmed model valid?
7. Design experiments.
8. Make production runs.
9. Analyse output data.
10. Document, present, and use results.

Appendix F includes a complete overview and more detailed explanation of the simulation steps presented by Law (2014). The first step of the model, to formulate a problem and plan the study, is completed in this section. The following things are incorporated in this first step:

- Stating the problem of interest (Chapter 1).
- Overall objectives of the study (Section 4.1.2).
- Specific questions to be answered by the study (Section 4.1.2).
- Performance measures that will be used (Section 4.1.3).
- Scope of the model (Section 4.1.5).
- System configurations to be modelled (Section 4.1.4).

4.1.2 Objective

As described before, the objective of the second part of this study is to provide a quantitative model based on the previously defined service designs, that can be used for the further development of the Rijnstate@home services. To be able to determine the required level of model detail, we define specific questions to be answered by the model. First, the model needs to assist the hospital in selecting appropriate service scenarios for the different patient groups and possibly for different scales of the project. Second, the model needs to provide some indication of the required nurse capacity for these service scenarios.

4.1.3 Performance measures

The various system configurations (service designs) need to be evaluated based on some performance measures. From the perspective of the hospital, the required nurse capacity (and related costs) for the scenarios and the waiting time experienced by patients, are the main point of interest. Furthermore, they would like to minimize the waiting time to increase patient satisfaction.

4.1.4 System configurations

To be able to decide on the generality of the simulation program, we determine system configurations that need to be modelled. In the formulation of the objective, we mention that the model needs to be based on the service designs defined by Stoker (2019). The seven previously defined scenarios are the configurations that need to be included in the model. Including these scenarios in the simulation model, will allow us to analyse the various configurations and possible combinations of scenarios. In the current situation, the medication at home is administered by nurses of the VZC. These nurses do not perform any other VZC activities on the days they are scheduled for the medication@home project. In the future, the administration of medication at home could be combined with the treatment of VZC patients at home. To include this in the model, an additional service design has been added: Patient is treated at home by a medication@home nurse.

1. Patient is treated at the hospital by a nurse at a certain specialty.
2. Patient is treated at the hospital by a general nurse of the hospital@home program.
3. Patient is treated at the hospital by a specialized nurse of the hospital@home program.
4. Patient is treated at home in collaboration with an external organisation.
5. Patient is treated at home by a nurse of a certain specialty.
6. Patient is treated at home by a general nurse of the hospital@home program.
7. Patient is treated at home by a specialized nurse of the hospital@home program.
8. Patient is treated at home by a medication@home nurse.

4.1.5 Modelling scope

The system configurations included in the model concern the processes performed by the Virtueel Zorgcentrum. The VZC is the main focus of the simulation model. The patient groups that will be included in this study are: COVID, COPD, bariatrics, chronic kidney damage, infectious diseases, gestational diabetes, and type 1 diabetes. However, the model should be flexible since more patient groups will be added to the VZC in the future. Appendix B contains more information about the initially included projects.

In some of the service scenarios, the treatment of a patient by a general or specialized nurse from the hospital@home program is included. Since the medication- and treatment@home programs are also part of the hospital@home program, the nurses mentioned in the service designs could also be part of one of these projects. Therefore, the medication- and treatment@home services should also be included in the model. These services do not need to be modelled into detail since they are not the main focus of the model.

4.2 Conceptual model

The second step in a simulation study, includes the development of a conceptual model (Law, 2014). This section consist of the model content, the experimental factors and responses, and the assumptions and simplifications made in the simulation model.

4.2.1 Model content

This section contains the content of the model. It revolves around the explanation of Figure 4.1, which contains a logic flow diagram of the simulation model.

Arrival process

The diagram in Figure 4.1 is divided into various coloured sections. The yellow section contains the arrival process of the patient. Here, different attributes of the patient are set by drawing random numbers or values from distributions. These attributes include:

- **PatientID**: Number used to identify individual patients.
- **PatientGroup**: Patient group the patient belongs to, e.g. COVID or COPD.
- **ServiceDesign**: Corresponding to the service design used for this patient.
- **LengthOfStay**: Duration of the at home monitoring of this patient.
- **Distance**: The distance (in km) of the patient to the hospital.
- **EventCode**: representing the event occurring during the LOS.
  (1 = emergency, 2 = complication, 3 = false flag, 100 = no event)

When the attributes are set, the patient moves to a queue and waits until a nurse is available. The patient is served by a nurse with the *Admission* duration, representing a nurse admitting a patient to the VZC. After this, the patient moves to the home situation.

When the patient arrives at the *Home* server, its path is determined by the selected *EventCode*. When the *EventCode* is equal to 100, no special event will occur and the patient remains in the home situation for the remainder of their *LengthOfStay*.

Emergencies

If the *EventCode* attribute of the patient is equal to 1, an emergency will occur in the future. The patient goes through the red section of the diagram. First, the remaining time until the emergency is determined (*EventTime*), and the patient remains in the home situation for this period. Next, drawing a random number from 0 to 1 determines whether the patient directly calls an ambulance or first calls the VZC. In the first situation, the *Destination* and *TravelTime* attributes are set. The patient then moves to the hospital through the Transport server, with a duration of *TravelTime*.

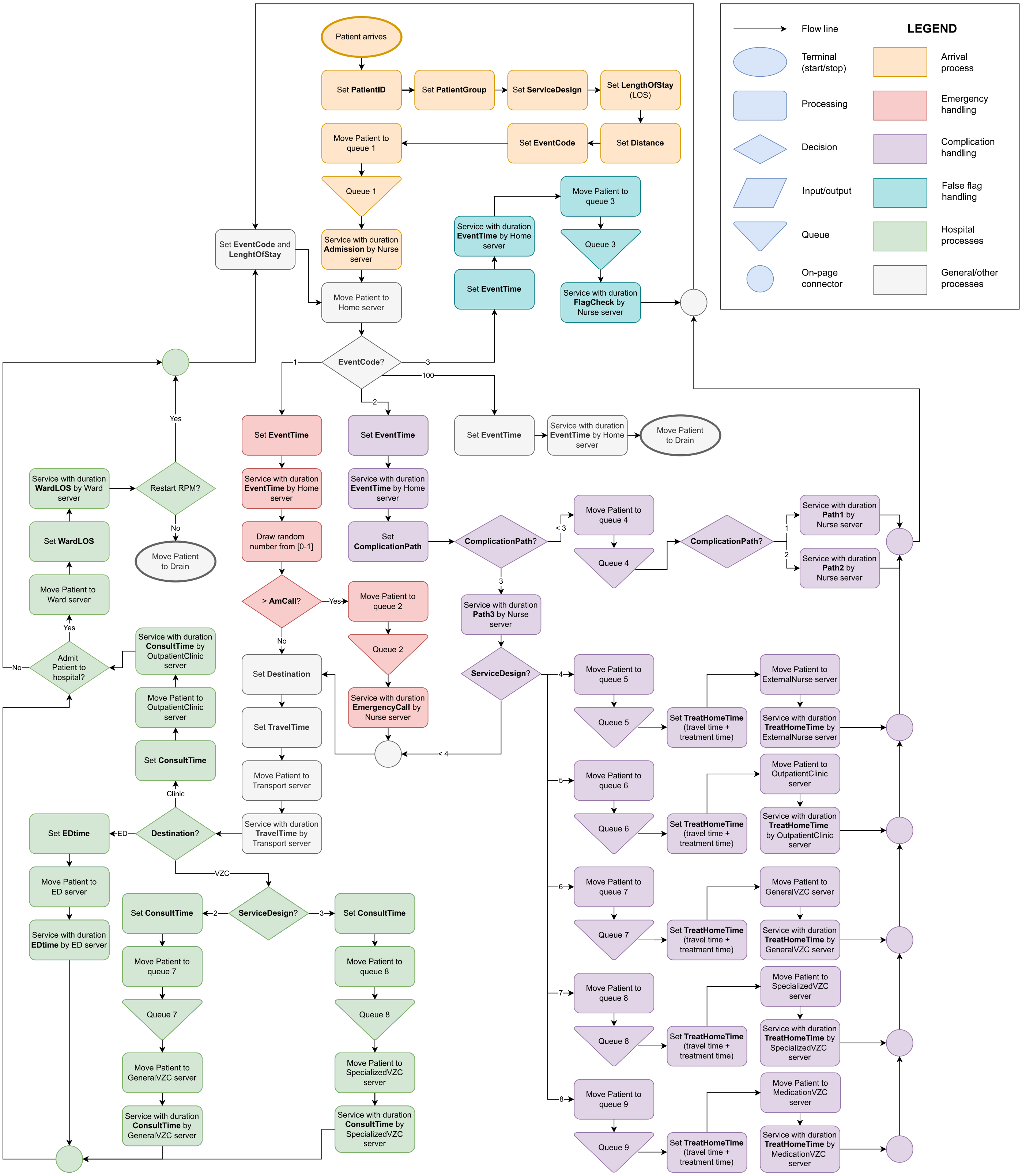


FIGURE 4.1: Simulation flow of *Patient* atom.

- **EventTime**: Time the patient spends at home before an event occurs.
- **Destination**: Destination of the patient within the hospital, e.g. the emergency department.
- **TravelTime**: Time needed to transport the patient to the hospital. Determined using the distance of the patient to the hospital and the mode of transportation (ambulance or not).

In the second situation, the patient moves to a queue waiting for service by one of the nurses. After the patient is served, he moves to the starting point of the first situation and follows the same path from there.

Complications

If the *EventCode* attribute of the patient is equal to 2, a complication will occur in the future. The patient goes through the purple section of the diagram. First, the remaining time until the complication is determined (*EventTime*), and the patient remains in the home situation for this period. Next, depending on the value of the chosen service design and the type of complication, the patient follows a different path.

In the model, a complication path is selected and the patient moves to a queue waiting for an available nurse. The three different complication paths are defined as follows:

1. VZC nurse advises patient.
2. VZC nurse advises patient after contact with treating specialty.
3. Appointment for consult is made after VZC nurse contacts treating specialty.

The patient moves to a queue waiting for an available nurse to serve them with a duration of *Path1*, *Path2* or *Path3* respectively. With complication path 1 and 2, the patients moves back to the *Home* server after this. With complication path 3 it becomes more complicated. In service design 1 to 3, the patient is treated at the hospital at the treating specialty (design 1) or a predetermined type of VZC nurse (design 2 and 3). The patients move to the same point in the flowchart where the emergency patients enter hospital departments, but get assigned a different *Destination*. In service design 4 to 8, the patient is treated at home by a external organisation or some predetermined type of nurse when the complication cannot be resolved. Depending on their service design, patients move to a queue and the *TreatHomeTime* attribute is determined. After service, the patients move back to the Home server.

- **TreatHomeTime**: Time needed to travel to the patient and provide treatment.

False flags

If the *EventCode* attribute of the patient is equal to 3, a false flag event will occur in the future. The patient goes through the turquoise section of the diagram. First, the remaining time until the false flag is determined (*EventTime*), and the patient remains in the home situation for this period. When the *EventTime* passed, the patients moves to a queue waiting for an available nurse, which will serve him with duration *FlagCheck*. Upon completion of the service, the patient moves back to the *Home* server.

Hospital processes

The hospital is represented by four different departments: the VZC, the emergency department, the outpatient clinic, and the ward. Patients enter one of these departments through the Transport server, as mentioned in the previous sections. Patients with the VZC as their destination, went through complication path 3 and are treated at the VZC because service design 2 or 3 is selected. When patients arrive at the VZC server, the *ConsultTime* is determined and they move to the queue for the *GeneralVZC* server or *SpecializedVZC* server for service design 2 and 3 respectively. Upon completion of the service, it is decided whether the patient needs to be admitted to the hospital. A patient either moves to the Home server or to the Ward server. The patient is served by the Ward server with a duration of *WardLOS* and then moves to the *Drain* or restarts home monitoring with a new *LengthOfStay*.

- **ConsultTime**: Time spend at a hospital department for consult.
- **WardLOS**: Time spend at the hospital ward.

Patients with the emergency department as their destination, flow from the red emergency handling section of the diagram. Upon arrival at the hospital, the *EDtime* attribute is set and the patient is served by the *ED* server with this duration. When service is completed, it is decided whether the patient needs to be admitted to the hospital as described earlier.

- **EDtime**: Time spend at the emergency department.

Patients with the outpatient clinic as their destination, went through complication path 3 and are treated at the outpatient clinic because service design 1 is selected. When patients arrive at the clinic, the *ConsultTime* is determined and they remain in the *OutpatientClinic* server for this duration. After this, it is decided whether the patient needs to be admitted to the hospital as described earlier.

4.2.2 Experimental factors and responses

The *experimental factors* of the model can be altered to create an improvement in or better understanding of the real world. To determine the required capacity, the number of available nurses needs to be varied. The patients group included and the number of patients per group can be varied using the arrival rate. The intensity of the contact between the VZC nurses and the patients can be selected by choosing daily, weekly, or monthly schedules for calls and measurement checks. To compare the various service designs, they are also selected as an experimental factor of the model. Table 4.1 mentions the experimental factors and included service designs.

The *responses* are the measured results of the model, used to evaluate the various service designs. The designs are compared based on the required nurse capacity, and the waiting time experienced by patients. Increasing the nurse capacity is expected to reduce the waiting time. Because a more stable waiting time is preferred over inconsistent waiting times, an option must exist to evaluate the waiting as the percentage of patients for which the waiting time lies below a threshold, comparable to a service level.

The definition of waiting time experienced by the patients differs for the different service designs. In the first three service designs, the patient is treated at the hospital in case a complication occurs that cannot be solved with consult by phone. In service design 4 to 8, the patient stays at home when a complication occurs and is visited by a nurse from the hospital or an external organization.

There are four queues that every patient, regardless of the chosen service design, can access: *Admission Queue*, *FlagCheck Queue*, *EmCall Queue*, and *Complication Queue*. The time in these queues is highly dependent on the priority they are given for treatment by the Nurse Server.

Experimental factors
- Number of nurses - Number of patients - Intensity of patient contact - Service designs 1. Patient is treated at the hospital by a nurse of a certain specialty. 2. Patient is treated at the hospital by a general nurse of the hospital@home program 3. Patient is treated at the hospital by a specialized nurse of the hospital@home program. 4. Patient is treated at home in collaboration with an external organisation. 5. Patient is treated at home by a nurse at a certain specialty. 6. Patient is treated at home by a general nurse of the hospital@home program. 7. Patient is treated at home by a specialized nurse of the hospital@home program. 8. Patient is treated at home by a medication@home nurse.
Responses
- Patient waiting time - Nurse utilization

TABLE 4.1: Experimental factors and responses

In three of the eight service designs, these are the only queues at which a waiting time can be measured. In service design 1 and 5, the patient is treated by a nurse from their specialty. Since no distinction is made between these departments in the model, all specialties are represented by one server with infinite capacity. There is no waiting time for this server, but the number of arrivals of a certain type can be registered. In service design 4, the patient is treated by a nurse from an external organization. This is also represented by a server with infinite capacity, similar to the various specialties within the hospital.

For the other service designs, in the event of a complication, the patient is treated by a nurse from the VZC (general of specialized) or a nurse who is administering medication at home. These nurses are represented by separate servers, thus the waiting time can be determined. When the patient is treated at home, the travel time to the patient is part of the waiting time. When the patient is being treated in hospital, the patient's travel time to the hospital is not taken into account.

The number of nurses required to reach a certain level is determined by varying the number of nurses. Measuring the utilization rate of the nurses can assist the user in determining the minimum required number. Nurse utilization is defined as the percentage of the total available time of nurses at which nurses are working.

4.2.3 Assumptions and simplifications

Assumptions

Assumptions have to be made about areas where there is limited knowledge of the system.

- Patients waiting for service by the VZC or service at any hospital department will wait for service for an infinite time. The capacity of these queues is therefore modelled as unlimited.
- The decision made at the VZC to either let the patient stay at home or visit the hospital is always accurate. Patients with complications and emergency patients are treated accurately.

- When the patient is treated at home (in service design 4 to 8) by a nurse or external organization, the complication is resolved after this and there is no need to travel to the hospital.

Simplifications

Model simplification involves leaving out components and interactions that have little effect on model accuracy and modelling components and interactions more abstract.

- The interactions needed to admit a patient to the VZC are modelled as a black box.
- The different interactions in the complications paths are modelled as a black box. They are represented as service by a nurse with a certain duration.
- Detailed process steps of medication@home are not included in the model. The services are modelled as a black box.
- Interactions needed to visit the patient at home (service design 5-8) are simplified into travel and treatment time.

4.3 Data analysis

4.3.1 Arrivals

Inpatients

The interarrival time of inpatient groups is based on data of their arrival to the hospital. The distribution found based on this data is then multiplied with a throughput factor to approximate the arrival to the VZC.

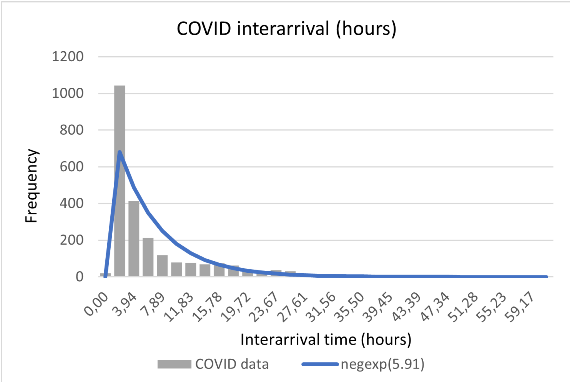
Because the COVID-19 pandemic influences the arrival and admission of inpatients to the hospital, data from the years 2018 and 2019 is used to determine the interarrival time of the non-COVID patient groups. The negative exponential distribution is typically used to model interarrival times. To determine whether the negative exponential distribution can be used to model the arrival of the inpatient groups, we compare it to a negative exponential distribution with the mean interarrival time of the hospital data using Microsoft Excel. Appendix G contains a more detailed explanation of this process.

Based on Chi-Square tests and visual inspection of the diagrams in Figure 4.2, we decide that the negative exponential distribution, with the mean interarrival time as parameter, is a adequate approximation of the arrivals.

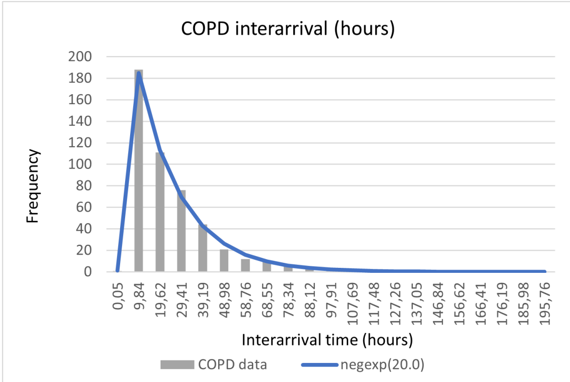
Patient group	Interarrival (sec)	Interarrival * 2 (sec)	Interarrival * 2 (hours)
COVID	negexp(21268)	negexp(42536)	negexp(11.82)
COPD	negexp(71941)	negexp(143882)	negexp(39.97)
Vitalys	negexp(26485)	negexp(52970)	negexp(14.71)
Infectious diseases	negexp(83646)	negexp(167292)	negexp(46.47)

TABLE 4.2: Interarrival times of inpatient patient groups

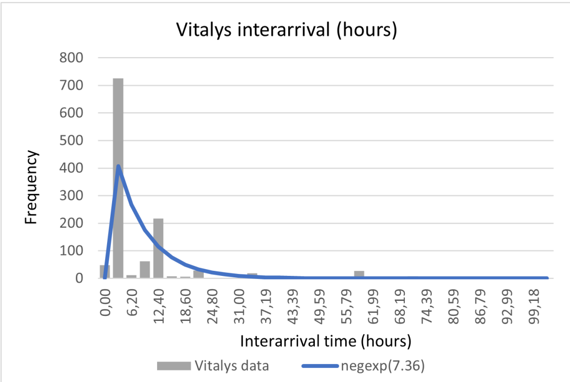
The VZC estimates that 3 to 4 patients with an infectious disease will arrive at the VZC each week. The interarrival time found in the hospital data is 83646 seconds (23.24 hours). When we multiply the interarrival time with a factor of two the interarrival time (46.47 hours) results in 3.6 arrivals per week, this approximates the estimation of the VZC nurses.



