Efficient Allocation of Midwives at the New Setup of the Emergency Medical Center at Medisch Spectrum Twente

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Preface

Dear reader,

You are about to read my Bachelor's thesis for the program of Industrial Engineering and Management at the University of Twente. The title of the thesis is: "Efficient Allocation of Midwives at the New Setup of the Emergency Medical Center at Medisch Spectrum Twente." The research aims to provide the hospital and the primary care midwife practices with insights into the impact on the workload when implementing the common Emergency Medical Center. During this research, I gained valuable experience working with different disciplines within the organization and between organizations.

I would like to thank Wilma de Groot for being my supervisor at MST during the first weeks of the research. She assisted me with getting familiar with the hospital, the processes, and shaping the assignment. I want to thank Lisanne Penterman for supervising me during the execution of the research. She was always available to help me, brainstorm together to gain new insights, connect me with the right specialists, and provide me with useful feedback. Throughout the research, I experienced MST as a pleasant place to work with supportive colleagues.

In addition to the MST employees, I would like to thank my first supervisor, Daniela Guericke. She was always available to help me throughout the research and regularly provided valuable feedback to improve my thesis. Lastly, I would like to thank my second supervisor, Sebastian Rachuba, for his feedback. I greatly enjoyed collaborating with both of you.

I hope you enjoy reading my thesis.

Emma Groot

Enschede, August 2023

Management summary

Introduction

Medisch Spectrum Twente is the hospital located in Enschede. The department that will be focused on within this thesis is the observatory. The observatory is part of the Woman Child Center, which serves as an emergency department for women. Women visit the observatory whenever there is a possible concern regarding the mother or the baby. The employees of the observatory and the primary care midwives in the region experience a high workload. This high workload may be lowered by using a new setup of an Emergency Medical Center in which the primary care midwives and the employees of the observatory will cover shifts. This center will operate during the evenings, nights, and weekends. The main research question addressed in this thesis is:

"How many midwives should be available at the Emergency Medical Center at the observatory during the evenings, nights, and weekends for an efficient allocation?"

Approach

First, the collaboration between the observatory and the practices are analyzed together with the internal processes and the problem the observatory and the practices are dealing with. Next to the current processes, the desired process is discussed with employees of MST. Based on this information, literature study is done to discover the best possible approach to determine the optimal number of midwives. Queuing theory is used to determine the allocation for the Emergency Medical Center. Data is collected and analyzed of the hospital and primary care midwife practices. Based on the data of MST and the practices, the arrival rates and service rates are determined, these rates are used as input for the queuing model. Different queuing models are used to conclude the optimal allocation of midwives for the center.

To answer the main research question, data is used to determine the arrival rates and the service rates for the weekdays and weekends. Since the arrival rates are not consequently higher or lower in certain months, the same arrival rate is chosen for the weekdays and the same arrival rate is chosen for the weekends. Additionally, the possible number of midwives is determined for the Emergency Medical Center. The possible number of midwives is based on the capacity of the observatory and the arrival rates. Besides the arrival rates, the service rates, and the possible number of midwives, the probability of arrival per hour is determined. Based on these probabilities, shifts can be made.

After the arrival rates, the service rates, and the possible number of midwives are determined, the values are implemented in the queuing model. Queuing theory is used since this is a stochastic model that can be used to determine the efficiency of the allocation of midwives and the efficiency of the system. The most important parameter considered in determining the optimal number of midwives is the average waiting time per patient. The optimal number of care providers is chosen based on the decrease in waiting time and the benefit of adding an extra care provider, but also on the rule of thumb that the average waiting time per patient has a maximum value of six minutes.

Four different experiments are done using queuing models. The outcomes of the experiments are expressed in the optimal number of care providers per shift and the corresponding total weekly workload. These outcomes can be compared with each other and with the current workload to determine the impact on the workload with the use of the new setup of the Emergency Medical Center. The first experiment is without shifts and with the average arrival rate. The second experiment is without shifts and with a higher arrival rate, the allocation outcome of the experiment with the higher arrival rate could be used in periods when expecting more arrivals. The third experiment is done with shifts, these shifts are based on the probability of arrival. For the weekdays, there is an evening shift and a night shift. The weekend has a day shift and a night shift. For each of the shifts, the average arrival rate is determined. In the last experiment, priority queuing is used together with the shifts and the average arrival rate per shift. The priority is based on the urgency of the patient, this urgency is determined during the triage.

Results

With the use of the new setup of the Emergency Medical Center, the total weekly workload can be lowered. For each of the experiments, the weekly workload is displayed in Figure 1. The optimal allocation of midwives, and thus the lowest weekly workload, is with the use of shifts. The optimal allocation when working with the shifts is that on weekdays during the evening five care providers need to be present, two care providers during the night, seven care providers during the day on the weekend, and three care providers during the night on the weekend. The weekly workload with shifts is in total 505 hours. Compared to the current workload of 1566 hours, this a weekly improvement of 1061 work hours. To ensure the observatory and the eleven practices benefit both on the implementation of the Emergency Medical Center, the current ratio in workload is considered. Applying this ratio to the improved total weekly workload, the employees of the observatory should work weekly 51 hours in the center, and the primary care midwives should work weekly 454 hours together in the center. An overview of the weekly workload for the observatory and the eleven practices can be found in Table 1.

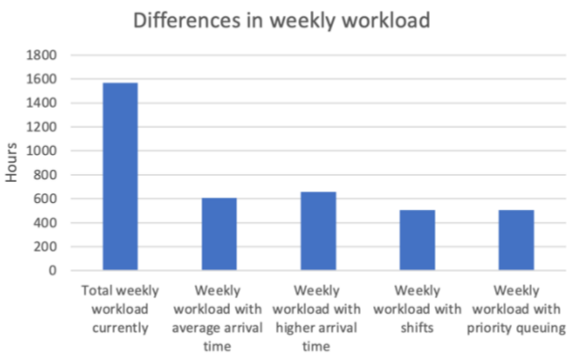

Figure 1: Differences in weekly workload

The weekly workload in hours		
	Current	With EMC
Observatory	158	51
Practices	1408	454
Total	1566	505

Table 1: Overview of the weekly workload

Based on the weekly hours that should be covered in the center, shifts can be allocated to the care providers. A possible division of the shifts is that the employees of the observatory will cover three shifts during the evening on weekdays, two night shifts on weekdays, and one shift on the weekend. The eleven primary care midwife practices will cover the other shifts. This is a total of 49 shifts per week for the practices, six for the observatory. This means that every practice needs to cover four or five shifts in the center weekly. Currently, every practice covers fourteen of those equivalent shifts. So, this is an improvement of nine to ten shifts per week per practice. For the observatory is this an improvement of thirteen shifts per week.