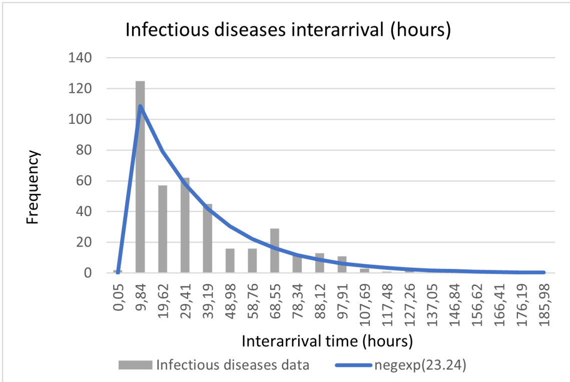
(A) Histogram of the interarrival time of COVID patients (n = 91)



(B) Histogram of the interarrival time of COPD patients (n = 480)



(C) Histogram of the interarrival time of Vitalys patients (n = 1183)



(D) Histogram of the interarrival time of Infectious diseases patients (n = 400)

FIGURE 4.2: Histograms of the interarrival time of inpatients and the selected negative exponential distribution with the mean interarrival time as parameter

Because no approximation is made for the other patient groups, this factor is also used for the remaining inpatient groups. This assumption can be made because the decision to admit a patient to the VZC is mainly based on characteristics such as language and home-situation, which transcend the medical condition of the patient.

Outpatients

The arrival of the outpatient groups cannot be based on hospital data because there is no admission to the hospital. The patients are monitored for a longer period of time, so a regular arrival rate would cause a build up of patients in the model over time. Each of the outpatient groups has a pilot size and estimated total population (per year). The interarrival time of the groups is estimated using this information.

Patient group	**Pilot size**	**Total population**	**Interarrival time (sec)**
Chronic kidney damage	50 patients	1000 patients/year	negexp(31536)
Gestational diabetes	5-10 patients	100-120 patients/year	negexp(286690)
Type 1 diabetes	45-90 patients	780-900 patients/year	negexp(39919)

TABLE 4.3: Interarrival times of outpatient patient groups

If patients arrive according to the total estimated yearly population, the interarrival time would be as displayed in Table 4.3. To prevent the build up of patients in the model over time, the pilot size is used as maximum number of patients for each group. This is realized in the simulation model by generating a maximum of 50 patients with chronic kidney damage and 90 patients with type 1 diabetes. Contrary to these patient groups, gestational diabetes patients leave the system after some time. When a gestational diabetes patient leaves the system, a new patient of this group will be generated.

4.3.2 Length of stay

Using statistical analysis techniques from the RStudio software, a distribution can be fitted on the length of stay (LOS) of 91 historical COVID patients. Appendix H depicts the corresponding RStudio script.

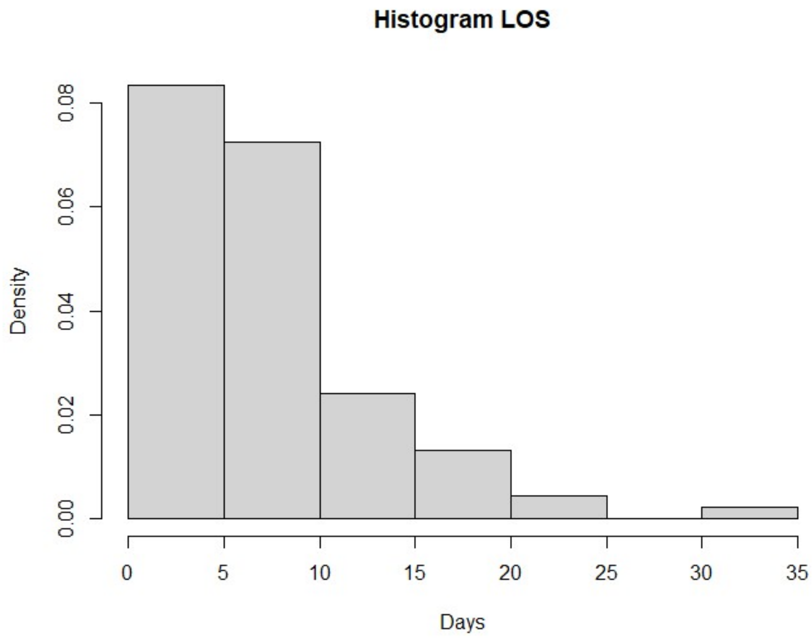


FIGURE 4.3: Histogram of the length of stay of COVID patients (n = 91)

Figure 4.3 depicts a histogram of the length of stay of COVID patients. Based on the shape of the histogram, the Normal distribution, Gamma distribution, Weibull distribution, and Exponential distribution are compared and tested using the Kolmogorov-Smirnov statistical test. This test compares a known probability distribution to the generated distribution of the dataset. With n = 91 and an alpha level of 0.05, the p-value can be calculated by: $1.36/\sqrt{n} = 1.36/\sqrt{91} = 0.142$. Table 4.4 depicts the K-S test statistics for the distributions.

The null hypothesis, that the data follows a certain distribution, is rejected when the K-S test statistic is larger than the p-value. In this case, the null hypothesis is rejected for three of the four distributions. The null hypothesis is accepted for the Gamma distribution, meaning that the length of stay of COVID patients can be represented by a Gamma distribution (shape = 2.77, rate = 0.352), as displayed in Figure 4.4.

According to Law (2014), the K-S is only valid if all parameters of the hypothesized distribution are known. For the LOS distribution, the parameters are estimated from the data. This may cause a smaller probability of a Type I error than specified, corresponding to a loss of power (Law, 2014). Alternative statistical tests (Chi-Square, Anderson-Darling) have been explored, but did not result in the acceptance of any theoretical distribution. The fitted Gamma distribution was the closest to the boundary of acceptance for both alternative statistical tests. Because of the small amount of available data, a pragmatic approach

Distribution	K-S test statistic
Normal	0.215
Gamma	0.135
Weibull	0.154
Exponential	0.278

TABLE 4.4: K-S test statistics of selected distributions

is preferred. Therefore, the previously defined Gamma distribution (shape = 2.77, rate = 0.352) is used as input for the simulation model.

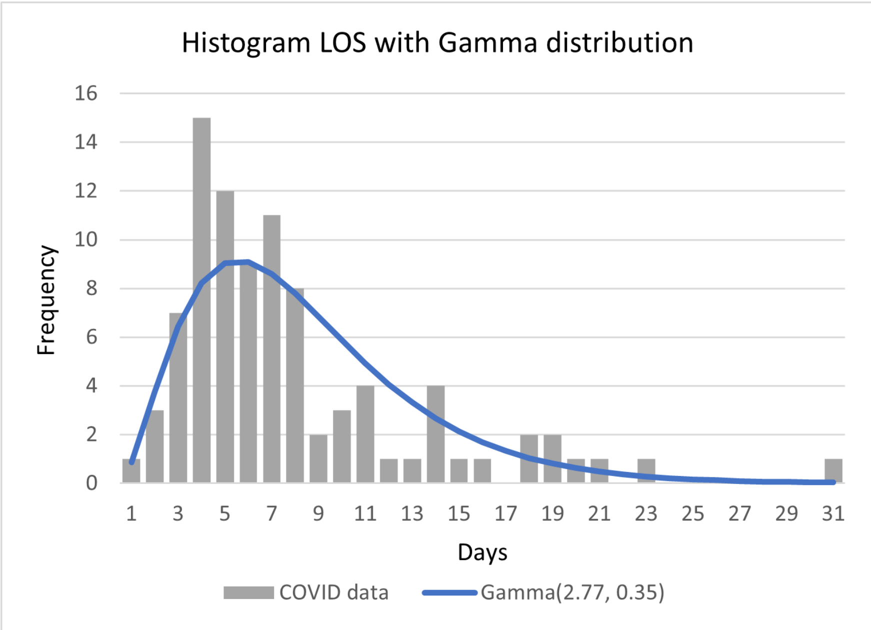


FIGURE 4.4: Histogram of the length of stay of COVID patients (n = 91) with Gamma(2.77, 0.35) distribution

No data is available of the length of stay of other patient groups in the VZC, since they are not included yet. The LOS of these patient groups is based on the expert opinion of five VZC nurses and the length of stay in the hospital. The same method is used to fit distributions based on the hospital length of stay as for the COVID patients. Appendix G depicts a similar RStudio script. Table 4.5 depicts the LOS estimated by VZC nurses and the fitted distribution for the six remaining patient groups.

For the COPD patients and patients with infectious diseases, the LOS estimated by the VZC nurses corresponds to the LOS found in the hospital data. These distributions can be used for the length of stay. Continuously monitored (out)patients, the patient with chronic kidney damage and type 1 diabetes, do not leave the simulation model so no distribution is needed. For the Vitalys patients, the LOS estimated by the VZC differs from the distribution fitted on the data. Because the VZC protocol for these patients clearly states that the stay should be at least two and no more than three weeks, a Uniform distribution is used in the simulation model. The gestational diabetes patients have a maximum LOS of nine months due to the pregnancy. Their length of stay is also represented by an Uniform distribution in the simulation model, with a minimum of one month and maximum of nine months.

Patient group	Estimated VZC LOS	Hospital LOS	Model LOS
COPD	6-8 days	Gamma(1.74, 0.26) Mean = 6.48	Gamma(1.74, 0.26) Mean = 6.48
Vitalys	2-3 weeks	*No distribution found* Mean = 1.55	Uniform(14.00, 21.00) Mean = 17.50
Chronic kidney damage	Continuous	N/A	Continuous
Infectious diseases	5-8 days	Weibull(1.24, 7.19) Mean = 6.36	Weibull(1.24, 7.19) Mean = 6.36
Gestational diabetes	1-9 months	N/A	Uniform(30.44, 273.93) Mean = 152.19
Type 1 diabetes	Continuous	N/A	Continuous

TABLE 4.5: Length of stay (LOS) per patient group

4.3.3 Complications and emergencies

Complication probability

For the COVID patients, the complication probability can be calculated using the data from the discharged patients (n = 91). According to the VZC nurses, only complications resulting in complication path 2 and 3 are documented in the data. Complication path 1, giving advice by phone, occurs for almost every patient. For the COVID patients, the complication probability assumed to be 0.90. For the patient groups that are not admitted to the VZC yet, no data about the probability of complications is available. The expert opinion of four VZC nurses resulted an estimated complication probability as shown in Table 4.6.

Patient group	Complication probability
COVID	0.90
COPD	0.90
Vitalys	0.75
Chronic kidney damage	0.30
Infectious diseases	0.40
Gestational diabetes	0.30
Type 1 diabetes	0.20

TABLE 4.6: Complication probability per patient group

Complication path probability

There is no data available about the probabilities of selecting a certain path. The expert opinion of five VZC nurses resulted an estimation of the complication paths probabilities as shown in Table 4.7.

Complication path	Probability
1: VZC nurse advises patient.	0.76
2: VZC nurse advises patient after contact with treating specialty.	0.14
3: Hospital appointment is made after VZC nurse contacts treating specialty.	0.10

TABLE 4.7: Complication path probabilities

Emergency probability

For the 91 COVID patients that are discharged from the VZC, it is documented whether an emergency occurred. In 16 of the 91 cases an emergency occurred, resulting in an emergency probability of 16/91=18%. In 10 of the 16 emergency cases, the patient needed to be readmitted to the hospital. For the remaining patient groups, no data about the probability of an emergency is available. The expert opinion of five VZC nurses resulted an estimated emergency probability as shown in Table 4.8.

Patient group	Emergency probability
COVID	0.18
COPD	0.13
Vitalys	0.25
Chronic kidney damage	0.10
Infectious diseases	0.17
Gestational diabetes	0.08
Type 1 diabetes	0.06

TABLE 4.8: Emergency probability per patient group

4.3.4 Travel time

The postal code of all patients that have been admitted to the VZC is known. With this, the travel time to these patients can be determined. We know that patients admitted to the VZC need to be located within the region of Arnhem. Since this is not a predefined region, we assume that patients live within a 25 kilometre radius of Rijnstate Arnhem. This is also the range used for the medication@home patients. There are 188 (4 digit) postal codes within this range. Based on Zwier (2021), the travel times between the postal code areas can be modelled by converting the codes to coordinates of the centre point of the area. The travel times are calculated using Bing Maps Developer Center, an API that can calculate driving times by car between coordinates (Zwier, 2021). Because 4 digit postal codes are used, the travel time between two patients in the same area is zero. To account for this, a minimum travel time of 5 minutes will be included in the simulation model.

4.3.5 Outside range measurements

Five nurses estimated the frequency of outlying measurements on a Likert Scale with the following response anchors: never, rarely, sometimes, often, always. Three out of five nurses indicated that they expect outlying measurements to occur often. The other two nurses indicated that they expect these measurement to occur sometimes.

4.3.6 Duration of VZC activities

Besides the monitoring of patients, the VZC nurses carry out various other tasks. A list of these tasks has been composed in collaboration with VZC nurses. An estimation of the duration of each of these activities can be made. However, because time needed for many of these activities will vary strongly over time, depending on the progression of the Rijnstate@home project and the number of included patients, we decide to measure the *direct* *patient time*. In this measurement we include the activities related to the monitoring mentioned in Table 4.9, and exclude other activities, e.g. national COVID coordination, development of new care paths, creating work schedules. An estimation of the duration of the activities in Table 4.9 is made by five VZC nurses.

Activity	Duration
Consult by phone	10 min.
Checking measurement (flag)	5 min.
Consulting treating specialty	10 min.
Admission of new patient	85 min.

TABLE 4.9: Estimated duration of VZC activities

4.4 Simulation set-up

4.4.1 Warm-up period

The simulation model created in this study is a non-terminating simulation since there is no natural event that specifies the end of a simulation run. This non-terminating simulation reaches a steady-state after a certain amount of running time, therefore a warm-up period needs to be calculated.

By using a warm-up period, observations from the beginning of the simulation run are deleted. We delete these observations because they depend on initial conditions (an empty system), therefore they are not representative for steady state behaviour of the model. We use Welch's graphical method to determine the warm-up period of the simulation model, which is the simplest and most general technique (Mahajan and Ingalls, 2005). Appendix I contains the steps as explained in "Simulation Modeling and Analysis" by Law (2014).

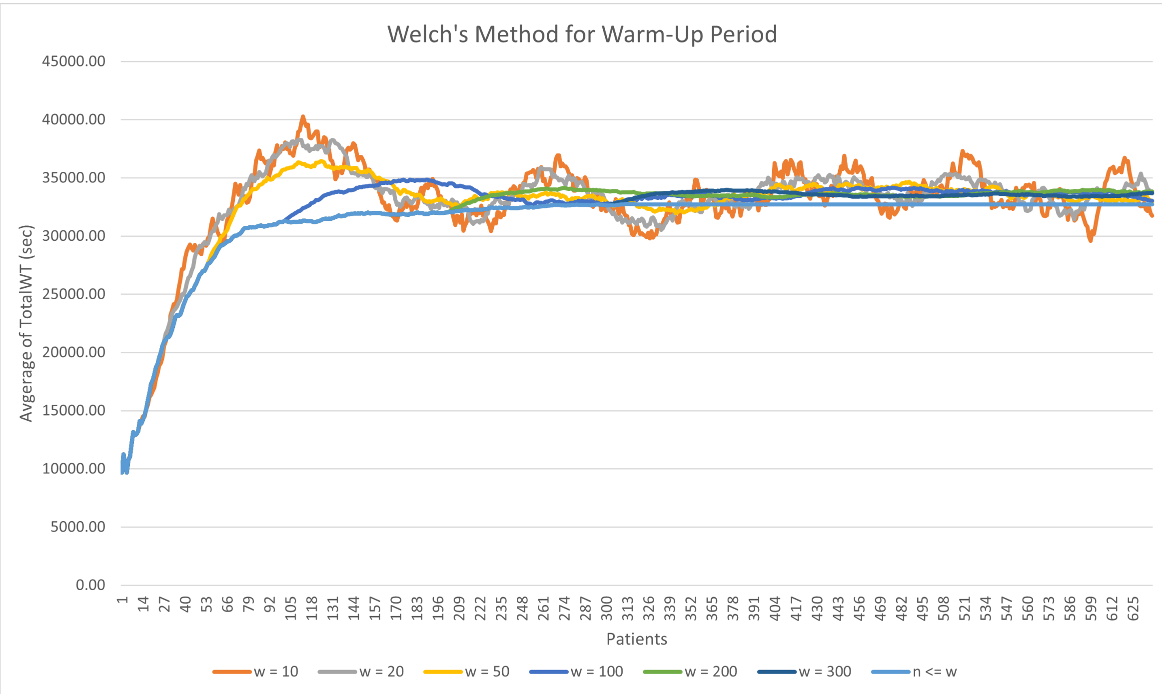


FIGURE 4.5: Determining the warm-up period using Welch's method

Figure 4.5 contains the output of Welch's graphical method. From this graph can be seen that the system stabilizes when 200 COVID patients went through the model. This corresponds to a warm-up period of approximately 100 days (2400 hours).

4.4.2 Run length

The replication/deletion approach is used when deleting observations (the warm-up period) from the runs. This means that from each run the first 2400 hours are not incorporated in calculations. By rule, the warm-up period can be at most 10% of the total run length, to ensure that the deleted portion of data is not too large. In this case, this results in a total run lenght of 24000 hours (approx. 1000 days).

4.4.3 Replications

The number of replications is determined using the sequential procedure. This entails performing replications of the simulation until the width of the confidence interval, relative to the average, is sufficiently small. The interval is considered to be sufficiently small when $\gamma \leq 0.05$.

$$\frac{t_{n-1,1-\frac{1}{2}\alpha}\sqrt{S^2/n}}{\bar{x}} < \gamma' \tag{4.1}$$

When using γ for the estimate of the relative error, the actual relative error γ' is at most $\gamma/1-\gamma$. Therefore, the corrected target value γ' can be rewritten as $\gamma' = \gamma/1-\gamma$. By rewriting Equation 4.1 to solve for n, and substituting the formula for γ' we derive an estimate for the number of replications needed to obtain a 95% confidence interval:

$$n^* = \min\left(i \leq n : \frac{t_{n-1,1-\frac{1}{2}\alpha}\sqrt{S^2/i}}{\bar{x}}\right) \tag{4.2}$$

The estimation obtained by solving n^* will provide the needed number of replications. The sequential procedure used for these calculations can be found in Appendix I. Using the average total waiting time of the patients in this procedure results in a minimum of ten replications. To account for the slight variance that may occur using the sequential procedure, the number of replications used in the experiments is twelve.

4.4.4 Common random numbers

It is important to consider the use of common random numbers, to be able to compare the confidence intervals of performance measures. In this model, random numbers are used to generate an interarrival time and length of stay from pre-defined distributions. For each experiment, twelve replications are performed. Each replication uses a different random number seed to prevent unnecessary correlation between the replications. For every first run of an experiment, the same random number seeds are used. This way, the performance of different experiments can be compared. The use of common random numbers is achieved by setting the *RunNr* as the generator seed when initializing a new simulation run.

4.5 Implementation and verification

The model is implemented in the Enterprise Dynamics (version 10.4) software of INCONTROL Simulation Solutions. To verify if the programmed model coincides with the conceptual model created in Section 4.2, checks were built into the model:

- The patient flows can be manually examined because each movement is documented.
- Patients cannot access atoms that are not related to their event and/or complication path. The software will display an error message if they try to enter critical atoms.

The functioning of frequently occurring parts of code has been checked using the patient flows and output tables of atoms. Besides this, the patient flow data has been used to verify if the numbers correspond to the input parameters of the model. For example, if an input parameter is that 10% of the patients should have an emergency, we verified this by generating 1000 patients and calculating the percentage of patients with an emergency. Due to the large computational time related to collecting this data, the checks are deactivated during the experimentation phase.

4.6 Validation

Model validation refers to the process of confirming that the model is a sufficient representation of reality and achieves its intended purpose. Since there is not enough data available about the current situation to compare to the model responses, this method of validation cannot be used. Therefore, the model is validates by means of *face validity*. This is the extent to which the test is viewed by stakeholders as covering the concept it claims to measure.

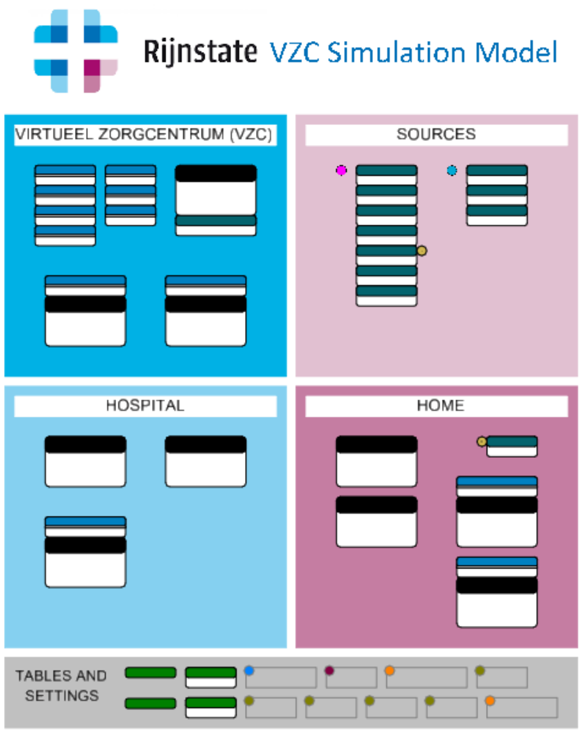
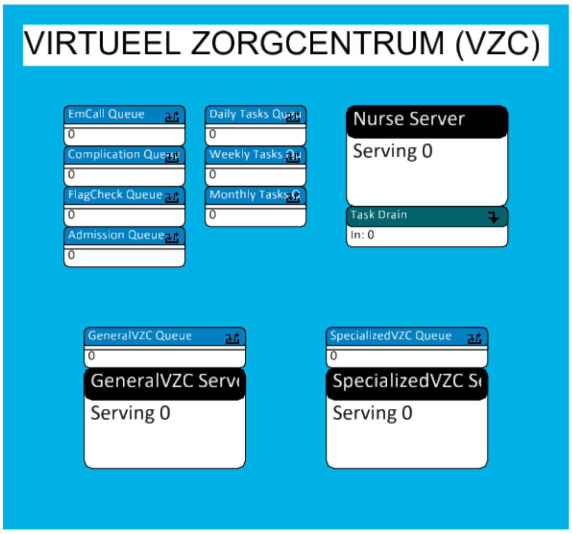


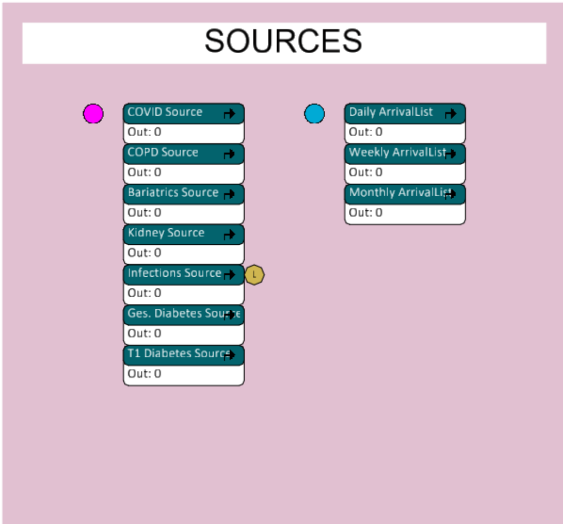
FIGURE 4.6: Overview of the dashboard of the simulation model

To assess the model's face validity, a meeting was held with a manager and project leader of the VZC. The flowcharts of the current situation have been discussed with VZC nurses earlier in the process. During the validation meeting, the assumptions and simplifications, simulation flowcharts, and the experiment set-up were discussed with the stakeholders. Furthermore, they were consulted on the user-friendliness of the input file and model's dashboard. The attendees of the validation meeting reacted positively to the model. They asked some questions about the features of the model and suggested some additional experiments to showcase the possibilities.

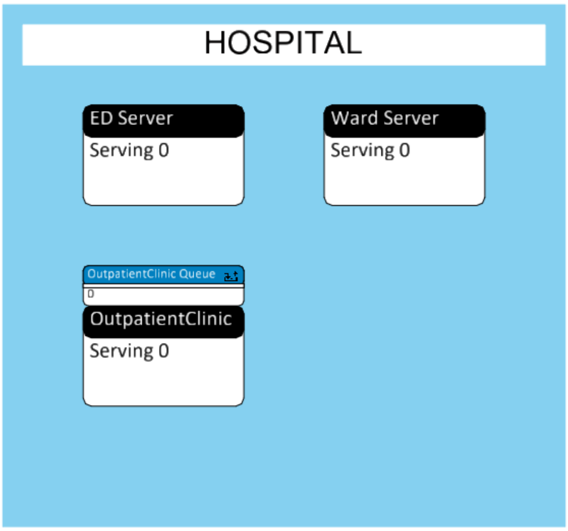
Figure 4.6 depicts an overview of the simulation model. Figure 4.7 contains a more detailed view. The model is divided into four sections, representing different locations and functions, corresponding to the process flow created earlier.



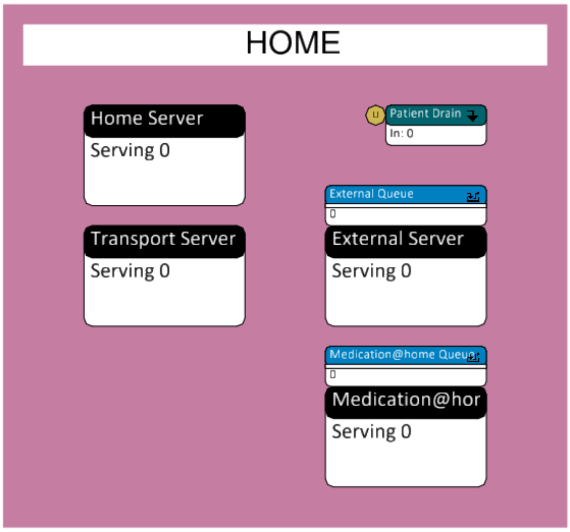
(A) Detailed view of the VZC section of the dashboard



(B) Detailed view of the Sources section of the dashboard



(C) Detailed view of the Hospital section of the dashboard



(D) Detailed view of the Home section of the dashboard

FIGURE 4.7: Detailed views of the dashboard of the simulation model

4.7 Experiments

The goal of the second part of this study is to develop a quantitative model that can prospectively assess and compare the previously defined service designs and can be used for the further development of the Rijnstate@home services in terms of capacity management. The goal of the Experiments section is to demonstrate the possibilities of the model and show that it can be used in the future for development of the services. The experiments are divided into four categories: service designs, capacity, patient groups, and the sensitivity analysis. The following subsections each discuss one category.

4.7.1 Service designs

The first set (experiment A) concerns the experimentation with the various service designs. Each of the eight experiments in this set corresponds to a service design. The service design is selected for all patients groups, with all other parameters being equal in each experiment. Table 4.10 depicts the configurations used for experiment A.

Code	SD	Nurses	GenVZC	SpecVZC	Med@home
A-I	1	3	1	1	2
A-II	2	3	1	1	2
A-III	3	3	1	1	2
A-IV	4	3	1	1	2
A-V	5	3	1	1	2
A-VI	6	3	1	1	2
A-VII	7	3	1	1	2
A-VIII	8	3	1	1	2

TABLE 4.10: Configurations for experiment set A, where SD = Service Design

4.7.2 Capacity

The capacity needed at the VZC can be assessed by varying the number of nurses. Three types of nurses are included in the model: nurses, general VZC nurses, and specialized VZC nurses. General and specialized VZC nurses are only used for certain service designs. The *Nurse* server is used by patients with every service design. In Experiment B, the number of nurses is varied. Service design 1 and 5 are used, since then all patients only use the *Nurse* server. Service design 1 is selected for the inpatient groups and service design 5 for the outpatient groups. Table 4.11 depicts the division of patient groups.

Nr	Group	In/Out
1	COVID	Inpatient
2	COPD	Inpatient
3	Vitalys	Inpatient
4	Chronic kidney damage	Outpatient
5	Infectious diseases	Inpatient
6	Gestational diabetes	Outpatient
7	Type 1 diabetes	Outpatient

TABLE 4.11: Division between in- and outpatients.

Code	SD	Nurses	GenVZC	SpecVZC	Med@home
B-I	1/5	1	1	1	2
B-II	1/5	2	1	1	2
B-III	1/5	3	1	1	2
B-IV	1/5	4	1	1	2
B-V	1/5	5	1	1	2

TABLE 4.12: Configurations for experiment set B, where SD = Service Design

In Experiment C, the number of general VZC nurses is varied. Service design 2 and 6 are used, since these are the service designs were patients visit the general VZC nurse. Service design 2 is selected for the inpatient groups and service design 6 for the outpatient groups.

Code	SD	Nurses	GenVZC	SpecVZC	Med@home
C-I	2/6	B	1	1	2
C-II	2/6	B	2	1	2
C-III	2/6	B	3	1	2

TABLE 4.13: Configurations for experiment set C, where SD = Service Design

In Experiment D, the number of specialized VZC nurses is varied. Service design 3 and 7 are used, since these are the service designs were patients visit the specialized VZC nurse. Service design 3 is selected for the inpatient groups and service design 7 for the outpatient groups.

Code	SD	Nurses	GenVZC	SpecVZC	Med@home
D-I	3/7	B	1	1	2
D-II	3/7	B	1	2	2
D-III	3/7	B	1	3	2

TABLE 4.14: Configurations for experiment set D, where SD = Service Design

4.7.3 Patient groups

Other experimental factors of the simulation model are the patient groups that are included and the number of patients or arrival rate. In Experiment E, the exclusion of patient groups is demonstrated by selecting only the inpatient (E-I) or outpatient (E-II) groups. Experiment F shows the scaling up of the pilot for patients with chronic kidney damage. The maximum number of patients for this group is varied from 50 (F-I) to 100 (F-III) patients.

Code	SD	Nurses	GenVZC	SpecVZC	Med@home	Group
E-I	1	B	1	1	2	Inpatient
E-II	1	B	1	1	2	Outpatient

TABLE 4.15: Configurations for experiment set E, where SD = Service Design

Code	SD	Nurses	GenVZC	SpecVZC	Med@home	Group 4
F-I	1	B	1	1	2	50
F-II	1	B	1	1	2	75
F-III	1	B	1	1	2	100

TABLE 4.16: Configurations for experiment set F, where SD = Service Design

4.7.4 Sensitivity analysis

The purpose of this sensitivity analysis is to show how the output varies if the estimated parameters are proved to be different. The Vitalys patients (Group 3) are the group for which the most assumptions needed to be made. In Experiment G, the interarrival time for this group is varied. Experiment F provides insight into the effect of the length of stay of these patients.

Code	SD	Nurses	GenVZC	SpecVZC	Med@home	Interarrival (sec)
G-I	1	B	1	1	2	2 * 52970
G-II	1	B	1	1	2	52970
G-III	1	B	1	1	2	0.5 * 52970

TABLE 4.17: Configurations for experiment set G, where SD = Service Design

Code	SD	Nurses	GenVZC	SpecVZC	Med@home	Length of stay
H-I	1	B	1	1	2	Uniform(7, 14)
H-II	1	B	1	1	2	Uniform(14, 21)
H-III	1	B	1	1	2	Uniform(21, 28)

TABLE 4.18: Configurations for experiment set H, where SD = Service Design

The set-up of the experiments concludes Chapter 4 of this thesis. In this chapter the development and construction of the simulation model have been discussed. The data analysis provided input for the simulation model and the simulation set-up has been determined. Chapter 5 will present the results of the experiments as described in this chapter.

Chapter 5

Results

This chapter presents the results to the experiments discussed in Section 4.7. Each section concerns one experiment set (A to H). The final section contains a summary of the conclusions drawn from the experiment results.

5.1 Experiment A

The purpose of experiment set A is to show the possibility of comparing service designs. Figure 5.1 contains the AvgTotalWT of all patients for each service design experiment. As mentioned in Section 4.2.2, the waiting time experienced by the patients varies for the different service designs. Figure 5.2 contains the AvgTotalWT per PatientGroup for each experiment.

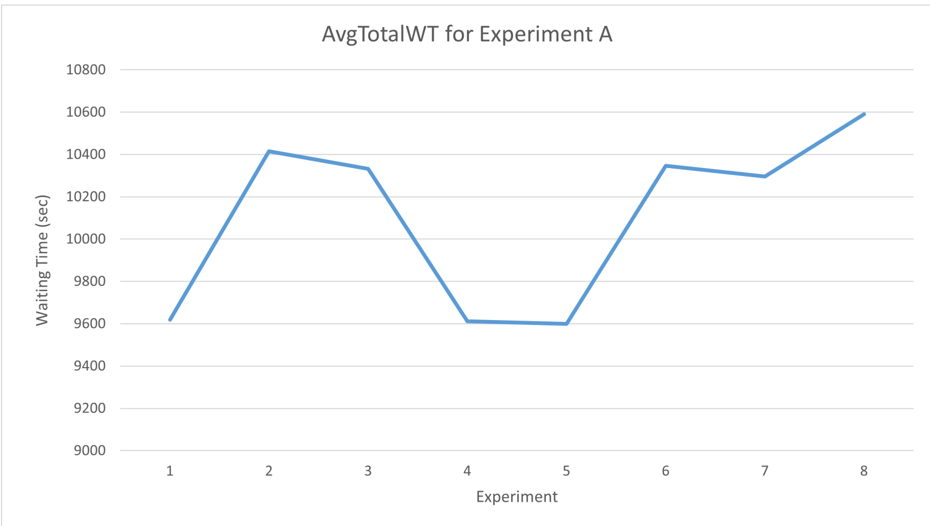


FIGURE 5.1: AvgTotalWT per PatientGroup for experiment set A

From Figure 5.1 we can see that there is a clear separation between experiments with a AvgTotalWT around 9600 seconds (I, IV, and V) and experiments with a AvgTotalWT of 10300 seconds and up (II, III, VI, VII, and VIII). When we subtract the lowest (I) from the highest (VIII) AvgTotalWT, we find that the difference is 1000 seconds (16,67 minutes). The higher waiting times for experiments II, III, VI, VII, and VIII can be explained by the servers involved in the associated service designs. The *GeneralVZC* server and *SpecializedVZC* server both have a capacity of 1 nurse in these experiments. They relate to service design 2 and 6, and 3 and 7 respectively. Increasing the capacity of these servers will decrease the waiting times. However, in the current experiment the same service design is selected for all patient groups. When a combination of service designs is used, increasing capacity on these servers will presumably not be needed. The capacity of the *Medication@home* server is always 2. This relates to service design 8. Furthermore, when service design 8 is selected, the patient experiences an additional waiting time of waiting for the medication@home nurse to finish service on the current at home administration.

Figure 5.2 shows the AvgTotalWT per patient group for each experiment. The AvgTotalWT for patient group 6 (gestational diabetes patients) is consistently lower than for the other patient groups. This can be explained by the fact that there are only 10 patients of this type included in the model, to simulate the pilot. Furthermore, the complication and emergency probability for this group are relatively low. This results in low waiting times since a higher percentage of the patients only experiences waiting time with VZC admission.

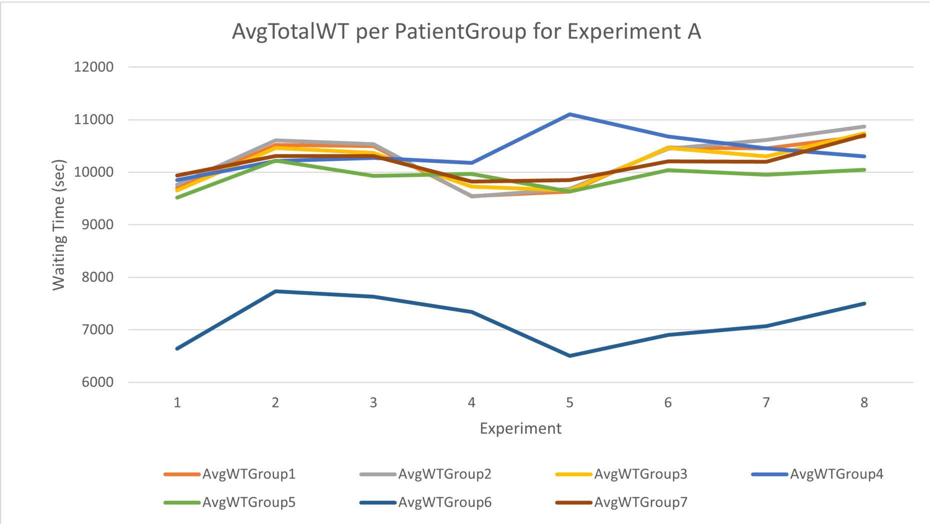


FIGURE 5.2: AvgTotalWT per PatientGroup for experiment set A

The utilization of the nurse servers changes as expected. From Table 5.1 can be seen that *GeneralVZC* server is only used in in experiment II and VI, since in the corresponding service designs the patients are treated by this type of nurse. With service design 2 the server utilization is lower than with service design 6, because patients are treated at the hospital and at home respectively. Treatment at home requires more nurse capacity due to travel times. This reasoning is the same for the SpecializedVZC server in Table 5.2 and service design 3 and 7. However, in this case the average busy period of the server is so low with service design 3 that it does not show in the table. The difference exists because the patient treatment time is lower with a specialized VZC nurse than with a general VZC nurse. The *Medication@home* server is only utilized when service design 8 is selected. Therefore, the only busy state percentage in Table 5.3 is that of experiment VIII. The busy state percentage is the fraction of total simulation time in which the server is busy. The distinction between service designs is based on the treatment of complications. Since the *Nurse* server is not treating patients with complications, the change of service design has a minimal impact on its utilization.