Conclusion and recommendations

The workload of the employees of the observatory and the primary care midwives can be lowered with the use of an Emergency Medical Center in which the employees of the observatory and the primary care midwives will cover shifts together. The optimal allocation is that on the weekdays, five midwives are needed during the evening shift and two midwives during the night shift. For the weekend, seven midwives need to be present during the day shift and three midwives during the night shift. With an operating Emergency Medical Center, weekly 1061 hours will be saved in total.

A recommendation for primary care midwife practices is to record the data in more detail. In this thesis, several estimations are made to be able to implement the data in the queuing model. With more accurate data on the practices, the optimal allocation of midwives can be determined with more certainty. With the outcome of this thesis, the conclusion can be drawn that any form of collaboration will lower the workload for both the observatory and the practices. A midwife at each of the practices is currently 24/7 available, this is unnecessary when looking at the number of consultations during the evenings, nights, and weekends. Practices can collaborate more with each other and/or with the hospital to save work hours and still cover all the consultations. So, the recommendation for MST and the practices: collaborate more to lower the workload. Based on the research in this thesis, the recommendation can be made that the new setup of the Emergency Medical Center will lower the workload significantly when working with shifts.

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1 Introduction

In this chapter, information is given about Medisch Spectrum Twente and the department that will be focused on. Next to this, the reason for the research and the problems will be explained. After this, all the research questions, together with the motivation and approaches, will be discussed. The last section contains information about the objective of the research.

1.1 About Medisch Spectrum Twente

In 1990, Medisch Spectrum Twente (MST) was created from the merger of multiple hospitals. MST is now one of the largest top clinical teaching hospitals with its main location in Enschede. MST also has two outpatient clinics located in Haaksbergen and Oldenzaal. Circa 3500 employees are active within the hospital to improve the health in region Twente (*Over MST - Medisch Spectrum Twente*, 2022).

The department that will be focused on within this thesis is the observatory. The observatory is part of the Woman Child Center, which is an emergency department for women. Depending on the urgency of the situation, suitable care is provided. The observatory is not accessible without a referral. The women who visit the observatory are patients of MST or the primary care midwife/general practitioner sends the patient to the observatory. Within the observatory, women and babies are observed and, whenever necessary, additional experiments are done. After the observation and possibly additional experiments, a woman can go home, needs to be admitted, or will give birth.

1.2 Reason for research

The reason for the research is that the primary care midwives and the employees of the observatory experience a high workload. The goal of the research is to find a suitable solution to lower the workload. Currently, a woman visits the observatory if the woman is a patient of MST or whenever the primary care midwife sends the patient to the observatory. The primary care midwife sends the patient to MST after determining the patient needs medical help. The urgency is determined via a triage, the triage happens twice in the process if the woman needs to go to the observatory and is not a patient of MST. This costs time and resources. The double operations should be limited, and actions should be combined to lower the workload. Therefore, MST wants to develop an Emergency Medical Center for the observatory and the primary care midwife practices during the evenings, nights, and weekends.

The Emergency Medical Center will be located inside the observatory. Primary care midwives will collaborate with the employees of the observatory. In this way, not all the primary care midwife practices have to be available during the evenings, nights, and weekends. MST and primary care midwife practices can work together during these time slots. This might result in a lower number of employees of the observatory and primary care midwives that need to work during the evenings, nights, and weekends.

1.3 Problem statement

1.3.1 Problem cluster

To find the core problem, a problem cluster is made which displays the relationships between different problems within the process. In the case of the primary care midwife practices and MST, the action problem is that the primary care midwives and the employees of the observatory experience a high workload. The action problem arises due to different issues within the primary care midwife practices, the hospital, and the collaboration between them. The high workload experienced by the primary care midwives and the employees of the observatory is the effect of three causes. These three causes are the effect of other causes. The main cause of all the problems in the problem cluster can be identified as the core problem. The problem cluster can be found in Figure 1.1.

The first cause for a high workload for primary care midwives is that every practice is 24/7 available. Since every practice is always available, one or more midwives in each practice must cover a shift. Whenever there is a shortage of midwives at a practice, the midwives experience a high workload since all the shifts need to be covered. This effect is caused by the inefficient allocation of midwives. All the midwife practices are available, which may not be necessary. This problem arises due to little collaboration between the primary care midwife practices.

The second and third cause of a high workload for the employees of the observatory and primary care midwives is because time and resources are lost due to double triage. This is an effect of the cause that there is no common triage point of the primary care midwife practices and the observatory. The triage is done at the practice and at the observatory, this costs a lot of time and resources, which leads to a higher workload. Currently, there is no common triage point because there is little collaboration between the primary care midwife practices and the observatory.

All these problems result in the action problem, however, there is a problem that causes the other problems and the action problem, this is the core problem. The core problem in this problem cluster is that there is little organized collaboration. This core problem results eventually in a high workload.