Exp	Atom	State	Average	St.Deviation	LB (95%)	UB (95%)	Minimum	Maximum
1	GeneralVZC Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
2	GeneralVZC Server	Busy	0.00	0.00	0.00	0.00	0.00	0.01
3	GeneralVZC Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
4	GeneralVZC Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
5	GeneralVZC Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
6	GeneralVZC Server	Busy	0.01	0.00	0.01	0.02	0.01	0.02
7	GeneralVZC Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
8	GeneralVZC Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00

TABLE 5.1: Busy state percentages of GeneralVZC server in experiment set A

Exp	Atom	State	Average	St.Deviation	LB (95%)	UB (95%)	Minimum	Maximum
1	SpecializedVZC Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
2	SpecializedVZC Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
3	SpecializedVZC Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
4	SpecializedVZC Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
5	SpecializedVZC Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
6	SpecializedVZC Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
7	SpecializedVZC Server	Busy	0.01	0.00	0.01	0.01	0.01	0.02
8	SpecializedVZC Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00

TABLE 5.2: Busy state percentages of SpecializedVZC server in experiment set A

Exp	Atom	State	Average	St.Deviation	LB (95%)	UB (95%)	Minimum	Maximum
1	Medication@home Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
2	Medication@home Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
3	Medication@home Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
4	Medication@home Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
5	Medication@home Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
6	Medication@home Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
7	Medication@home Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
8	Medication@home Server	Busy	0.01	0.00	0.01	0.01	0.01	0.01

TABLE 5.3: Busy state percentages of Medication@home server in experiment set A

Exp	Atom	State	Average	St.Deviation	LB (95%)	UB (95%)	Minimum	Maximum
1	Nurse Server	Busy	0.31	0.01	0.3	0.32	0.29	0.33
2	Nurse Server	Busy	0.31	0.01	0.31	0.32	0.29	0.33
3	Nurse Server	Busy	0.31	0.01	0.31	0.32	0.30	0.33
4	Nurse Server	Busy	0.31	0.01	0.31	0.32	0.30	0.33
5	Nurse Server	Busy	0.32	0.01	0.31	0.32	0.30	0.33
6	Nurse Server	Busy	0.31	0.01	0.31	0.32	0.30	0.33
7	Nurse Server	Busy	0.31	0.01	0.31	0.32	0.30	0.32
8	Nurse Server	Busy	0.31	0.01	0.31	0.32	0.29	0.32

TABLE 5.4: Busy state percentages of Nurse server in experiment set A

5.2 Experiment B

In experiment set B, we compare the performance of different *Nurse* server capacities. In Section 4.7 we proposed five experiments in this set. However, with a *Nurse* server capacity of 1, the waiting times become infinitely long. This experiment is excluded from the set and we conclude that the capacity of the *Nurse* server should be at least 2 for the current parameters. Table 5.5 lists the new set of experiments.

Code	SD	Nurses	GenVZC	SpecVZC	Med@home
B-I	1/5	2	1	1	2
B-II	1/5	3	1	1	2
B-III	1/5	4	1	1	2
B-IV	1/5	5	1	1	2

TABLE 5.5: Adjusted configurations for experiment set B, where SD = Service Design

The percentage of the total time that a server is in a certain state is displayed in Figure 5.3. From this figure can be seen that the average fraction of time the server is busy decreases as the number of nurses increases. Even with the minimum number of nurses, there is still 20% idle time for the *Nurse* server. From this figure we would conclude that two nurses are sufficient with the current parameters. However, when looking at Figure 5.4a and Figure 5.4b, we see that waiting time for the weekly and monthly tasks becomes very large when only two nurses are present. Increasing the number of nurses to three yields a significant decrease in waiting time.

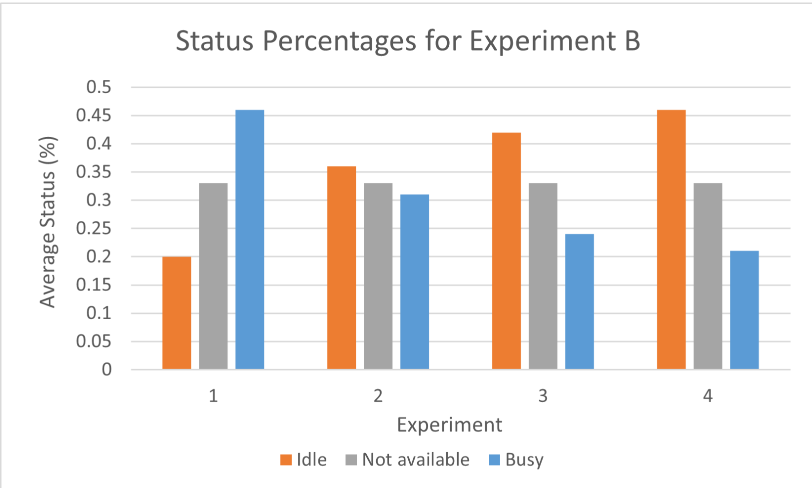
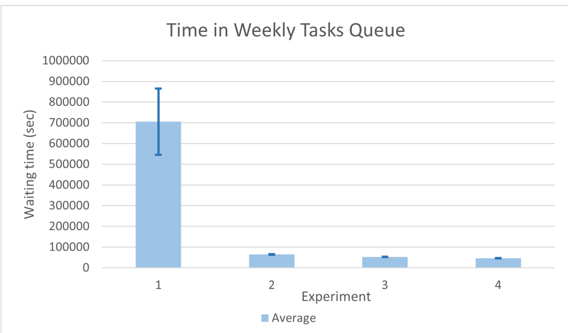
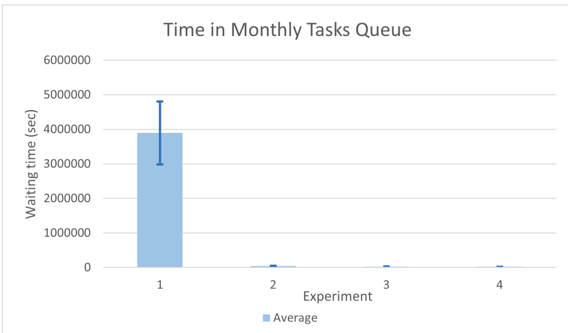


FIGURE 5.3: State percentages for experiment set B



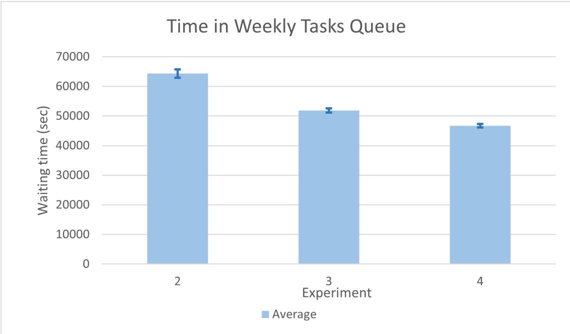
(A) Average waiting time in the weekly task queue



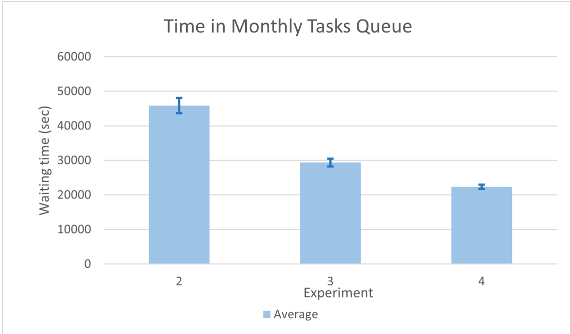
(B) Average waiting time in the monthly task queue

FIGURE 5.4: Graphs of the average waiting time in two task queues and the 95% confidence interval

A further analysis of the weekly and monthly tasks queue results in the figures in Figure 5.5. To decide on the number of nurses required, the user needs to make a decision based on the maximum allowable delay of treating the daily, weekly, and monthly tasks. Table 5.6 shows the data from the performed experiments. In this case we find the waiting time in the queues acceptable when the capacity of the *Nurse* server is three (experiment II).



(A) Average waiting time in the weekly task queue



(B) Average waiting time in the monthly task queue

FIGURE 5.5: Graphs of the average waiting time in two task queues and the 95% confidence interval (experiment II-IV)

Exp	Nurses	Atom	Seconds	Std. Dev. (sec)	Minutes	Hours
2	3	Daily Tasks Queue	37306	107	621.8	10.36
3	4	Daily Tasks Queue	34182	96	569.7	9.50
4	5	Daily Tasks Queue	32410	141	540.2	9.00
2	3	Weekly Tasks Queue	64311	2240	1071.8	17.86
3	4	Weekly Tasks Queue	51864	1087	864.4	14.41
4	5	Weekly Tasks Queue	46700	904	778.3	12.97
2	3	Monthly Tasks Queue	45851	3411	764.2	12.74
3	4	Monthly Tasks Queue	29349	1761	489.1	8.15
4	5	Monthly Tasks Queue	22328	990	372.1	6.20

TABLE 5.6: Average time in task queues expressed in multiple time units

5.3 Experiment C

In experiment set C, we compare the performance of different *GeneralVZC* server capacities. From Table 5.7 we can see that the busy state percentage of the *GeneralVZC* server is low, even when the capacity is equal to one. Based on this data we conclude that only one general VZC nurse is needed with the current parameters.

Exp	Atom	State	Average	St.Deviation	LB (95%)	UB (95%)	Minimum	Maximum
1	GeneralVZC Server	Idle	0.37	0.00	0.37	0.37	0.37	0.37
1	GeneralVZC Server	Busy	0.00	0.00	0.00	0.01	0.00	0.01
1	GeneralVZC Server	Not available	0.63	0.00	0.63	0.63	0.63	0.63
2	GeneralVZC Server	Idle	0.37	0.00	0.37	0.37	0.37	0.37
2	GeneralVZC Server	Busy	0.00	0.00	0.00	0.00	0.00	0.01
2	GeneralVZC Server	Not available	0.63	0.00	0.63	0.63	0.63	0.63
3	GeneralVZC Server	Idle	0.37	0.00	0.37	0.37	0.37	0.37
3	GeneralVZC Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
3	GeneralVZC Server	Not available	0.63	0.00	0.63	0.63	0.63	0.63

TABLE 5.7: State percentages for experiment set C

5.4 Experiment D

In experiment set D, we compare the performance of different *SpecializedVZC* server capacities. From Table 5.8 we can see that the busy state percentage of the *SpecializedVZC* server is low, even when the capacity is equal to one. Similar as for experiment set A, the average busy period of the server is so low that it does not show in the table. The difference exists because the patient treatment time is lower with a specialized VZC nurse than with a general VZC nurse. Based on this data we conclude that only one specialized VZC nurse is needed with the current parameters.

Exp	Atom	State	Average	St.Deviation	LB (95%)	UB (95%)	Minimum	Maximum
1	SpecializedVZC Server	Idle	0.37	0.00	0.37	0.37	0.37	0.37
1	SpecializedVZC Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
1	SpecializedVZC Server	Not available	0.63	0.00	0.63	0.63	0.63	0.63
2	SpecializedVZC Server	Idle	0.37	0.00	0.37	0.37	0.37	0.37
2	SpecializedVZC Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
2	SpecializedVZC Server	Not available	0.63	0.00	0.63	0.63	0.63	0.63
3	SpecializedVZC Server	Idle	0.37	0.00	0.37	0.37	0.37	0.37
3	SpecializedVZC Server	Busy	0.00	0.00	0.00	0.00	0.00	0.00
3	SpecializedVZC Server	Not available	0.63	0.00	0.63	0.63	0.63	0.63

TABLE 5.8: State percentages for experiment set D

5.5 Experiment E

Experiment set E shows the possibility to include and exclude patient groups. In the first experiment, only inpatient patient groups are included. In the second experiment, the outpatient patient groups are included. The outpatient groups stay in the model for a longer period of time and generally are less labour intensive. Calls and measurements of these patients are less frequent (weekly or monthly instead of daily). The complication and emergency frequency is lower for these patient groups. The effect of this can be seen in the figures below.

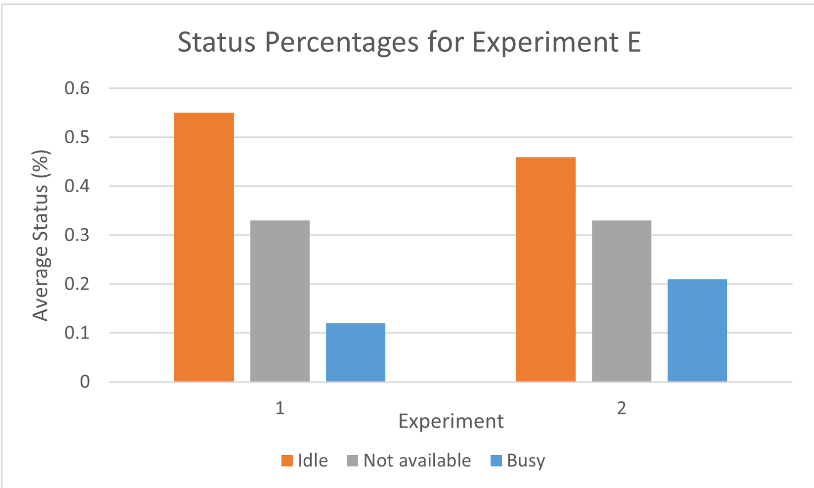
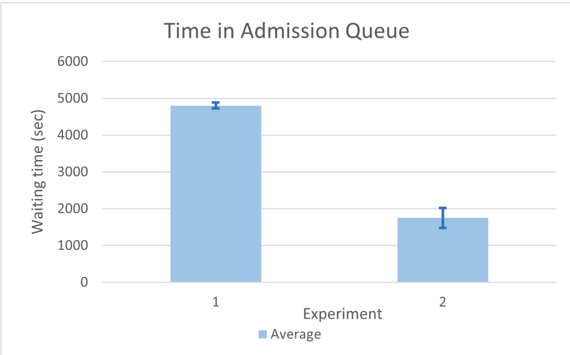


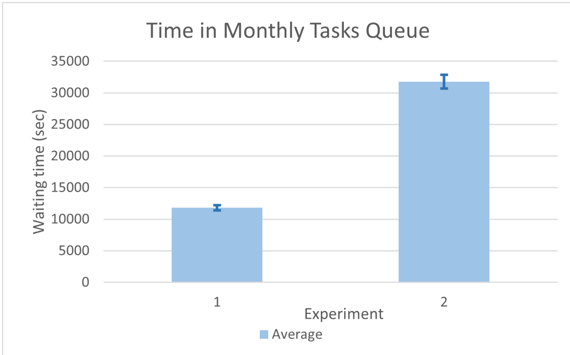
FIGURE 5.6: State percentages for experiment set E

The number of tasks related to outpatients is lower than for inpatients. However, the number of patients present at a given time during the simulation is greater when outpatients are included, since their length of stay is very long. Therefore, the number of tasks incurred is still greater and the utilization of the *Nurse* server is higher. Figure 5.6 shows the state percentages for both experiments in set E.

The difference between the two groups becomes more evident when we look at the waiting time in different queues in Figure 5.7. The waiting time in the *Admission* queue of Figure 5.7a a lower for experiment II, when outpatient groups are selected. This is as expected, since outpatient are admitted to the VZC once and stay for a longer period of time. There is a maximum number of included patients for each outpatient group, when this number is reached the *Admission* queue is not used anymore. Figure 5.7b shows the waiting time for a task queue. Since the number of patients in the model is greater with only outpatient groups, the number of daily, monthly, and weekly tasks is also greater, resulting in a longer waiting time in the related queues.



(A) Average waiting time in the Admission queue



(B) Average waiting time in the monthly task queue

FIGURE 5.7: Graphs of the average waiting time in two queues and the 95% confidence interval

5.6 Experiment F

In experiment set F, we show the possibility to compare performances when increasing the number of patients of a patient group, in this case chronic kidney damage patients. Figure 5.8 shows the AvgTotalWT per patient group for each experiment. Similar to the results found in Experiment set A, the AvgTotalWT for patient group 6 (gestational diabetes patients) is consistently lower than for the other patient groups. Overall, the average patient waiting times stay relatively stable.

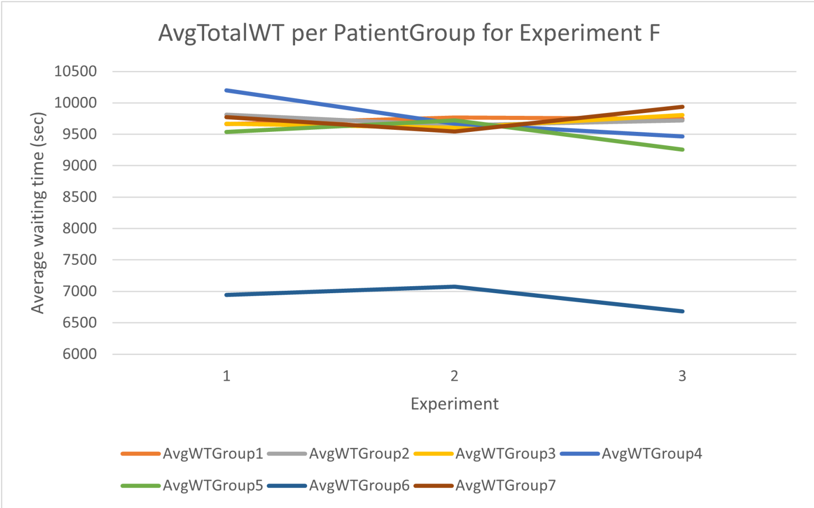
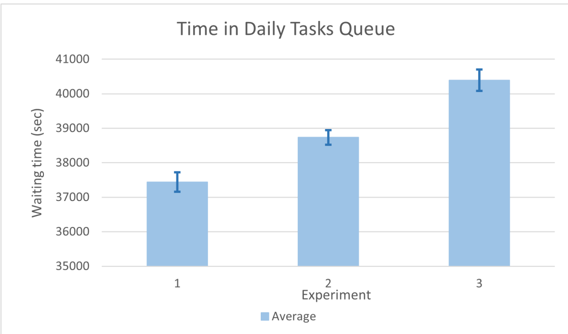
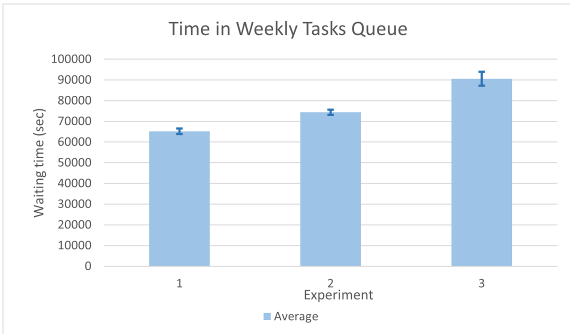


FIGURE 5.8: AvgTotalWT per PatientGroup for experiment set F

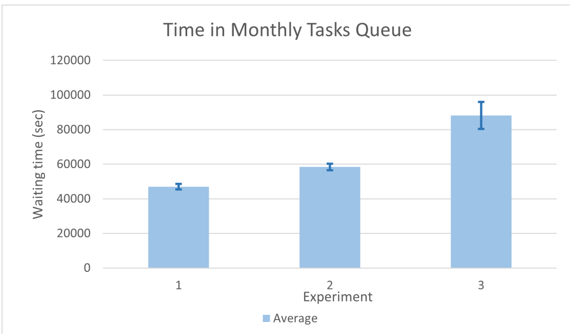
The main effect of increasing the number of patients in this patient group is an increased processing time of the monthly and weekly tasks, as shown in Figure 5.9b and Figure 5.9c respectively. This is because the number of emergencies and complications for this group is relatively low, but the number of weekly and monthly tasks is directly related to the number of patients in this group. Since this patient group does not have any daily tasks, the waiting time in this queue does not change as much as for the other two queues in Figure 5.8.



(A) Average waiting time in the daily task queue



(B) Average waiting time in the weekly task queue



(C) Average waiting time in the monthly task queue

FIGURE 5.9: Graphs of the average waiting time in two task queues and the 95% confidence interval

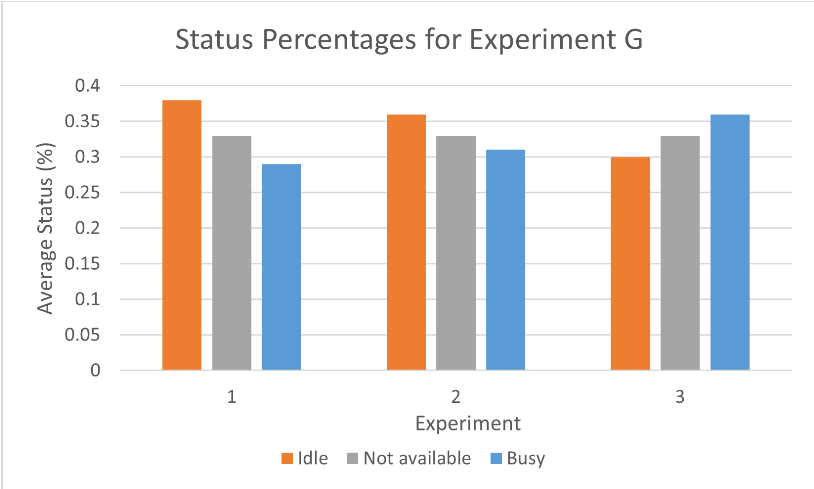


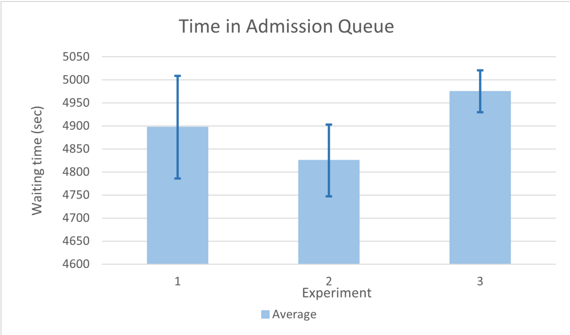
FIGURE 5.10: State percentages for experiment set G

5.7 Experiment G

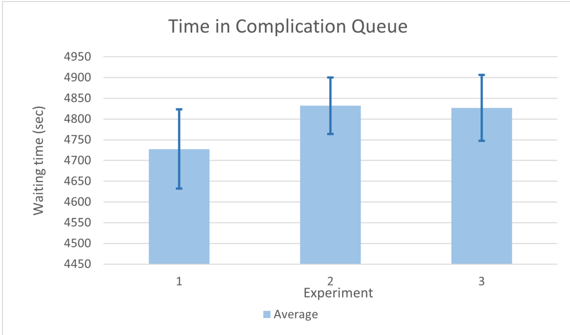
The sensitivity analysis consists of experiment sets G and H. In experiment set G, the arrival rate of the Vitalys patients is increased, resulting in more patients in the system. Naturally, this results in an increase of the busy state percentage of the *Nurse* server and a decrease of idle time, as shown in Figure 5.10.

When looking at the average time spent in queues, we distinguish between two types of queues. All queues mentioned in Figures 5.11 and 5.12 are in front of the *Nurse* server. The queues from Figure 5.11 are related to the admission of patients and occurrence of the different events. The waiting times in these queues does not differ significantly when increasing the number of Vitalys patients. The waiting times for the queues in Figure 5.12 shows a more significant change. This is because these queues are directly related to the number of patients in the system.

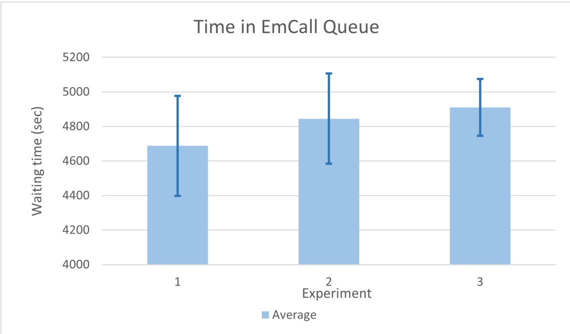
From this set of experiments we learn that the arrival rate of Vitalys patients affects the performance of the system, presumably because it increases the total number of patients in the model.



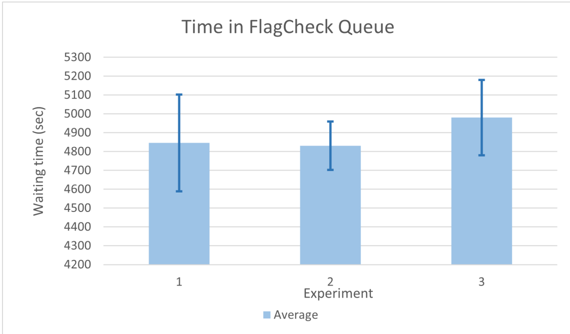
(A) Average waiting time in the Admission queue



(B) Average waiting time in the Complication queue

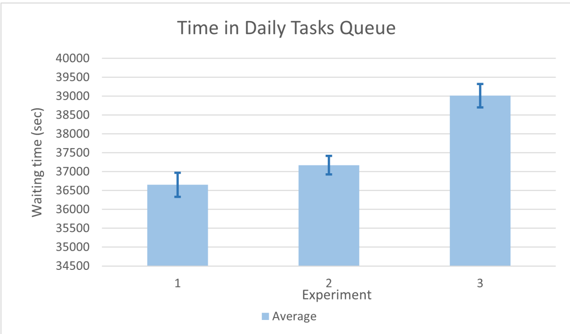


(C) Average waiting time in the EmCall queue

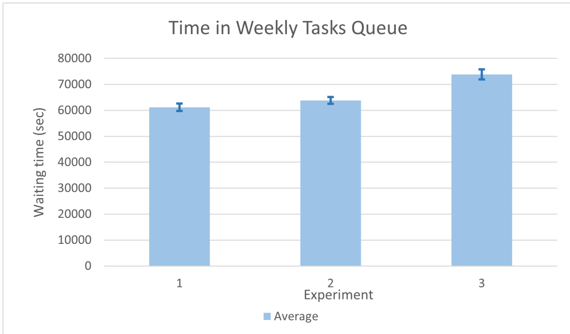


(D) Average waiting time in the FlagCheck queue

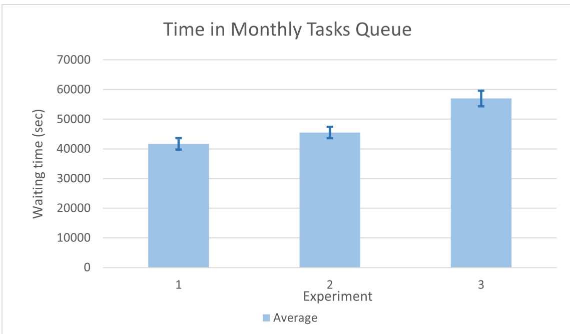
FIGURE 5.11: Graphs of the average waiting time in queues and the 95% confidence interval



(A) Average waiting time in the daily task queue



(B) Average waiting time in the weekly task queue



(C) Average waiting time in the monthly task queue

FIGURE 5.12: Graphs of the average waiting time in two task queues and the 95% confidence interval

5.8 Experiment H

Experiment set H is the second part of the sensitivity analysis. These experiments show the impact of altering the length of stay of Vitalys patients. Increasing the length of stay also increases the number of patients in the system, but not as much as the increase caused by the arrival rate adjustments in the previous set of experiments. Therefore, we expect to see the same effects as from the experiments in G, only to a lesser extent.

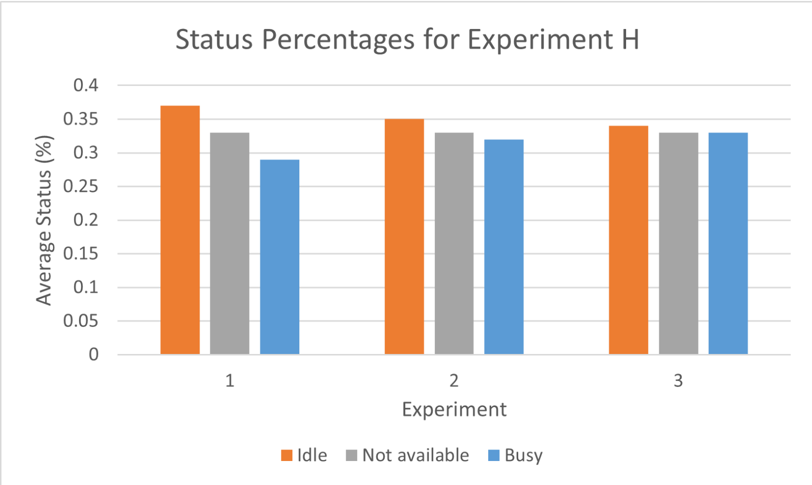


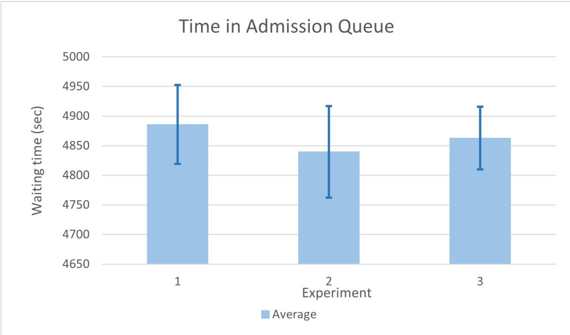
FIGURE 5.13: State percentages for experiment set H

From the state percentages in Figure 5.13 we can see that the increase in busy percentage over from experiment I to III is 0.05. In the same graph of experiment set G (Figure 5.10) the increase over the experiments is equal to 0.07, which suggests that the effect of increasing the interarrival time is larger than that of increasing the length of stay of Vitalys patients.

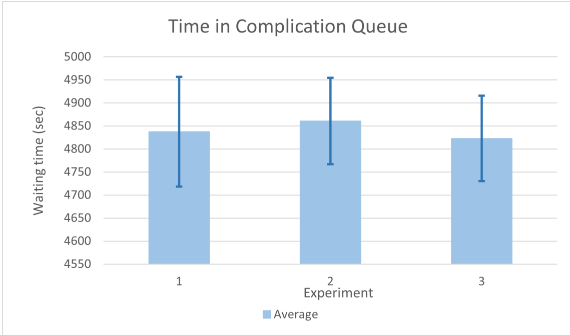
Increasing or decreasing a length of stay for patients staying at the hospital has a greater impact on capacity than for the virtual care. Patients staying at the hospital occupy beds that could otherwise be used for other patients. Patients included in the VZC only cause an increase in the measurements that need to be checked and monitoring calls that need to be made.

The waiting time in queues stays relatively stable and it not influenced by the length of stay of Vitalys patients, as shown in Figure 5.14. Figure 5.15 shows that the time spent in the task queues increases as the length of stay increases. This can be explained by an increased number of Vitalys patients, resulting in more daily and weekly tasks for the VZC. More daily and weekly tasks also results in an increase in waiting time of the monthly task queue, since daily and weekly tasks have a higher priority than monthly tasks in the model.

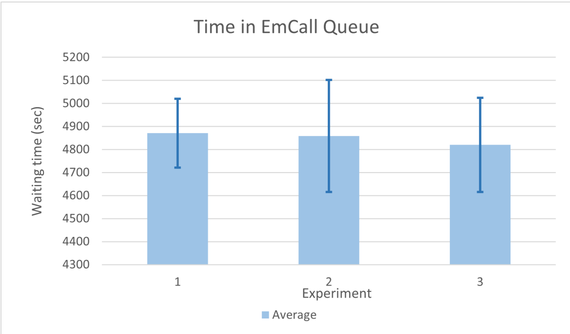
From this set of experiments we learn that the length of stay of Vitalys patients affects the performance of the system, presumably because it increases the total number of patients in the model.



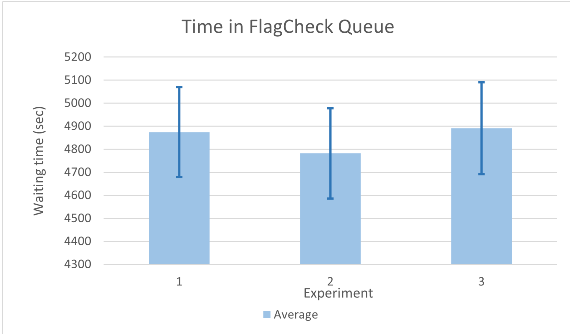
(A) Average waiting time in the Admission queue



(B) Average waiting time in the Complication queue

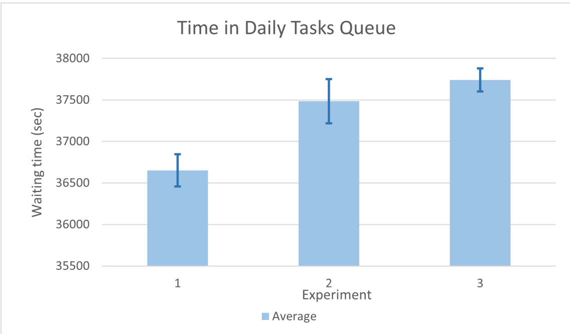


(C) Average waiting time in the EmCall queue

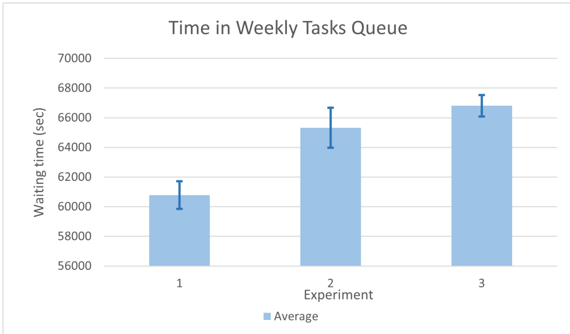


(D) Average waiting time in the FlagCheck queue

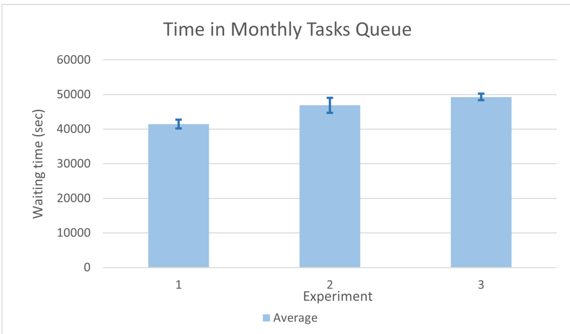
FIGURE 5.14: Graphs of the average waiting time in queues and the 95% confidence interval



(A) Average waiting time in the daily task queue



(B) Average waiting time in the weekly task queue



(C) Average waiting time in the monthly task queue

FIGURE 5.15: Graphs of the average waiting time in two task queues and the 95% confidence interval

5.9 Conclusion

This section summarizes the findings from the experiments performed in this chapter. The conclusions below depend on the current parameters of the model and cannot be generalized across all settings.

- The results of the experiments are in line with the expectations. Varying the settings of the simulation model changes the output as expected.
- The decision on the number of nurses should be based on the utilization as well as the waiting time in queues prior to the involved server. In Experiment B we learned that 20% idle time can still results in exponential waiting times.
- The *GeneralVZC* server and *SpecialzedVZC* server should have multiple tasks. The busy state percentage is very low when solely treating patients with complications.
- Including only outpatient groups requires less time for patient admission, since less unique patients are admitted. The busy state percentage of the *Nurse* server is higher because the number of patients included at the same time is greater.
- The performance of the system depends on the arrival rate and length of stay of the individual patient groups.

Chapter 6

Conclusion and discussion

This final chapter summarizes the conclusions of this study and recommendations for the future. It provides an overview of the research goals and the achievements.

6.1 Conclusion

The goal of this study was to (1) perform a benchmark of hospital@home services and the link with hospital control centres in a number of large (STZ) hospitals, and to (2) develop a quantitative model that can prospectively assess and compare the previously defined service designs and can be used for the further development of the Rijnstate@home services in terms of capacity management.

The benchmark has been performed amongst the hospitals in the mProve network. The lessons learned from the benchmark are as follows:

- When we compare the current situation to the predefined service designs, no variety exists in the service designs used for the provision of virtual care.
- The different characteristics of the patient groups and initiatives make it harder to compare services across hospitals. Also, each hospital uses a different definition of virtual care.
- Although the path of development of hospital@home services is different in each hospital, the goal of each hospital is to centralize initiatives in the long term.
- Combining different hospital@home services is an unexplored area in most hospitals.
- The amount of available (quantitative) data is not very extensive. Measuring and showing results can be a great incentive for people to devote more time to the hospital@home initiatives.

The simulation model can be used for the intended purpose, prospectively assessing and comparing service designs to assist Rijnstate in the development of their services. The model is validated together with stakeholders and the experiments yielded the expected results. At this point the input data is not reliable enough to make detailed analyses. It is possible to compare scenarios and designs, but choices for parameters (such as the number of nurses) cannot be accepted directly.

The main purpose of the experiments was to showcase the experiment possibilities of the model. Besides this, the experiments resulted in several findings. They provided insight into the impact of the number of patients and the patientmix, for example the difference between virtual care for inpatients and outpatients. Including only outpatient groups requires less time for patient admission, since less unique patients are admitted. The utilization of nurses is higher because the number of patients included at the same time is greater. Other findings of the experiments are:

- The decision on the number of nurses should be based on the utilization as well as the waiting time in queues prior to the involved server.
- When the scale is small, nurses should have multiple tasks to reach an acceptable utilization rate.
- The performance of the system depends on the arrival rate and length of stay of the individual patient groups.

6.2 Discussion

The two main issues experienced during this research were the lack of data and the discrepancy between different definitions. A large amount of the input data is based on expert opinions and data from other processes. When the input data is retrieved from the reality, this will increase the reliability of the model and enable the user to perform more detailed analysis. In particular the data related to the patient groups. It became clear from the sensitivity analysis that this input data directly affects the output of the model. The need for uniform definitions and parameters resulted from both the benchmark and the simulation model. Making a direct comparison between hospitals is hard, since the patientmix within the initiatives is different across hospitals. Finding rules of thumb, such as the optimal number of patients per nurse, is not possible because of this. The impact of including different patient groups in the service is also visible in the experiment results. To increase the comparability of hospitals, the mProve network should aim to develop a universal definition of virtual care and parameters that can be measured across all its hospitals.

One of the conclusions from the experiment section is that when the scale is small, nurses should have multiple tasks to reach an acceptable utilization rate. Currently, the division of tasks is coded directly in the model, meaning that the user cannot easily adjust it. To experiment with the tasks on a more detailed level, the model needs to be further developed. The division of tasks can then be used as an experimental factor.