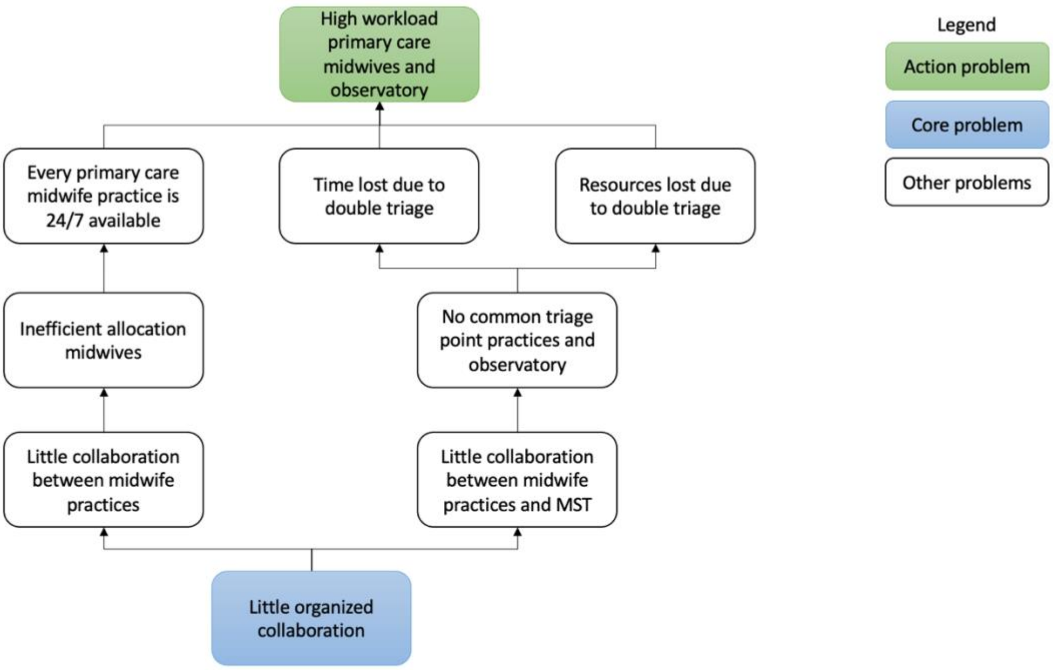

Figure 1.1: Problem cluster

1.3.2 Action problem

The action problem, according to Heerkens (2015), is the gap between the norm and reality perceived by the problem owner. Based on the problem cluster, the action problem is formulated as follows:

"The primary care midwife practices and Medisch Spectrum Twente should collaborate more to lower the workload for the primary care midwives and the employees of the observatory."

1.3.3 Core problem

While determining the problem cluster, the causes of the action problem are determined. The main cause in the problem cluster is the core problem, this is the problem that needs to be solved to solve the action problem. The overall workload can be lowered by an organized collaboration between the practices and MST. Therefore, the core problem is formulated as follows:

"There is little organized collaboration between the primary care midwife practices and the observatory."

1.4 Research design

Now the problem cluster is identified, and the action problem and the core problem are clear, the main research question can be formulated. The main research question for this thesis is:

"How many midwives should be available at the Emergency Medical Center at the observatory during the evenings, nights, and weekends for an efficient allocation?"

To answer the main research question in the end, 11 sub-research questions are set up. In each of the chapters in this thesis, sub-research questions are answered by conducting qualitative or quantitative research. In this section, the sub-research questions are described, and an explanation is given about how the research questions will be answered.

1. **What is the current process?**

The first step is to get familiar with the current processes, how the processes look like, and what might happen in the different processes. The current processes need to be clear to eventually be able to determine the workload of the employees of the observatory and the primary care midwives. To answer this question, qualitative and descriptive research will be conducted. The observatory and the primary care midwife practices will be interviewed to understand the current processes. Also, an employee of the observatory will be accompanied for a day to get familiar with the possible processes at the department. The answer to this question can be found in Chapter 2.

2. **How do the observatory and the primary care midwife practices currently collaborate?**

When analyzing the situation, the collaboration between the observatory and the primary care midwife practices needs to be analyzed. This collaboration needs to be clear to have a more detailed overview of the processes between the hospital and the practices and to make better calculations in the end of the workload. This question will be answered using qualitative and descriptive research. Employees of the observatory will be consulted to have a clear overview of the collaboration. The answer to this question can be found in Chapter 2.

3. **What are the differences between the current process and the desired process?**

The differences between the current process and the desired process need to be clear to determine what wants to be changed. But also, what the points of improvement are within the process. Qualitative and descriptive research will be used to answer the question. This will be done using interviews with the employees of the observatory. Different employees will be interviewed to capture the desired process. Everyone needs to agree on the desired process to conduct the best possible research and to achieve the best possible outcome. The result can be found in Chapter 2.

4. **Which mathematical models are relevant for an efficient allocation of midwives at the Emergency Medical Center?**

To calculate and find out what the current workload is and what the impact is of the Emergency Medical Center on the workload, the right mathematical model should be used. There exist various mathematical models, but not every model can be used in every situation. That is why a literature study needs to be done to find out which model or models apply to this specific situation. Also, the data available at the hospital plays a role in which model can be chosen for the research. The literature review together with the importance of the requirements determines the mathematical model that will be used within this thesis. The answer to this question can be found in Chapter 3.

5. How can the allocation of midwives be determined using mathematical modeling?
To conclude the impact of the Emergency Medical Center on the workload, knowledge should be gained about how the allocation of midwives can be determined when using mathematical modeling. Qualitative and descriptive research will be done to gain knowledge. This will be done through a literature study. The result can be found in Chapter 3.

6. What are the requirements for the setup of the Emergency Medical Center?
There might be some constraints and requirements for an Emergency Medical Center. These requirements need to be clear to make accurate computations. Whenever there are constraints, these constraints need to be included in the model to achieve the best possible outcome. To answer this question, a literature study will be done to find out what the requirements are for an Emergency Medical Center. The answer to this question can be found in Chapter 3.

7. What are the input values for the selected mathematical model?
To use the selected mathematical model, the input values should be clear. These values are determined when analyzing the data. Data of both the hospital and the practices are used when selecting the input values. The input values are determined in Chapter 4.

8. What is the current workload of the employees of the observatory and the primary care midwives?
To make recommendations in the end and to observe the improvement of the Emergency Medical Center, the current workload needs to be calculated for both the observatory and practices. Data will be used, so this research is quantitative research. The current workload will be calculated based on the current schedule at the observatory and the primary care midwife practices. The workload will be expressed in the number of hours worked per week. The outcome and the conclusion can be found in Chapter 5.

9. How does the new setup impact the workload of the observatory employees?
To answer the main research question and to make recommendations, the workload of the employees of the observatory should be calculated in the situation with the Emergency Medical Center. This will be done with the mathematical model chosen in Chapter 3 and is thus quantitative research. The impact on the workload of the observatory employees is the difference between the current workload and the workload in the new situation with the Emergency Medical Center. The difference in workload will be expressed in the number of hours. The outcome of the calculations can be found in Chapter 6.

10. How does the new setup impact the workload of the primary care midwives?
To answer the main research question and to make recommendations, the workload of the primary care midwives should be calculated as well in the situation with the Emergency Medical Center. This will be done with the mathematical model chosen in Chapter 3 and is thus quantitative research. The impact on the workload of the primary care midwives is the difference between the current workload and the workload in the new situation with the Emergency Medical Center. The difference in workload will be expressed in the number of hours and will be calculated for the eleven practices. The outcome of the calculations can be found in Chapter 6.

11. What are the recommendations for the implementation of the solution?
The last sub-research question is to make recommendations for the observatory and primary care midwife practices. This recommendation will be based on the outcome of the impact on the workload for the observatory and each of the primary care midwife practices. The differences in the workload for the observatory and for each of the practices will be translated into the corresponding recommendation. Also, recommendations can be made concerning the limitations of the research. The answer to this question can be found in Chapter 7.

1.5 Research objective

The objective of the research is to make recommendations for the observatory and for the primary care midwife practices in the region on how to lower the workload. These recommendations will be based on the difference in workload for the observatory and each of the practices with the use of the Emergency Medical Center during the evenings, nights, and weekends. Additionally, the recommendations will be made on other possible outcomes and limitations of the research. The Emergency Medical Center will not be implemented right after the thesis. However, this thesis will give insights into the benefits of a possible Emergency Medical Center for both the primary care midwife practices and the observatory in which MST and the practices will collaborate more than in the current process.

2 Analysis of situation

In this chapter, the current situation is analyzed and discussed, and the desired process is discussed with employees of MST. The outcome of the meetings with the employees of MST is visualized in a Business Process Model and Notation (BPMN) model. In this chapter, three sub-research questions will be answered:

“What is the current process?”

“How do the observatory and the primary care midwife practices currently collaborate?”

“What are the differences between the current process and the desired process?”

2.1 Current process

To solve the problem and thus lower the workload of the primary care midwives and the employees of the observatory, the current process should be clear. The current process is examined by asking questions to the employees of MST and by accompanying an employee of the observatory for a day to get familiar with the processes. During this day, various regular appointments and emergency appointments took place.

The current process can be found in Figure 2.1. The process during the evenings, nights, and weekends starts with a patient who realizes something is wrong. Whenever the woman is a patient of MST, the observatory can be called, otherwise, the woman calls the primary care midwife practice. In both cases, a triage happens when calling the observatory or the primary care midwife practice. During the triage, the urgency is determined: this can be urgent, not very urgent, or not urgent at all. For the observatory, whenever the case is urgent, the woman needs to visit the observatory immediately. If the observatory determines that the case is not very urgent, the woman needs to visit the observatory within a certain timeframe, but not immediately. Whenever the employee of the observatory determines that the case is not urgent at all, the woman receives advice, but no further action is taken for the moment.

For primary care midwife practices, the urgency is determined in the same way, only the steps after the triage are different. Whenever the midwife determines that the case is urgent, the midwife calls the observatory, and the triage happens again. If the midwife determines the case is not very urgent, the primary care midwife examines the patient. After the examination, the midwife decides whether the woman needs to visit the observatory or if there is no urgency for further actions for the moment. When the case is not urgent at all, the woman receives advice, but no further steps are taken for the moment. In the current process, all the primary care midwife practices are available during the evenings, nights, and weekends to receive calls and examine women.

As can be seen in Figure 2.1, the employees of the observatory and the primary care midwives collaborate when the primary care midwife calls the observatory for a patient referral. This happens when the primary care midwife decides that the woman needs to be examined by the observatory whenever the case is urgent. The patient starts at the observatory in the triage phase. This is in the current process the only action in which the observatory and the practices collaborate.