This study focused on the quantitative aspects of the provision of virtual care. An important factor of this type of care is the added benefit for the patients. Receiving care in the comfort of their own home increases patient satisfaction. This is one of the main drivers to move more care to the home situation. The perspective of the patient is not taken into account as response factor, since this is not quantified in the model. Further research can be done on the resulting patient satisfaction and the trade-off with the increased costs of virtual care.

The main academic value of this research is the translation of the predefined service designs into a quantitative model. This model, with the current parameters, is adjusted to the services of the Virtueel Zorgcentrum of Rijnstate. By making some adjustments, the model can also be used in other hospitals, provided that the process is comparable. Furthermore, the example of how to simplify the processes of virtual care into a simulation model can be useful in other instances. This research also provides an application of the benchmark method of Van Hoorn et al. (2006) in a situation were almost no quantitative indicators are available, by combining it with the Donabedian model (Donabedian, 1988).

The value for practice is a simulation model that can be used for the development of the Rijnstate at home services. Also, the conducted experiments provide insight into the differences between patient groups and underline the impact of the choice of patient groups. Most service designs developed by Nienke Stoker (2019) are not yet used in practice. The insight on the influence of these service designs is useful before implementing them into practice.

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Appendix A

Service designs by Stoker (2019)

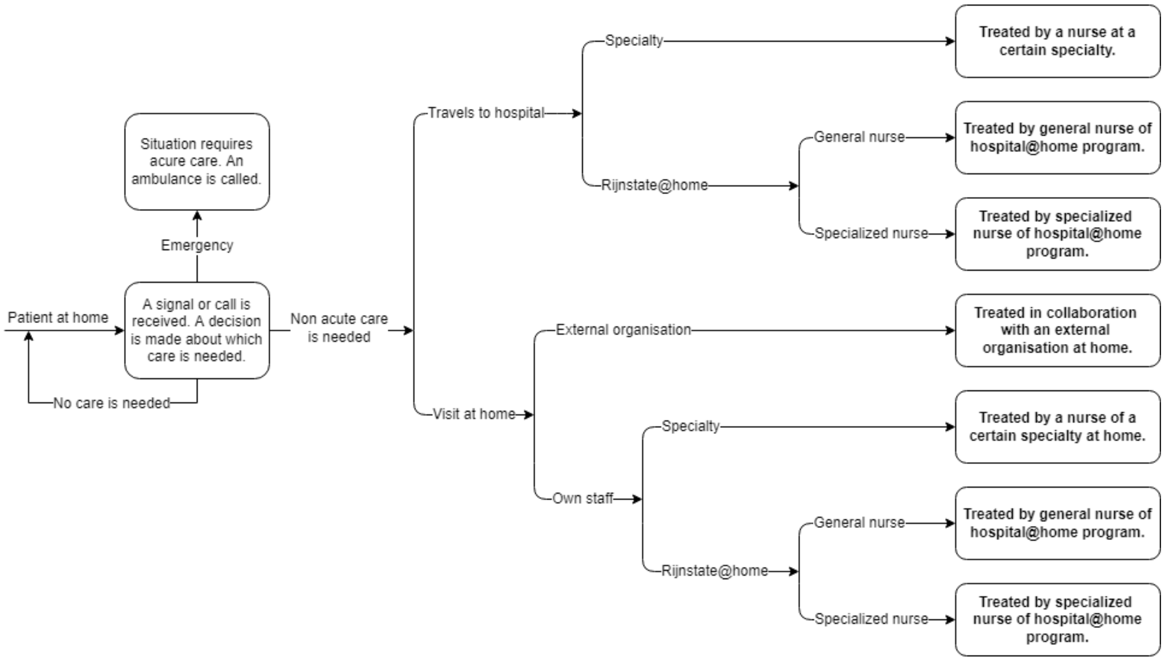


FIGURE A.1: Overview of the service delivery scenarios. Reprinted from "Service Designs for Rijnstate@home" (p. 18) by Stoker, N.H. (2019). University of Twente.

Appendix B

Planned VZC projects

PATIENT GROUP	GOAL	MONITORING DEVICE	# PATIENTS IN PILOT	# PATIENTS PER YEAR
Type 1 diabetes	Optimize the blood glucose control by visual monitoring and data analysis using artificial intelligence (AI). The intended result is a reduction in diabetes-related complications, patient centred care, fewer physical contact moment and increased patient satisfaction.	Flash Glucose Monitor (FGM)	10	900
Gestational diabetes	By monitoring the glucose values through the Engage platform, we aim to improve care, increase self-management for the patient and decrease the workload in the diabetes department.	Glucometer	10	100-120
Infectious diseases	Early discharge of patients with erysipelas, urinary tract infection, pneumonia and eventually other infectious diseases. These patients are clinically stable but now remain hospitalized for IV antibiotics. Home monitoring is performed by the VZC and the antibiotics are administered via regular home care or from nurses from the VZC in the context of medication@home.	Blood pressure monitor, POCT kit, and thermometer	10	70-100
Chronic kidney damage	Renewing the care process around chronic kidney damage with the help of monitoring at home. The routine care includes 3-6 hospital visits per year with outpatient contact, blood pressure measurement, and lab checks. By weekly remote monitoring of vital signs and intervening on the basis of deviations, the care could be less standardized and more personalized. Above all, monitoring of a number of parameters is more reliable in the home setting.	Blood pressure monitor, scale, and POCT kit	50	200-500
COPD	To improve the aftercare for COPD patients, to achieve early discharge and prevent readmission to the hospital. This is done by daily monitoring through the CCQ and education about action plans and divis.	Clinical COPD Questionnaire (CCQ)	10	500 (clinical)
Bariatrics	To improve aftercare for bariatric patients, to achieve early discharge and prevent readmission to the hospital. This is done by continuous monitoring using the Healthdot, which measures a patient's respiratory rate, heart rate, activity and body position.	Healthdot	30	1400

FIGURE B.1: Overview of intended patient groups in the VZC

Appendix C

Defining the HCC

Throughout literature, multiple terms are used to indicate the services of a what we describe as a hospital control centre (HCC), the most common alternative being the 'hospital command centre'. In my understanding, these terms have the same meaning.

Appendix D includes the search strings and other details of the conducted literature research. This research resulted in two articles that provide information about the workings of a hospital control centre. As mentioned by Kane et al. (2019), HCCs are not often described in literature yet. Industries such as oil and gas, air traffic control, and entire city governments have developed command centres to manage their operations (Kane et al., 2019). Many elements of these control centres can also be applied in hospitals. Core elements of the command centres from other industries are strategic colocation of teams, automated visual displays of real-time data providing a global view, predictive analytics, standard work and rule-based protocols (Kane et al., 2019).

The Capacity Command Centre (CCC) as described by Kane et al. (2019) centralizes previously isolated administrative processes and local performance initiatives. It is innovative in the degree to which it incorporates real-time data, predictive analytics, and simulation modelling through its connection with systems engineering (Kane et al., 2019). The Command Centre Generation 1 (CC1) as described by Collins (2021) displays essential data representing the input, throughput, and output variables of the interdependent components of the emergency department in real time. It enables timely and strategic operational efforts using pre-established standard operating procedures (Collins, 2021).

The research of Kane et al. (2019) and Collins (2021) provides some insight into the working of HCCs, but neither of them provides a clear definition. To be able to define the 'hospital control centre', I continued the search through websites of healthcare professionals and companies implementing hospital control centres. Here, more information was obtained about the definition of the control centre.

Performation offers smart solutions to healthcare providers to help them organize their processes and give direction to patient care and capacity. They have successfully implemented control centres in a number of hospitals throughout the Netherlands. In their whitepaper about integral capacity management in hospitals (Performation, n.d.) the power of hospital control centres is explained. According to Performation, a HCC can be defined as a central place that includes all data sources and brings together relevant information about supply and demand of capacity within the hospital. External factors that can influence the various patient flows to the hospital are also included. This creates an overview and supports balanced decision making. Currently, these decisions are often taken at various times and in multiple departments of the hospital, without having any overview (Performation, n.d.).

Furthermore, they describe the HCC as a control tower where capacity and care professionals and managers meet. Real-time data is visualized on large screens and smart calculation models are used to make a predictive analyses (Performation, n.d.).

GE Healthcare is a leading global medical technology and digital solutions innovator. They enable clinicians to make better decision through intelligent devices and data analytics (GE Healthcare, 2021). According to GE, a hospital control centre should be a central node with information, authority, and means to anticipate, identify, and resolve bottlenecks, delays, and risks. Control centres complement other performance tools with their capability to make decisions in real time (GE Healthcare, 2019).

INTER is a system integrator and IT consultant which provides supporting solutions for HCCs (INTER, n.d.). According to Thijs Assink, their medical account manager, a control room can have multiple functions within a hospital. For example safety and surveillance, energy and utilities, parking facilities, emergency centres, crisis management or to create insight into patient flows and capacity management (INTER, 2020).

ICT&health is an official healthcare innovation knowledge platform, which provides information about relevant developments and innovations in healthcare in collaboration with specialists and policymakers from the industry. They have written about several HCC initiatives throughout the Netherlands (ICT&health, 2019)(ICT&health, 2020). According to the Amphia hospital in Breda, the hospital control centre is a central meeting point. The team responsible for the control centre provides insight and advice about capacity management and organizes capacity based on production agreements and developments. Furthermore, they provide insight into the current situation in the hospital and adjust accordingly (ICT&health, 2019). In an article about the Noordwest hospital group, the control centre is defined as a place that provides insight into the overall situation in the hospital. It is a space where all operational and tactical data is brought together, such that available capacity can be optimally utilized and coordinated. In addition, the HCC can also look ahead, allowing for early identification of bottlenecks (ICT&health, 2020).

Source / Concept	Centralization	Visual displays	Real-time data	Predictive analysis	Supported decision making
Kane et al. (2019)	X	X	X	X	
Collins (2021)			X	X	X
Performation (n.d.)	X	X	X	X	X
GE Healthcare (2019)	X		X	X	X
INTER (2020)	X				X
ICT&health (2019)	X			X	X
ICT&health (2020)	X			X	X

TABLE C.1: Elements mentioned in the HCC definition per source

Several elements are used in most definitions and description of hospital control centres, as displayed in Table C.1. Two definition include four of the five selected elements, but the most complete description is provided by Performation (n.d.). From this description, the following definition of a hospital control centre is derived:

A hospital control center is a central place that includes all data sources and brings together relevant information about supply and demand of capacity within the hospital. Real-time data and smart calculation models are used for predictive analyses and to support balanced decision making.

Appendix D

Literature search strings

Question 1.1 Which benchmark method is most suitable for this research?

This section contains the search strings and other detailed information about the literature research performed to answer the Question 1.1 above. Knowledge obtained from this research is summarized in 2.1.

DATABASE	SEARCH STRING	RANGE	RESULTS	AFTER READING TITLE	AFTER READING ABSTRACT
Scopus	TITLE (benchmark* AND method* AND (review OR compar*)) AND (LIMIT-TO (EXACTKEYWORD, "Benchmarking")	All years	71	5	3
	TITLE (benchmark* AND (healthcare OR "health care")) AND (LIMIT-TO (EXACTKEYWORD, "Benchmarking")	All years	109	19	10
	TITLE (benchmark* AND method* AND compari*) AND (LIMIT-TO (EXACTKEYWORD, "Benchmarking") AND (LIMIT-TO (SUBJAREA, "MEDI"))	All years	10	3	3
	TITLE (benchmark* AND hospital* AND (overview OR review))	All years	3	2	2
	TITLE ("benchmark methods" OR "benchmarking methods") AND (LIMIT-TO (EXACTKEYWORD, "Benchmarking")	All years	53	10	5
Web of Science	TITLE (benchmark* AND method* AND (hospital* OR healthcare OR "health care"))	All years	15	6	4
	TITLE (benchmark* AND method* AND compari*) AND (LIMIT-TO (SUBJAREA, "Health Care Sciences Services", "Medical Informatics"))	All years	6	3	2
	TITLE ("benchmark methods" OR "benchmarking methods")	All years	26	7	3
				Removing duplicates	-5
				Not available for reading	-6
				Removed after scanning	-9
				SELECTED FOR REVIEW	**12**

TABLE D.1: Search strings for the benchmarking literature research

After articles that are not available for reading and duplicates have been removed, all remaining articles are scanned and their usefulness is assessed. Most articles are removed because they do not contain detailed information about the benchmarking process. In the end, twelve articles are selected to be read into detail. Two additional articles are added about the benchmarking method proposed by Rijnstate. Furthermore, four articles resulting from the 'NFU benchmarking OR project' are added upon recommendation of the supervisory committee. The resulting articles are displayed in Table D.2.

#	ARTICLE	AUTHORS	YEAR	KEYWORDS
1	A comparative analysis of data-driven methods in building energy benchmarking	Ding, Y. & Liu, X.	2020	Comparative analysis; Data-driven approaches; Energy benchmarking; Energy performance
2	Development of a Conceptual Benchmarking Framework for Healthcare Facilities Management: Case Study of Shanghai Municipal Hospitals	Li, Y., Cao, L., Han, Y., Wei, J.	2020	Benchmarking; Facilities management; Healthcare; Performance measurement
3	Development of a benchmark tool for cancer centres; results from a pilot exercise	Wind, A., Dijk, J. van, Nefkens, I., Lent, W. A. M. van, Nagy, P., Janulionis, E., Helander, T., Rocha-Goncalves, F., Harten, W. H. van	2018	Benchmarking; Quality of care; Quality improvement; Cancer centres
4	Benchmarking specialty hospitals, a Scoping review on theory and practice	Wind, A. & Harten, W. H. van	2017	Benchmarking; Specialty hospitals; Quality improvement
5	Statistical benchmarks for health care provider performance assessment: A comparison of standard approaches to a hierarchical bayesian histogram-based method	Paddock, S.M.	2014	Bayesian statistics; hierarchical model; provider profiling; public reporting; statistical benchmark
6	Benchmarking as a development tool in healthcare	Torkki, P. & Lillrank, P.	2013	Benchmarking; Healthcare operations management; Key performance indicators
7	A Review of Different Benchmarking Methods in the Context of Regional Airports	Merkert, R., Odeck, J., Brathen, S., Pagliari, R.	2012	Airport; Benchmarking; Comparative study; Performance assessment; Stochasticity
8	The Contextual Benchmark Method: Benchmarking e-Government services	Jansen, J., de Vries, S., van Schaik, P.	2010	Benchmarking; CBM; Contextual analysis; E-Government; Electronic services
9	A new benchmarking method to advance the two-model DEA approach: Evidence from a nursing home application	Chang, D.-S., Yang, F.-C.	2010	Benchmarking; Data envelopment analysis; Nursing home; Quality
10	International benchmarking of specialty hospitals. A series of case studies on comprehensive cancer centres	Lent, W. A. M. van, De Beer, R. D., Harten, W. H. van	2010	
11	Data envelopment analysis models for identifying and benchmarking the best healthcare processes	Benneyan, J.C., Sunnetci, A., Mehmet, E.	2008	Benchmarking; Data envelopment analysis; DEA; Healthcare; Hyper-efficiency; Proportional data; Weight restrictions
12	Benchmarking the purchasing function of operating room departments in eight University Hospitals	Oostveen, A.	2008	
13	Een duurzaam stappenplan voor benchmarking	Hoorn, A. F. van, Houdenhoven, M. van, Wullink, G., Hans, E. W., Kazemier, G.	2007	
14	Een nieuw stappenplan voor benchmarking	Hoorn, A. F. van, Houdenhoven, M. van, Wullink, G., Hans, E. W., Kazemier, G.	2006	
15	Benchmarking OK: Van appels met peren naar Elstar met Jonagold	Hoorn, A.F. van	2005	
16	The value of hospital library benchmarking	Todd-Smith, B. & Markwell, L. G.,	2002	
17	Benchmarking applied to healthcare	Camp, R. C. & Tweet A. G.	1994	
18	Collaborative benchmarking in health care	Mosel, D. & Gift, B.	1994	

TABLE D.2: Results from the benchmarking literature research

Question 1.2 What are relevant performance indicators for this benchmark?

This section contains the search strings and other detailed information about the literature research performed to answer the Question 1.2 above. Knowledge obtained from this research is summarized in Section 2.1.3.

DATABASE	SEARCH STRING	RANGE	RESULTS	AFTER READING TITLE	AFTER READING ABSTRACT
Scopus	TITLE ((kpi OR "performance indicators") AND (hospital OR healthcare OR "health care")) AND PUBYEAR > 2014	2015 - 2021	89	11	2
	TITLE-ABS-KEY ((kpi OR (performance AND indicators) AND benchmark* AND (healthcare OR hospital OR "health care") AND ("at home" OR "virtual ward" OR "virtual care" OR "home based"))	All years	10	3	2
	TITLE-ABS-KEY ((kpi OR "performance indicators") AND ("hospital at home" OR "virtual ward" OR "virtual care" OR "home hospital services" OR "home based care" OR "home hospitalization" OR "home health care" OR "home hospital services"))	All years	8	3	3
	TITLE-ABS-KEY ((kpi OR "performance indicators") AND hospital AND (control OR command)) AND PUBYEAR > 2014	2015 - 2021	167	10	2
	TITLE-ABS-KEY ((kpi OR "performance indicators") AND hospital AND benchmark*) AND (LIMIT-TO (EXACTKEYWORD, "Hospitals") OR LIMIT-TO (EXACTKEYWORD, "Key Performance Indicators") OR LIMIT-TO (EXACTKEYWORD, "Hospital"))	All years	173	15	9
	TITLE-ABS-KEY ((kpi OR "performance indicators") AND hospital AND ("at home" OR "in the home" OR "virtual" OR "home based") AND PUBYEAR > 2014	2015 - 2021	13	4	3
Web of Science	hospital AND "performance indicators" (Topic) and "organizational" OR "arrangement" OR "coordination" OR "structuring" (Abstract) Refined by: Publication Years: 2021 or 2020 or 2019 or 2018 or 2017 or 2016 or 2015 Languages: English	2015 - 2021	47	8	4
	(kpi OR "performance indicators") AND hospital (Title)	All years	79	11	7
	(kpi OR "performance indicators") AND hospital AND benchmark* Refined by: Web of Science Categories: Health Care Sciences Services or Health Policy Services or Management or Medical Informatics or Operations Research Management or Engineering Industrial or Computer Science	All years	33	7	3
	(kpi OR "performance indicators") AND hospital AND (home OR virtual) Refined by: Publication Years: 2021 or 2020 or 2019 or 2018 or 2017 or 2016 or 2015 Languages: English	2015 - 2021	27	6	2
				Removing duplicates	- 4
				Not available for reading	- 3
				Removed after scanning	- 21
				SELECTED FOR REVIEW	**9**

TABLE D.3: Search strings for the KPI literature research

#	ARTICLE	AUTHORS	YEAR	KEYWORDS
1	Towards KPI-Based Health Care Process Improvement	El Hadj Amour, E. A., & Ghannouchi, S. A.	2017	BPM; Business process; Data mining; Emergency department; Healthcare; KPI; Satisfaction
2	Benchmarking operating room departments in the Netherlands: evaluation of a benchmarking collaborative between eight university medical centres.	Van Veen-Berkx, E., De Korne, D. F., Olivier, O. S., Bal, R. A., Kazemier, G.	2016	Benchmarking; Collaborative benchmarking; Health services; Knowledge-sharing; Learning from others; Operating rooms; Performance indicators; Performance management system; University medical centres
3	International Benchmarking and Best Practice Management: In Search of Health Care and Hospital Excellence	Von Eiff, W.	2015	Benchmarking; Best practice; Best-in-class; Leapfrogging
4	Hospital performance management: A multicriteria decision-making approach	Tyagi, A., & Singh, P.	2017	Multi-criteria decision-making; Hospital performance management; Performance indicators; Strategies
5	Implementation of renal key performance indicators: Promoting improved clinical practice	Toussaint, N. D., McMahon, L. P., Dowling, G., Soding, J., Safe, M., Knight, R., Fair, K., Linehan, L., Walker, R. G., Power, D. A.	2015	Chronic kidney disease; Dialysis; Education; Key performance indicator; Transplantation
6	Developing Strategic Health Care Key Performance Indicators: A Case Study on a Tertiary Care Hospital	Khalifa, M., & Khalid, P.	2015	Evidence based healthcare; Hospitals; Scorecards; Strategic key performance indicators
7	Structural and operational redesigning of patient-centered ambulatory care pharmacy services and its effectiveness during the COVID-19 pandemic	Thorakkattil, S. A., Nemr, H. S., Al-Ghamdi, F. H., Jabbour, R. J., Al-Qaaneh, A. M.	2020	Access to medication; Ambulatory care; COVID-19; Drug management; Structural changes
8	Relevance of Key Performance Indicators (KPIs) in a Hospital Performance Management Model	Ioan, B., Nestian, A., & Tiţă, S. M.	2012	Hospitals; Performance management model; KPI – key performance indicators
9	Assessing hospital performance indicators. What dimensions? Evidence from an umbrella review	Carini, E., Gabutti, I., Frisicale, E. M., Di Pilla, A., Pezzullo, A. M., De Waure, C., Cicchetti, A., Boccia, S., Specchia, M. L.	2020	Hospital evaluation; Hospital performance; Indicator; Performance dimensions; Performance measurement; Quality

TABLE D.4: Results from the KPI literature research

Question 2.1 What research has already been done concerning optimizing hospital@home services?