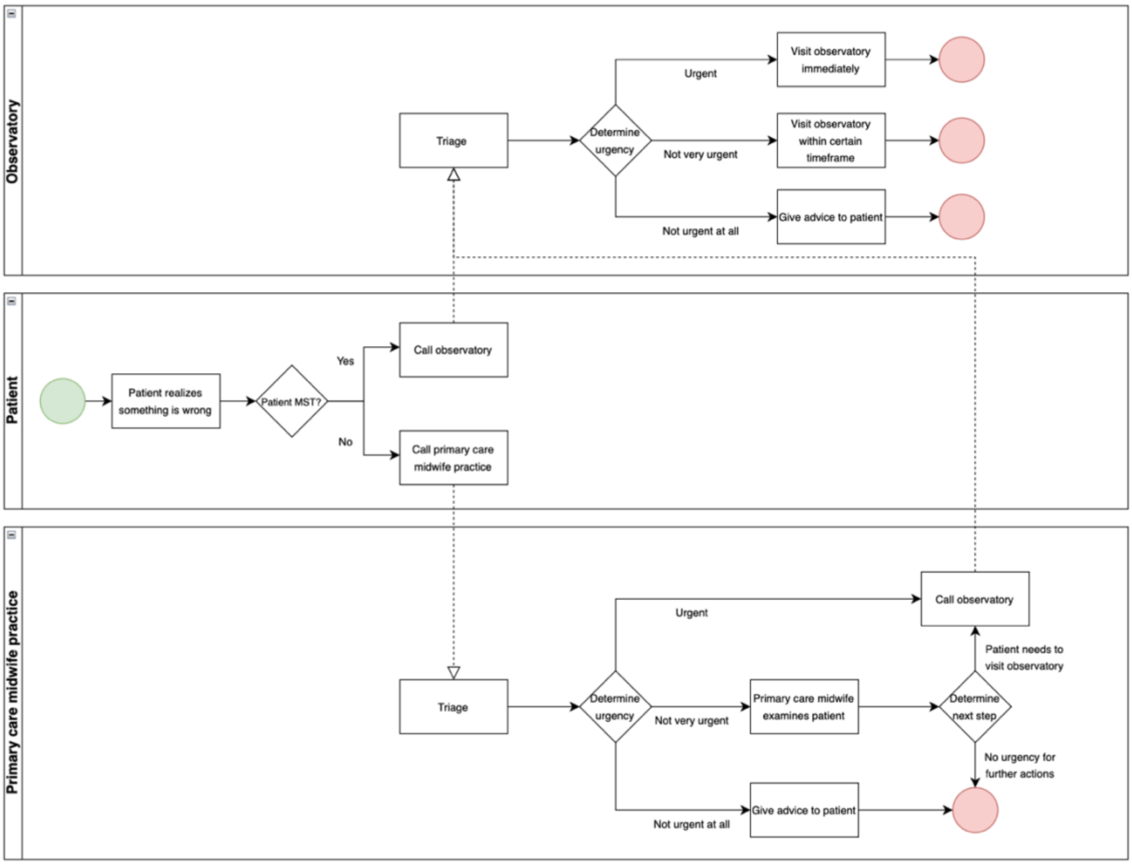

Figure 2.1: BPMN model current process

2.2 Desired process

Next to the current process, the desired process should be clear as well to solve the problem and thus lower the workload of the primary care midwives and the employees of the observatory. The desired process is determined by discussing the plan for the Emergency Medical Center with the employees of MST.

The desired process can be found in Figure 2.2. This is the process that needs to be realized during the evenings, nights, and weekends with the setup of the new Emergency Medical Center. The process starts with the patient who realizes something is wrong. Again, the observatory or the primary care midwife practice is called. Only the difference is with the setup of the new Emergency Medical Center that the primary care midwives are working at the observatory department instead of at the practices. During the triage, the urgency is determined in the same way the urgency is determined at the observatory in the current process. So, whenever the triage is determined as urgent, the patient needs to visit the observatory immediately. Whenever the case is not very urgent, the patient needs to visit the observatory within a certain time frame. If the case is not urgent at all, the patient receives advice, and no further steps are taken for the moment.

For the triage, there will be two phone numbers. One phone number for patients of MST and one phone number for patients of all the primary care midwife practices. In this way, the two different types of patients will be separated when triaging the patients. However, since all the calls will be answered at the Emergency Medical Center at the observatory, the primary care midwives can collaborate with the employees of the observatory. So, in this desired process, the primary care midwives cover shifts at the observatory, which means that not all the primary care midwife practices are available during the evenings, nights, and weekends. Thus, with this setup, there will be a lot of collaboration between the primary care midwives and the employees of the observatory.

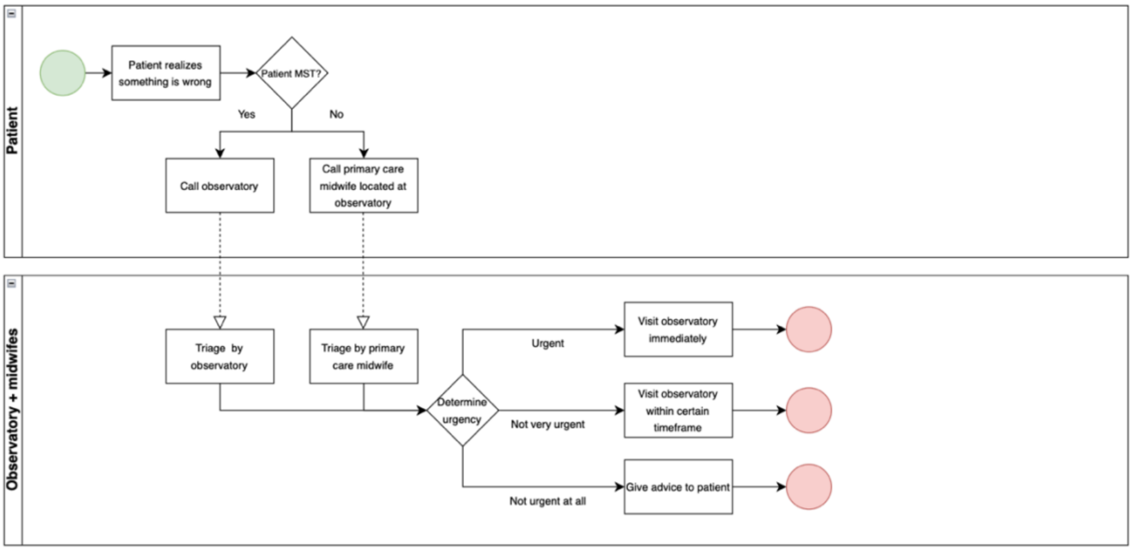

Figure 2.2: BPMN model desired process

2.3 Stakeholders

Since the goal of this thesis is to determine an efficient allocation of midwives at the setup of the new Emergency Medical Center to lower the workload, multiple stakeholders are involved. In the following paragraphs, each stakeholder is discussed with the corresponding role within this thesis.

MST, and more specifically the observatory, is a stakeholder in this thesis since the Emergency Medical Center will be located at the observatory. With the setup of the new Emergency Medical Center, the goal is to lower the workload of the employees of the observatory.

The primary care midwife practices in the region are stakeholders in this thesis as well. The primary care midwife practices will be working together with the observatory. In the current situation, all primary care midwife practices are always available. With the new setup of the Emergency Medical Center, the workload will be lowered for the primary care midwives since the practices do not have to cover all shifts at the Emergency Medical Center at the same time, but only some of them.

Next to the hospital and the practices, the patients are also stakeholders in this thesis. With the setup of the new Emergency Medical Center, contacting the observatory or the primary care midwife will be easier during the evenings, nights, and weekends. Only one triage and examination location need to be visited instead of two, this is beneficial for the women.

2.4 Conclusion

Currently, whenever the patient realizes that something is wrong, the patient of MST calls the observatory, otherwise the woman calls the primary care midwife practice. The triage happens at the observatory for the patients of MST and at the primary care midwife practice whenever the woman is a patient of the practice. During the triage, the urgency is determined, and based on the urgency further steps are taken. In some cases, if the case is urgent, a patient of the primary care midwife practices needs to visit the observatory. In this case, the woman is first triaged by the primary care midwives and then triaged by the observatory.