This section contains the search strings and other detailed information about the literature research performed to answer the Question 2.1 above. Knowledge obtained from this research is summarized in Section 2.2.

DATABASE	SEARCH STRING	RANGE	RESULTS	AFTER READING TITLE	AFTER READING ABSTRACT
Scopus	TITLE-ABS-KEY (hospital AND home AND (optimiz* OR simulation OR queue*) AND model*) AND PUBYEAR > 2014 AND (LIMIT-TO (EXACTKEYWORD, "Hospitals") OR LIMIT-TO (EXACTKEYWORD, "Simulation") OR LIMIT-TO (EXACTKEYWORD, "Telemedicine") OR LIMIT-TO (EXACTKEYWORD, "Hospital Care") OR LIMIT-TO (EXACTKEYWORD, "Health Care Planning") OR LIMIT-TO (EXACTKEYWORD, "Logistic Models") OR LIMIT-TO (EXACTKEYWORD, "Optimization"))	2015 - 2021	161	25	13
	TITLE-ABS-KEY (("hospital at home" OR "hospital in the home" OR "hospital care at home" OR "virtual ward") AND model*) AND PUBYEAR > 2014	2015 - 2021	106	14	2
	TITLE-ABS-KEY (hospital AND ("at home" OR "virtual ward" OR "in the home") AND ("operations research" OR "operations management")	All years	5	2	0
	TITLE (home AND (hospital OR healthcare) AND model*) AND PUBYEAR > 2014	2015 - 2021	62	6	5
Web of Science	hospital at home mathematical model (Topic) Refined by: Publication Years: 2021 or 2020 or 2019 or 2018 or 2017 or 2016 or 2015	2015 - 2021	29	4	4
	hospital at home operations research model (Topic)	All years	19	2	2
	hospital at home operations management model (Topic)	All years	31	4	2
	hospital at home simulation model (Topic) Refined by: Publication Years: 2021 or 2020 or 2019 or 2018 or 2017 or 2016 or 2015	2015 – 2021	71	12	7
				Removing duplicates	- 6
				Not available for reading	- 5
				Removed after scanning	- 11
				SELECTED FOR REVIEW	**13**

TABLE D.5: Search strings for the modelling literature research

#	ARTICLE	AUTHORS	YEAR	KEYWORDS
1	Routing and scheduling in Home Health Care: A Literature Survey and Bibliometric Analysis	Di Mascolo, M., Martinez, C., Espinouse, M.-L.	2021	Home health care; Home service; Routing and scheduling; Optimization; Hospital at home; Uncertainties
2	A New Optimization Approach for a Home Health Care Problem	Aiane, D., El-Amraoui, A., Mesghouni, K.	2015	Home health care problem; Planning; MILP model; Optimization; Human behavior
3	Optimal Scheduling in Home Health Care	Ji, Y.	2019	Home Health Care logistics; Vehicle routing; Time windows; Pickup and delivery
4	Mathematical models to improve the current practice in a Home Healthcare Unit	Quintanilla, S., Ballestin, F., Pérez, Á.	2019	Home healthcare problem; Heuristics; Nonlinear integer programming; Linear integer programming
5	Operational research as implementation science: definitions, challenges and research priorities	Monks, T.	2016	
6	An application of constraint solving for home health care	Cattafi, M., Herrero, R., Gavanelli, M., Nonato, M., Malucelli, F.	2015	Constraint programming; Nurse scheduling applications; Home health care; Large neighbour-hood search; Routing problems; Lagrangian relaxation
7	Stochastic Bi-level Programming Model for Home Healthcare Scheduling Problems Considering the Degree of Satisfaction with Visit Time	Chen, H., Luo, X., Zhang, Z., Zhou, Q.	2021	Home health care; Bi-level programming; Stochastic travel times; Routing; Meta-heuristic
8	Optimizing Home Hospital Health Service Delivery in Norway Using a Combined Geographical Information System, Agent Based, Discrete Event Simulation Model	Viana, J., Ziener, V. M., Holhjem, M. S.	2017	
9	Simulation of home-hospital impacts on crowding – FM implications	Fard, J., Roper, K. O., Hess, J.	2016	Performance management; Simulation; Healthcare; Facility management; Computer simulation; Hospitals
10	Queues with Time-Varying Arrivals and Inspections with Applications to Hospital Discharge Policies	Chan, C. W., Dong, J., Green, L. V.	2016	Queueing; Time-varying arrival rates; Infinite server queues; Healthcare
11	A Simulation-Driven Approach to Decision Support in Process Reorganization: A Case Study in Healthcare	Amantea, I. A., Di Leva, A., Sulis, E.	2020	Risk management; Business process simulation; Healthcare
12	Performance Evaluation of an Integrated Care for Generic Departments Using Discrete-Event Simulation	Franck, T., Augusto, V., Xie, X., Gonthier, R., Achour, E.	2015	
13	Scheduling Optimization of the Home Health Care Problem with Stochastic Travel and Care Times	Bazirha, M., Kadrani, A., Benmansour, R.	2020	Genetic algorithm; Home health care; Routing; Scheduling; Stochastic programming with resource model; Simulation

TABLE D.6: Results from the modelling literature research

What is the definition of a hospital control centre?

At the start of the research, another short literature review has been performed to find a definition for the hospital control centre. Knowledge obtained from this research is summarized in Appendix C.

SEARCH STRING	SCOPE	DATE OF SEARCH	RANGE	RESULTS
Search protocol for Scopus				
("hospital control" OR "hospital command") AND cent*	Article title, Abstract, Keywords	20-09-2021	All years	283
"operations control" AND cent* AND (hospital OR healthcare OR "health care")	Article title, Abstract, Keywords	20-09-2021	All years	14
"operations management" AND (hospital OR healthcare OR "health care") AND (integral OR complete)	Article title, Abstract, Keywords	20-09-2021	All years	26
hospital AND capacity AND (command OR control)	Article title, Abstract, Keywords	20-09-2021	All years	9
			TOTAL	**332**
			Removing duplicates	- 0
			Removed based on inclusion and exclusion criteria	- 287
			Removed based on title	- 40
			Removed based on abstract	- 2
			Not available for reading	- 1
			SELECTED FOR REVIEW	**2**

TABLE D.7: Search strings for the HCC literature research

INCLUSION	Reason	EXCLUSION	Reason
Language: English	Search strings are in English, no Dutch articles were included. I am not able to read other languages.		
Keywords: Hospital, Hospitals, Control Center, Occupation	This keyword must be included in the article for it to be relevant to our search.		

TABLE D.8: Inclusion/exclusion criteria of the HCC literature research

#	SOURCE	AUTHORS	YEAR	KEY CONCEPTS	FINDINGS
1	Use of Systems Engineering to Design a Hospital Command Center	Kane, E. M., Scheulen, J. J., Püttgen, A., Martinez, D., Levin, S., Bush, B. A., Huffman, L., Jacobs, M. M., Rupani, H., Efron, D. T.	2019	Systems engineering, Capacity, Command centre, Predictive analytics, Healthcare	Systems engineering approach to the development of a capacity command centre (CCC). The CCC centralizes previously isolated processes and local performance initiatives. Core elements of command centres in other industries are analysed.
2	Use of High-Reliability Principles in the Evolution of a Hospital Command Centre	Collins, B.	2021	Hospital command centre, Real-time data, Predictive analytics, Conceptual	The command centre displays essential data representing the input, throughput and output variables of the interdependent components of the emergency department, enabling timely and strategic operational efforts using pre-established standard operating procedures.

TABLE D.9: Results from the HCC literature research

Appendix E

Operational research methods

Operational research (OR) uses mathematical models, quantitative and qualitative, to support decision making in complex problems (Monks, 2015)(Winston and Goldberg, 2004). A mathematical model is a representation of a real situation, that may be used to make better decisions or to better understand the situation (Winston and Goldberg, 2004). These models can be either static or dynamic, linear or nonlinear, integer or noninteger, and deterministic or stochastic. Operations research methods have been used in healthcare in a variety of areas, such as: scheduling and management of patients, emergency medicine, hospital performance, and other complex logistical or operational problems (Monks, 2015). Commonly used OR techniques that are considered in this section include: mathematical programming, queueing theory, and simulation.

E.1 Mathematical programming

E.1.1 Linear programming

Linear programming (LP) is a method used to solve optimization problems. In any linear program, the goal is to maximize or minimize some function of the variables included, subject to a number of constraints (Winston and Goldberg, 2004). An integer programming problem (ILP) is an LP in which some or all of the variables are required to be nonnegative integers. When only some of the variables are required to be integer, it is called a mixed integer programming problem (MILP). Usually, integer programming problems are harder to solve than LPs (Winston and Goldberg, 2004).

E.1.2 Dynamic programming

Dynamic programming (DP) is another technique that can be used to solve optimization problems. In dynamic programming the solution is usually obtained by working backwards, starting at the end of the problem (Winston and Goldberg, 2004). DPs are frequently used to solve inventory, network, and resource-allocation problems. According to Winston & Goldberg (2004), a problem should have the following characteristics to be able to apply dynamic programming:

1. The problem can be divided into stages with a decision required at each stage.
2. Each stage has a number of states associated with it.
3. The decision chosen at any stage describes how the state at the current stage is transformed into the state at the next stage.
4. Given the current state, the optimal decision for each of the remaining stages must not depend on previously reached states or previously chosen decisions.

5. If the states for the problem have been classified into one of T stages, there must be a recursion that relates the cost or reward earned during stages t, t+1, ..., T the cost or reward earned from stages t+1, t+2, ..., T.

E.1.3 Routing models

A problem of interest when optimizing hospital at home services is the home health care routing and scheduling problem (HHCRSP). This problem is an extension of vehicle routing problem (VRP), but with some uncommon constraints that make it more difficult to solve (Cissé et al., 2017). The VRP is a generalized version of the travelling salesman problem (TSP), which are both widely known optimization problems. The VRP designs optimal delivery routes to customers, where each vehicle can only travel one route, and each vehicle starts and ends at one central depot (Braekers, Ramaekers, and Van Nieuwenhuyse, 2016). The goal of the problem is to minimize the costs of visiting each customer exactly once. Cissé, Yalçındağ, Kergosien, Şahin, Lenté, & Matta (2017) describe the HHCRSP as "a set of patients scattered in a geographic area who need care services, i.e., visits at home, which must be provided by care workers" and provide an overview of OR models used to solve this problem.

Most of the HHCRSP models in literature are formulated as VRPs or extensions of this model. Some of these extensions include: the periodic vehicle routing problem (PVRP) (An et al., 2012), vehicle routing problem with time windows (VRPTW) (Di Mascolo, Martinez, and Espinouse, 2021), the vehicle routing problem with simultaneous delivery and pickup time windows (VRPSDPTW) (Ji, 2019), the multiple traveling salesman problem with time windows (MTSPTW) (Aiane, El-Amraoui, and Mesghouni, 2015), and the multiple depot traveling salesman problem with time windows (MDTSPTW) (Cissé et al., 2017). Recently, Zwier (2021) successfully applied the HHCRSP to the medication at home services of the Isala hospital in Zwolle.

E.2 Simulation

In most mathematical models, the goal is to determine optimal solutions. But not all real-world problems can be solved with these models. When problems are highly complex, involve stochastic relations, or require many simplifying assumptions, the best alternative available is a simulation model (Winston and Goldberg, 2004)(Law, 2014). This alternative form of modelling is defined by Winston & Goldberg (2004) as "a technique that imitates the operation of a real-world system as it evolves over time". Simulations can be used to compare system designs for a single system and to estimate the performance of an existing system (Law, 2014). Furthermore, it allows the researcher to study a system over a long time period. Something to keep in mind when performing a simulation study, is that it yield estimates of a system's true characteristics (Law, 2014). The system needs to be extensively validated and independent runs are required to produce reliable outputs.

According to Passin, Jobin, & Cordeau (2002), simulation studies in the health sector can be divided into three categories: planning resource capacity, assessing operating rules, and analysing a range of decisions or scenarios. Viana, Ziener, Holhjem, Ponton, Thogersen, & Simonsen (2017) use simulation in the context of hospital care at home. In their study they evaluate the effectiveness of home hospital services, optimize the current configuration, and evaluate potential future scenarios. Fard, Roper, & Hess (2016) also apply (discrete event) simulation in this field, to analyse the impact of a home-hospital program on emergency department crowding. Franck, Augusto, Xie, Gonthier, & Achour (2015) compare two configurations of geriatric services by creating an discrete event simulation.

E.3 Queueing theory

Queueing models have been extensively used to examine the patient flows in hospitals (Chan, Dong, and Green, 2017). They can also be helpful when identifying required levels of staff, equipment, beds, and when making decisions about resource allocation. The advantage of queueing models is that they require little data in comparison to simulation models (Green, 2010). A queueing model is described by an input (arrival) process and an output (service) process (Winston and Goldberg, 2004). An example of application in healthcare is the study of Chan, Dong, & Green (2017), in which they developed a queueing system to optimize the timing of patient inspections by physicians prior to discharge. In this system, servers who complete service can only be freed at pre-specified inspection time. This phenomenon is typical for the healthcare setting and does not exist in other service systems, since then it is immediately known when a customer has completed service (Chan, Dong, and Green, 2017).

E.4 Conclusion

Multiple modelling methods can be used in the context of healthcare optimization. The National Academy of Engineering and Institute of Medicine reported that queueing theory and discrete event simulation are the most powerful methods to analyse systems (Kolker, 2010). According to Kolker (2010), DES models are much more flexible and versatile than queueing formulas, since they are free from assumptions about the arrival process and the service time. Using different examples, he demonstrates that even simple DES models have a significant advantage over queueing models. Robinson (2004) also mentions that simulation models require few, if any, assumptions. Furthermore, he adds the advantage of transparency through the visualizations that can be created of a system. This makes the model easier to understand for a non-expert and can increase their confidence in it. To make a comparison between various scenarios and service designs, simulation is the most commonly used method in healthcare. This research will probably involve a considerable amount of uncertainty and also simplifying assumptions. A simulation model can incorporate all of this. Furthermore, simulation can be used to create an environment in which future developments of the Rijnstate@home project can be analysed.

Appendix F

Simulation study steps

1. Formulate a problem and plan the study.
   1.1 Problem of interest is stated by manager.
   1.2 One or more kickoff meetings are conducted, were the overall objectives, specific questions to be answered, performance measures, scope, system configurations, and the time frame, are discussed.
   1.3 Select the software for the model.
2. Collect data and define a model.
   2.1 Collect information on the system structure and operating procedures.
   2.2 Collect data (if possible) to specify model parameters and input probability distributions.
   2.3 Delineate above information and data in a written assumptions document.
   2.4 Collect data (if possible) on the performance of the existing system (for validation purposes in step 6).
   2.5 Choosing the level of model detail.
   2.6 There should not be a one-to-one correspondence between each element of the model and the corresponding element of the system.
   2.7 Start with a "simple" model and embellish it as needed.
   2.8 Interact with the manager (and other key project personnel) on a regular basis.
3. Is the assumptions document valid?
   3.1 Perform a structured walk-through of the assumptions document before an audience of managers, analysts, and SMEs.
4. Construct a computer program and verify.
   4.1 Program the model in a programming language or in simulation software.
   4.2 Verify (debug) the simulation computer program.
5. Make pilot runs.
   5.1 Make pilot runs for validation purposes in step 6.
6. Is the programmed model valid?
   6.1 If there is an existing system, then compare model and system (from step 2) performance measures for the existing system.
   6.2 Regardless of whether there is an existing system, the simulation analysts and SMEs should review the model results for correctness.
   6.3 Use sensitivity analyses to determine what model factors have a significant impact on performance measures and, thus, have to be modelled carefully.
7. Design experiments.
   7.1 Specify the length of simulation runs, length of the warmup period, and number of independent simulation runs needed.
8. Make production runs.
   8.1 Production runs are made for use in step 9.
9. Analyse output data.
   9.1 Determine the absolute performance of certain system configurations.

   9.2 Compare configurations in a relative sense.
10. Document, present, and use results.
   10.1 Document assumptions, computer program, and study's results for future use.
   10.2 Present study's results.

Appendix G

Distribution of inpatient arrivals

To find a distribution for the interarrival time of inpatient patient groups, an exponential distribution is created to model the interarrival times and tested using a Chi Square test. Below, the process for the COPD patient group is shown. Figure G.1 includes a part of the input data for the calculation. The data of 2018-2019 is used, to ensure the COVID-19 pandemic does not impact the results.

OpnameNr	OpnameDatumTijd	Interarrival (sec)	2018-2022	2018-2019
	26-01-17 11:00		85014,61538	72090,438
	27-11-18 2:58			
	5-12-18 16:31	739980,0	739980,0	739980
	7-12-18 18:22	179460,0	179460	179460
	10-12-18 10:59	232620,0	232620	232620
	11-12-18 0:58	50340,0	50340	50340
	12-12-18 11:44	125160,0	125160	125160
	12-12-18 21:16	34320,0	34320	34320
	13-12-18 10:03	46020,0	46020	46020
	14-12-18 16:39	110160,0	110160	110160
	15-12-18 6:58	51540,0	51540	51540
	18-12-18 10:00	270120,0	270120	270120
	18-12-18 23:14	47640,0	47640	47640
	19-12-18 12:09	46500,0	46500	46500
	20-12-18 14:43	95640,0	95640	95640
	22-12-18 20:09	192360,0	192360	192360
	23-12-18 0:27	15480,0	15480	15480
	23-12-18 8:04	27420,0	27420	27420
	23-12-18 11:39	12900,0	12900	12900
	23-12-18 16:52	18780,0	18780	18780
	24-12-18 12:20	70080,0	70080	70080
	24-12-18 13:04	2640,0	2640	2640
	24-12-18 20:09	25500,0	25500	25500
	25-12-18 14:32	66180,0	66180	66180
	27-12-18 1:40	126480,0	126480	126480
	27-12-18 19:02	62520,0	62520	62520
	27-12-18 19:40	2280,0	2280	2280
	28-12-18 19:26	85560,0	85560	85560
	29-12-18 8:50	48240,0	48240	48240
	30-12-18 17:59	119340,0	119340	119340
	31-12-18 5:39	42000,0	42000	42000
	1-01-19 5:28	85740,0	85740	85740
	1-01-19 13:26	28680,0	28680	28680
	2-01-19 8:36	69000,0	69000	69000
	2-01-19 13:29	17580,0	17580	17580
	2-01-19 22:01	30720,0	30720	30720
	3-01-19 7:12	33060,0	33060	33060
	...	...	...	...

FIGURE G.1: Input data of the COPD arrivals

2018-2019				
Verzamelbereik	*Frequentie*	*CDF exp*	*Interval*	*# Obs*
180	1	0,00	0,0024937	1,194506
35409	188	0,39	0,3855955	184,7002
70637	111	0,62	0,2365399	113,3026
105866	76	0,77	0,1451032	69,50442
141094	44	0,86	0,0890122	42,63683
176323	21	0,91	0,0546037	26,15516
211551	12	0,95	0,0334961	16,04464
246780	10	0,97	0,0205479	9,842431
282009	5	0,98	0,0126049	6,037746
317237	5	0,99	0,0077324	3,703798
352466	3	0,99	0,0047433	2,27206
387694	2	1,00	0,0029098	1,393774
422923	0	1,00	0,0017850	0,854997
458151	1	1,00	0,0010950	0,52449
493380	0	1,00	0,0006717	0,321744
528609	0	1,00	0,0004120	0,197371
563837	0	1,00	0,0002528	0,121075
599066	0	1,00	0,0001551	0,074272
634294	0	1,00	0,0000951	0,045562
669523	0	1,00	0,0000583	0,027949
704751	0	1,00	0,0000358	0,017145
Meer	1			

Bin	**p**	**INV**	**exp**	**count**	**error**
1	0,047619	3517,304	22,85714	28	1,157143
2	0,0952381	7215,06	22,85714	24	0,057143
3	0,1428571	11112,79	22,85714	21	0,150893
4	0,1904762	15233,37	22,85714	25	0,200893
5	0,2380952	19603,82	22,85714	26	0,432143
6	0,2857143	24256,43	22,85714	20	0,357143
7	0,3333333	29230,16	22,85714	19	0,650893
8	0,3809524	34572,63	22,85714	23	0,000893
9	0,4285714	40342,95	22,85714	13	4,250893
10	0,4761905	46615,64	22,85714	18	1,032143
11	0,5238095	53486,59	22,85714	24	0,057143
12	0,5714286	61082,07	22,85714	23	0,000893
13	0,6190476	69573,1	22,85714	32	3,657143
14	0,6666667	79199,44	22,85714	25	0,200893
15	0,7142857	90312,23	22,85714	29	1,650893
16	0,7619048	103455,9	22,85714	22	0,032143
17	0,8095238	119542,4	22,85714	21	0,150893
18	0,8571429	140281,5	22,85714	26	0,432143
19	0,9047619	169511,7	22,85714	17	1,500893
20	0,952381	219481	22,85714	18	1,032143
21	1	1E+11	22,85714	25	0,200893
				Sum	17,00536
				Chi Sq	31,41043

FIGURE G.2: Calculation of the intervals and execution of Chi Square test

Figure G.2 includes the calculation of the theoretical distribution and the execution of the Chi Square test. Figure G.3 shows a visual representation of the observerd frequencies in the data compared to the exponential distribution.

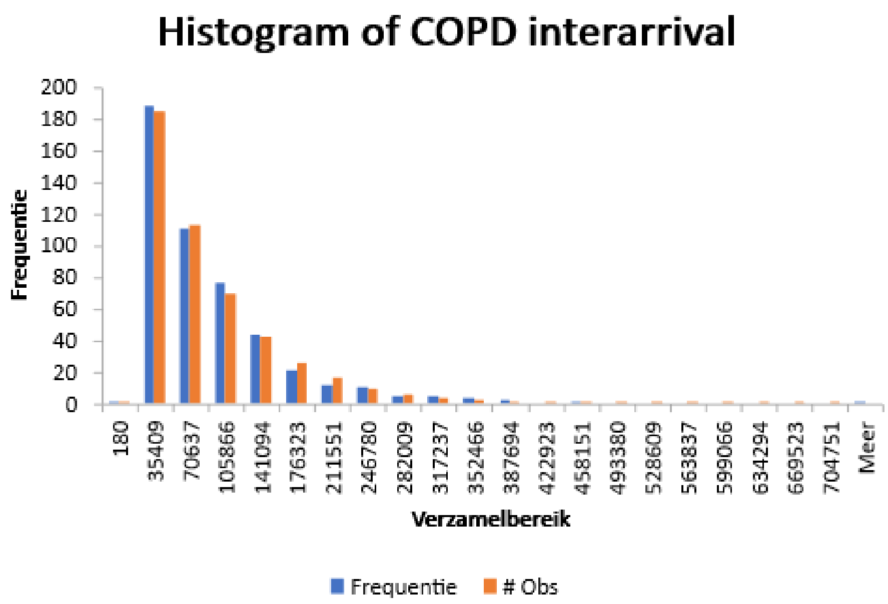
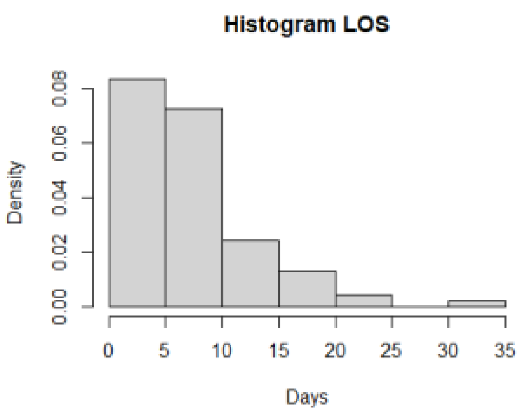


FIGURE G.3: Visual representation of the observed frequencies and exponential distribution

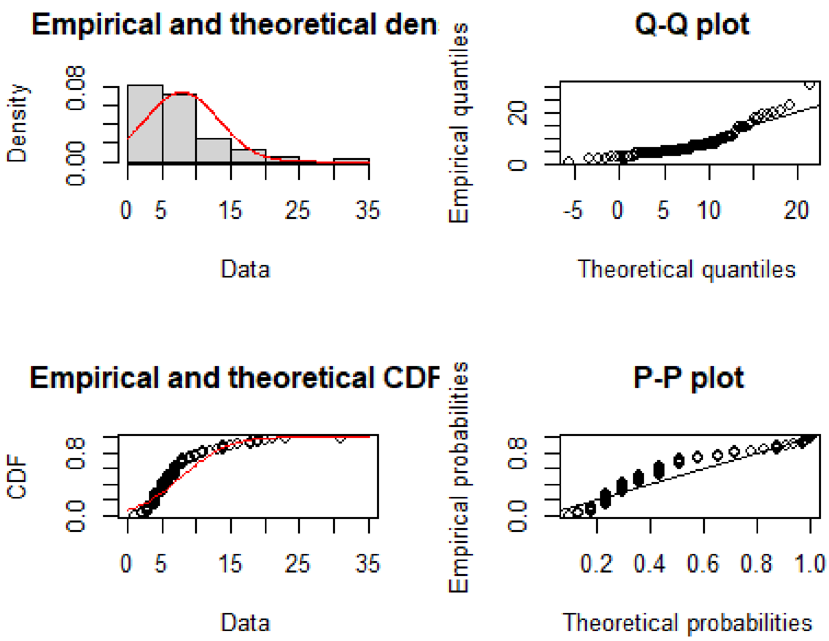
Appendix H

RStudio script for LOS

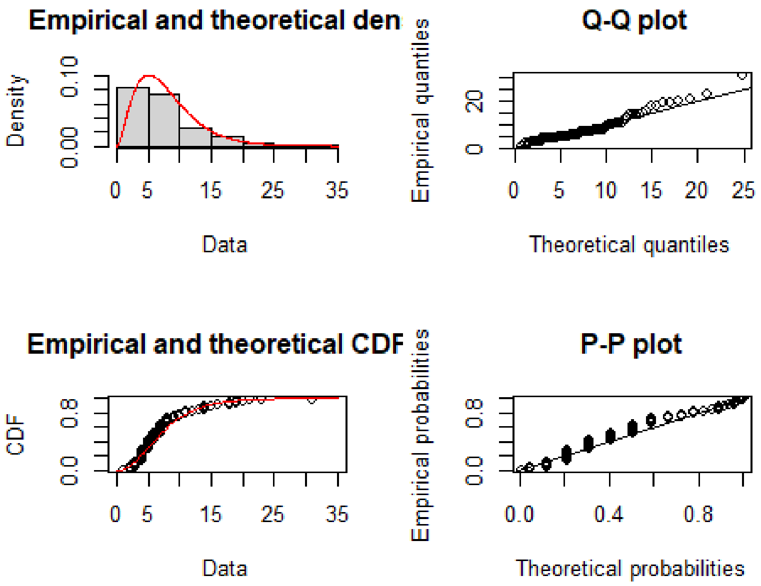
```
library(dplyr)

##
## Attaching package: 'dplyr'

## The following objects are masked from 'package:stats':
##
##     filter, lag

## The following objects are masked from 'package:base':
##
##     intersect, setdiff, setequal, union

library(fitdistrplus)

## Loading required package: MASS

##
## Attaching package: 'MASS'

## The following object is masked from 'package:dplyr':
##
##     select

## Loading required package: survival

library(EWGoF)

setwd("~/Thesis/Model") # Set directory
datafile <- read.csv("Ligdagen.csv", header = TRUE) # Load data file
set.seed(1)

datafile <- datafile %>% # Rename columns
  rename(Ligdagen = ï..Ligdagen)

hist <- hist(datafile$Ligdagen, main = "Histogram LOS", xlab = "Days", freq = FALSE)
# Create histogram of data
```



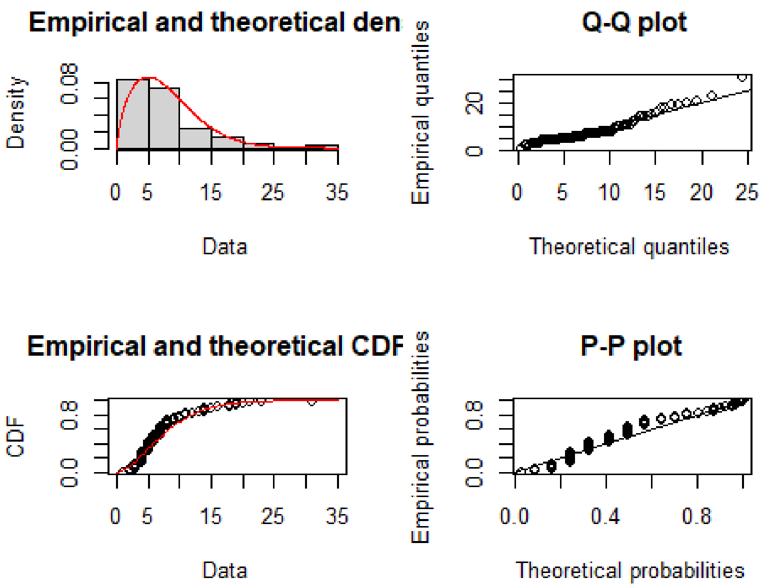
```r
dist_norm <- fitdist(datafile$Ligdagen, distr = "norm") # Fit normal distribution
dist_norm

## Fitting of the distribution ' norm ' by maximum likelihood
## Parameters:
##      estimate Std. Error
## mean 7.868132  0.5584340
## sd   5.327121  0.3948724

plot(dist_norm) # Plot normal distribution
```



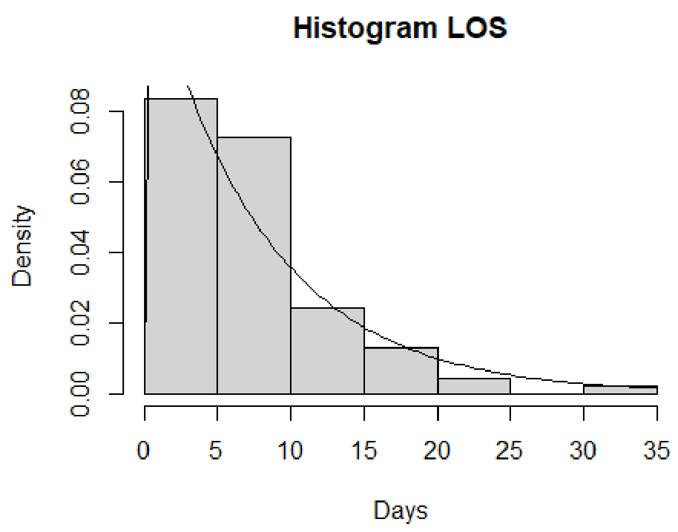

```r
dist_gamma <- fitdist(datafile$Ligdagen, distr = "gamma") # Fit gamma distribution
dist_gamma

## Fitting of the distribution ' gamma ' by maximum likelihood
## Parameters:
##        estimate Std. Error
## shape 2.7679061 0.38815333
## rate  0.3517997 0.05408456

plot(dist_gamma) # Plot gamma distribution
```




```
dist_weib <- fitdist(datafile$Ligdagen, distr = "weibull") # Fit weibull distribution
dist_weib

## Fitting of the distribution ' weibull ' by maximum likelihood
## Parameters:
##       estimate Std. Error
## shape 1.623836  0.1225869
## scale 8.863757  0.6075265

plot(dist_weib) # Plot weibull distribution
```



```
dist_exp <- fitdistr(datafile$Ligdagen, "exponential") # Fit exponential distribution
dist_exp

##       rate
##   0.12709497
##  (0.01332317)

hist <- hist(datafile$Ligdagen, main = "Histogram LOS", xlab = "Days", freq = FALSE)
curve(dexp(x, rate = dist_exp$estimate, log = FALSE), add = TRUE) # Plot exponential
distribution
```




```
gof1 <- gofstat(list(dist_norm, dist_gamma, dist_weib), fitnames = c("Normal",
"Gamma", "Weibull"))    # Goodness-of-fit test
gof2 <- ks.test(datafile$Ligdagen, "pexp", dist_exp$estimate) # Goodness-of-fit (K-S)
test

## Warning in ks.test(datafile$Ligdagen, "pexp", dist_exp$estimate): ties should
## not be present for the Kolmogorov-Smirnov test

# Calculate critical value with alpha level 0.05
c <- 1.36/sqrt(nrow(datafile))
c

## [1] 0.1425667

# Null hypothesis can be accepted if K-S test statistic is below c
ks_norm <- gof1$ks[1]
ks_gamma <- gof1$ks[2]
ks_weib <- gof1$ks[3]
ks_exp <- gof2$statistic

ks_norm

##    Normal
## 0.2154003
```

```r
ks_gamma

##    Gamma
## 0.134589

ks_weib

##   Weibull
## 0.1541321

ks_exp

##         D
## 0.2776516

# 'Ligdagen' follows a Gamma distribution with:
shape <- dist_gamma$estimate[1]
rate <- dist_gamma$estimate[2]

shape

##    shape
## 2.767906

rate

##      rate
## 0.3517997
```

Appendix I

Simulation set-up methods

1. Make n replications of the simulation ($n \geq 5$), each of length m (where m is large). Let Y_{ji} be the ith observation from the jth replication ($j = 1, 2, ..., n; i = 1, 2, ..., m$).
2. Let $\bar{Y}_i = \sum_{j=1}^{n} Y_{ji}/n$ for $i = 1, 2, ..., m$. The averaged process $\bar{Y}_1, \bar{Y}_2, ...$ has means $E(\bar{Y}_i) = E(Y_i)$ and variances $Var(\bar{Y}_i) = Var(Y_i)/n$. Thus, the averages process has the same transient mean curve as the original process, but its plot has only $(1/n)$th the variance.
3. To smooth out the high-frequency oscillations in $\bar{Y}_1$, $\bar{Y}_2$, ..., we further define the moving average $\bar{Y}_i(w)$ (where w is the *window* and is a positive integer such that $w \leq \lfloor m/4 \rfloor$) as follows:

$$\bar{Y}_i(w) = \begin{cases} \dfrac{\sum_{s=-w}^{w} \bar{Y}_{i+s}}{2w + 1} & \text{if } i = w + 1, \ldots, m - w \\[2ex] \dfrac{\sum_{s=-(i-1)}^{i-1} \bar{Y}_{i+s}}{2i - 1} & \text{if } i = 1, \ldots, w \end{cases}$$

   Thus, if i is not too close to the beginning of the replications, then $\bar{Y}_i(w)$ is just the simple average of $2w + 1$ observations of the averaged process centered at observation i. It is called a moving average since i moves through time.
4. Plot $\bar{Y}_i(w)$ for $i = 1, 2, ..., m - w$ and choose l to be that value of i beyond which $\bar{Y}_1(w), \bar{Y}_2(w), ...$ appears to have converged.

N	AvgTotalWT	Run. Average	Variance	T-value	CIHW	Delta	Check
1	35622,64684	35622,64684					
2	29470,21982	32546,43333	18926179	4,302653	13235,88	0,449127	No
3	33466,12635	32852,99767	9745035	3,182446	5735,776	0,17139	No
4	30787,79516	32336,69704	7562955	2,776445	3817,727	0,124001	No
5	34465,67517	32762,49267	6578726	2,570582	2948,61	0,085552	No
6	33709,43335	32920,31611	5412430	2,446912	2324,015	0,068943	No
7	34433,34382	33136,46293	4837395	2,364624	1965,707	0,057087	No
8	34333,09783	33286,04229	4325330	2,306004	1695,605	0,049387	No
9	30957,22155	33027,28443	4387265	2,262157	1579,423	0,05102	No
10	32402,76966	32964,83296	3938793	2,228139	1398,375	0,043156	Yes
11	36948,52442	33326,98672	4987622	2,200985	1482,066	0,040112	Yes
12	32683,52945	33273,36528	4568705	2,178813	1344,392	0,041134	Yes
13	31718,57361	33153,76592	4373932	2,160369	1253,119	0,039507	Yes
14	31261,14157	33018,57847	4293335	2,144787	1187,729	0,037994	Yes
15	34266,71937	33101,78786	4090525	2,13145	1113,061	0,032482	Yes
16	30596,08036	32945,18115	4210234	2,119905	1087,451	0,035542	Yes
17	35492,0821	33094,99885	4328665	2,109816	1064,626	0,029996	Yes
18	35962,34224	33254,2957	4530796	2,100922	1054,049	0,02931	Yes
19	31571,28159	33165,71601	4428166	2,093024	1010,437	0,032005	Yes
20	34157,55473	33215,30795	4244292	2,085963	960,9357	0,028132	Yes

Relative error =	0,05
Corrected target value =	0,047619

FIGURE I.1: Determining the number of replications using the sequential method