In the current process, the primary care midwife practices and the observatory collaborate whenever the primary care midwife calls the observatory for a patient referral. This is the only action in which the practices and the observatory collaborate.

The differences between the current process and the desired process are that with the setup of the new Emergency Medical Center, the triage happens at one location, at the observatory. Another difference is that the primary care midwife practices cover shifts at the Emergency Medical Center during the evenings, nights, and weekends and do not have to be all available.

3 Theoretical framework

In this chapter, literature research is conducted to gain knowledge about relevant mathematical models, how the selected model can be used within this thesis, and what the requirements are for an Emergency Medical Center. The information gathered in this chapter will help to determine the workload of the primary care midwife practices and the workload of the employees of the observatory and to get familiar with the guidelines of an emergency center. Three sub-research questions will be answered:

"Which mathematical models are relevant for an efficient allocation of midwives at the Emergency Medical Center?"

"How can the allocation of midwives be determined using mathematical modeling?"

"What are the requirements for the setup of the Emergency Medical Center?"

3.1 Mathematical models

The observatory and the practices deal with a lot of uncertainty since the emergencies are random and not controllable. For this allocation problem, the uncertainty should be considered. According to Winston and Goldberg (2004), in some allocation problems, deterministic models can be used, and in other allocation problems, stochastic models can be used. In the following two sections, these two types of models are discussed together with the use of the models for this specific research. For different situations and circumstances, different models are used. The use of the right model is important to make sure the research is executed in the best possible way to achieve the best possible outcome. Since the research includes both the hospital and the practices, many employees from different locations need to be considered in determining the most efficient allocation of midwives.

3.1.1 Deterministic models

For the allocation problem in this thesis, there is a lot of uncertainty for the observatory and for the primary care midwife practices during the evenings, nights, and weekends. Because during those time slots, there are no regular appointments, only emergencies. These emergencies are not controllable and should be determined with randomness to make sure enough care providers are available. That is the reason why deterministic models cannot be used for this thesis.

3.1.2 Stochastic models

The difference between deterministic models and stochastic models is that for stochastic models the future is uncertain, therefore randomness determines the next state. According to Winston and Goldberg (2004), two types of stochastic processes exist, discrete-time stochastic processes and continuous-time stochastic processes. Discrete-time stochastic processes are used when observing the relation between the random variables and some characteristics at discrete time points. Continuous-time stochastic processes focus on the state that can be viewed at any time.

According to Winston and Goldberg (2004), inventory models, Markov chains, probabilistic dynamic programming, queuing theory, and forecasting models are examples of stochastic models.

In inventory models, the stock is managed over a long period (Boucherie et al. (2021)). Within this thesis, the stock is not managed, therefore inventory models are not applicable.

According to Boucherie et al. (2021), Markov chains can be used for the analysis of dynamic stochastic systems in which the state changes over time. The state of the Markov chain changes according to probability. The next state only depends on the current state. Markov chains are not a suitable stochastic model for this thesis, since not only the current state should be considered for the allocation of midwives at the Emergency Medical Center. For the allocation of midwives, the past should be considered in making an efficient allocation.

Based on the book of Winston and Goldberg (2004), in probabilistic dynamic programming, the goal is to minimize the expected costs or maximize the expected reward. The calculations are made via backward induction. Components of probabilistic dynamic programming are the state of the current condition, the action that can be made at every stage, the probabilities of transitioning to another state, and the reward or costs included based on the action in the stage. Within this thesis, there are no probabilities of transition to another stage. Also, the goal in this thesis to find an optimal allocation, not to minimize costs. So, probabilistic dynamic programming is not applicable to this thesis.

According to Winston and Goldberg (2004), queuing theory is a developed mathematical model to describe waiting lines. The actions and changes within these waiting lines can be analyzed with the use of queuing theory. A queue has an arrival and a departure process. The arrivals are called customers, which are patients within this thesis. The arrival process describes how the patients enter the system. The departure process describes how the patients leave the system; this is the service time distribution. The queue has a discipline, this discipline determines in which order the patients are served. With the use of queuing theory, the system can be analyzed and improved, and optimal resource allocation can be determined. Since for this thesis, an efficient allocation of midwives needs to be determined to lower the workload, the arrival process and the service time distribution can be used to determine an efficient allocation. Therefore, queuing theory is a suitable stochastic model for this thesis.

The last type of stochastic model according to Winston and Goldberg (2004) is the forecasting model. Forecasting models are used to forecast future values of a time series based on the past values of a time series. Future demand for a product can be determined with forecasting. The past trends and patterns of demand are assumed to continue in the future. To use this type of stochastic model, specific data about past trends and patterns of demand should be available. Forecasting can be applied to queuing models to determine the number of arrivals during a time slot. For this thesis, forecasting might be used to predict future patterns. However, since specific data must be available and the Emergency Medical Center copes with random arrivals and variating service times. Next to this, there is no historical data available, therefore forecasting model is not the suitable stochastic model to use.

Based on this information, queuing theory is most applicable to this research since queuing theory gives insights into the capacity that is needed. In this thesis, the workload of the employees of the observatory and the workload of the primary care midwives is calculated. This will be done by examining and calculating how many hours midwives are currently working. After this is determined, an efficient allocation of midwives will be made based on the number of emergencies and the service rate. The number of hours worked for the efficient allocation will be compared to the current workload. In this way, the possible improvement of the workload with the use of the setup of the new Emergency Medical Center can be determined.

3.2 Queuing theory

To determine the efficiency of the allocation of midwives and the efficiency of the system, queuing theory is used. According to Ala et al. (2023): “A queue analysis represents a numeric summary of the queuing process, including some premises on the probabilistic existence of the arrival and operation tasks, server number and form, and queue organization.” Kendall (1951) developed a notation to describe queuing models. This notation contains six characteristics: A/B/C/D/E/F and can be found in Table 3.1 (Vass and Szabo, (2015)). These six characteristics are discussed in this section (Winston and Goldberg, 2004).

A	Arrival distribution
B	Service time distribution
C	Number of servers available
D	System's capacity
E	Calling population
F	Queue discipline

Table 3.1: Notation queuing model

A: Arrival distribution

For the arrival process, four standard abbreviations are used:

- M = interarrival times are independent, identically distributed random variables having an exponential distribution.
- D = interarrival times are independent, identically distributed, and deterministic.
- E_k = interarrival times are independent, identically distributed Erlangs with shape parameter k.
- GI = interarrival times are independent, identically distributed, and governed by some general distribution.

B: Service time distribution

For the service time distribution, four standard abbreviations are used:

- M = service times are independent, identically distributed, and exponentially distributed.
- D = service times are independent, identically distributed, and deterministic.
- E_k = service times are independent, identically distributed Erlangs with shape parameter k.
- G = service times are independent, identically distributed, and follow some general distribution.

C: Number of servers available

The number of servers (s) available at the Emergency Medical Center will be determined in the experiments.

D: System's capacity

The capacity of the system could be an integer, which is the finite option, or infinite. In this case, the system's capacity is infinite, since the women who visit the Emergency Medical Center can wait in the waiting room.

E: Calling population

The number of potential patients can be in general any integer number of infinite patients. In this case, only women visit the Emergency Medical Center. So, technically the number cannot be infinite and should be limited to the number of women.

F: Queue discipline

The queue discipline is described in the following way:

- FCFS = first come, first served
- LCFS = last come, first served
- SIRO = service in random order
- GD = general queue discipline

According to Joseph (2020) and the available data of both MST and primary care midwife practices, an M/M/s queuing model is most suitable for queuing an emergency department. So, the arrival process and the service time distribution will be exponential. According to Boucherie et al. (2021), for the M/M/s queue, the following assumptions must be made:

- Patients arrive following a Poisson process with an average of λ patients per unit of time.
- A patient's service time is exponentially distributed with an expected value of $1/\mu$ units of time.
- There are s servers, with one common queue.
- There is an infinite waiting room.
- The patients will be served in the FCFS order.

3.2.1 Birth-death processes

According to Winston and Goldberg (2004): "A birth-death process is a continuous-time stochastic process for which the system's state at any time is a nonnegative integer." If steady-state probabilities exist, the steady-state probabilities can be determined with the use of a birth-death process. There are three laws of motion for birth-death processes (Winston and Goldberg (2004)).

The first law is that with probability $\lambda_j\Delta t + o(\Delta t)$, a birth happens between time t and time t + Δt. A birth in the queuing system is an arrival. In this case, a birth is a patient that arrives at the Emergency Medical Center. Whenever a woman arrives at the Emergency Medical Center, the state in the system increases by 1. The variable that is called the birth rate is λ_j in state j.

The second law contains information about the death process. There is a probability $\mu_j\Delta t + o(\Delta t)$ that a death happens between time t and time t + Δt. In this case, a death in the process is a patient that leaves the Emergency Medical Center after completion of medical care at the center. Whenever a woman leaves the Emergency Medical Center, the state in the system decreases by 1. The variable that is called the death rate is μ_j in state j. μ_0 should be 0 since a negative state cannot occur in the process.

The third law of motion for the birth-death process is that the births and the deaths that occur in the process are independent of each other. So, in this case, the probability of the number of women that arrive at the Emergency Medical Center is independent of the probability of the number of women that leave the Emergency Medical Center.

A birth-death rate diagram for a M/M/s queuing system can be found in Figure 3.1.

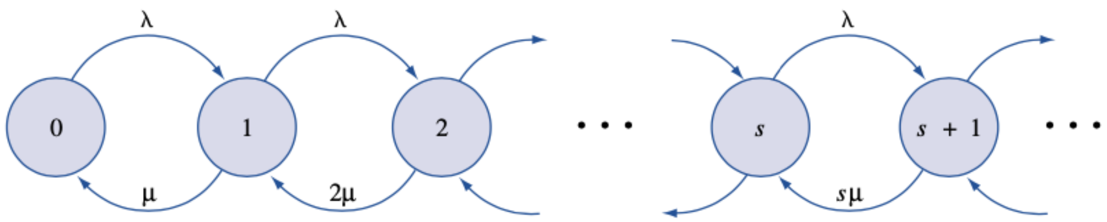

Figure 3.1: Rate diagram for a M/M/s queuing system (Winston and Goldberg (2004))

3.2.2 Use of queuing model

To determine an efficient allocation of the midwives at the Emergency Medical Center, the queuing model should be used correctly. By determining the expected number of patients that will arrive at the Emergency Medical Center, the expected amount of time a patient spends in the system, the number of patients a midwife can help within a certain time frame, and the number of patients that can be served at the same time, the number of midwives needed can be determined. This information will be based on the data of the primary care midwife practices and of the observatory. This data contains information about the number of phone consultations and physical consultations, how much time the consultations cost, and the number of primary care midwives and employees of the observatory. Also, the data will give insight into the current schedule and the number of care providers working per shift.

All this information can be used as input or will be output, with the use of the queuing equation. With the correct use of the queuing equations, an efficient allocation of midwives can be determined for the new setup of the Emergency Medical Center.

3.3 Requirements Emergency Medical Center

When designing an Emergency Medical Center, there might be some guidelines and requirements. These guidelines and requirements are determined by all the involved parties. All these guidelines and requirements for emergency care are documented in the quality framework for emergency care. This framework is a national quality framework and describes how all healthcare parties must collaborate to always deliver excellent care for the patient. Next to this quality framework, there are also specific procedures for emergency midwifery care. These procedures are for the primary care midwives and the midwives at the hospital. The requirements for the Emergency Medical Center can be translated into constraints for the queuing model when taking the whole hospital into account. Since the requirements and guidelines are not used within this thesis, the rules can be found in Appendix 9.2.

3.4 Conclusion

The mathematical model that will be used for this thesis is a queuing model. The type of queuing model that will be used is a M/M/s model with an infinite waiting room and the patients will be helped in order of first come, first served. The allocation of midwives can be determined based on the data gathered from the practices and the hospital in combination with the queuing equations. To allocate midwives to the Emergency Medical Center, the arrival rate and the service rate should be clear together with the capacity of the Emergency Medical Center.

Since the Emergency Medical Center should provide care of good quality, there are some guidelines and requirements for an emergency department. These rules will not be used in this thesis, but can be found in Appendix 9.2

4 Solution approach

In this chapter, the solution approach is explained. The goal of this thesis is to determine an efficient allocation of midwives at the new setup of the Emergency Medical Center to lower the workload of the employees of MST and the primary care midwife practices. The midwives on duty at the Emergency Medical Center will be a combination of employees of the observatory and primary care midwives. The data collection method is discussed and the data analysis method. After the collection and analysis of the data, the implementation of the data in the queuing model is discussed together with the appropriate equations. In this chapter, one sub-research question will be answered:

"What are the input values for the selected mathematical model?"

4.1 Research design

The following four sub-research questions are answered in the next chapters:

"What is the current workload of the employees of the observatory and the primary care midwives?"

"How does the new setup impact the workload of the observatory employees?"

"How does the new setup impact the workload of the primary care midwives?"

"What are the recommendations for the implementation of the solution?"

To answer each of these questions, data is collected, analyzed, and implemented. The data is collected from MST and primary care midwife practices. Based on the current allocation of midwives, the current workload can be determined for the employees of the observatory and primary care midwives. With the use of the information in the datasets, the arrival rate and the service rate can be determined. With the outcome of the data analysis and the use of the queuing model, an efficient allocation of midwives can be made for the Emergency Medical Center. The impact of the new setup of the Emergency Medical Center on the employees of the observatory and the primary care midwives can be determined by comparing the current allocation and workload with the allocation and workload at the Emergency Medical Center. Using the outcome of the sub-research questions, recommendations for the implementation and further research can be given.

4.2 Data collection and analysis

To get insight into the current situation, the occupation, and the workload at the observatory and primary care midwife practices, data is collected. Existing datasets are used, interviews are conducted, and research is done to extract usable information. After the data is collected, the data is analyzed to determine the arrival rate and the service rate at both the observatory and the practices.

4.2.1 Data collection

For this thesis, data from the observatory and the eleven primary care midwife practices in the region are needed. To collect usable data from MST, existing datasets are used, and interviews are conducted with employees of MST. The interviews are conducted to collect information about the planning and shifts at the observatory. This information is needed to get insight into the current workload at the observatory. The existing datasets contain information about the number of consultations per day, the arrival time of a patient, the departure time of a patient, the referral of which type of care provider, and the type of appointment.

Three primary care midwife practices shared data of the practice. These datasets contain information about the average number of consultations for the weekdays and the weekends and the average number of calls for the weekdays and the weekends. The data is given for the evenings and nights from Monday to Friday and the weekends the whole day. On the websites of primary care midwife practices, the number of midwives per practice is found. Based on the shifts and the number of midwives at the practices, the workload of the primary care midwives can be determined. The data collected from the practices can be found in Table 4.1.

		Physical consultations		Phone consultations	
Practices	# midwives	Weekdays	Weekend	Weekdays	Weekend
Practice 1	4	1	2	1	5
Practice 2	5	1	2	2	7
Practice 3	2	1	1	1	3

Table 4.1: Data collected from the primary care midwife practices

4.2.2 Data analysis

The data is analyzed for the observatory and practices. The goal of the data analysis is to determine the arrival rate and the service time distribution for the observatory and practices. The arrival rate and the service time distribution can then be implemented in the queuing model to determine an efficient allocation of midwives for the new setup of the Emergency Medical Center. The data is analyzed using Microsoft Excel.

Data analysis observatory

For the observatory, data is available for 2021 and earlier. To obtain a representative overview of the situation, data is taken from the years 2019, 2020, and 2021. Based on the data and the interviews with the employees of MST, the summer months are the busiest at the observatory. This is because most of the babies are born in September, thus there are more consultations during the months before birth at the observatory. Also, the employees of the observatory go on vacation, with the result that fewer care providers are available. Both the occupation in the summer months and the vacation of care providers result in a higher workload. For this reason, data from the months June, July, August, and September is used for the data analysis. The outcome of the data analysis of these months will contribute (together with the data analysis of the practices) to a representative allocation of midwives at the new setup of the Emergency Medical Center. The data used for the analysis is data from the evenings and nights on weekdays and on the weekends the whole day.

First, in the existing dataset of MST, the data is filtered. The years 2019, 2020, and 2021 and the months June, July, August, and September are selected. The years are compared to observe any differences and the months are also compared to observe differences in arrival rates and service time distributions. Secondly, an overview of the data on weekdays is made from 5 PM to 9 AM and an overview of the data is made for the weekends.

The arrival rate at the observatory contains the arrival of physical consultations and phone consultations in the center per day. For the arrival rate, a different rate is chosen for the weekdays and the weekend. For each month, the same arrival rate is chosen since the arrival rates per month were not consequently higher or lower. The value of the arrival rate for the weekdays is 6.27 arrivals per day. For the weekend, the same applies, the values per day and month were not consequently higher or lower, so the same value is chosen. The value of the arrival rate for the weekend is 12.60 arrivals per day. In Figure 4.1, the average arrival rates can be found for the weekdays. In Figure 4.2, the average arrival rates can be found for the weekends.

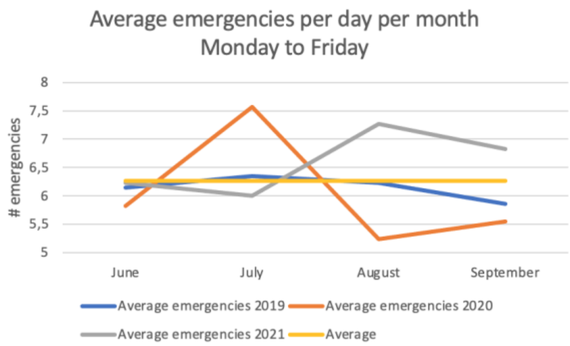

Figure 4.1: Arrival rates weekdays

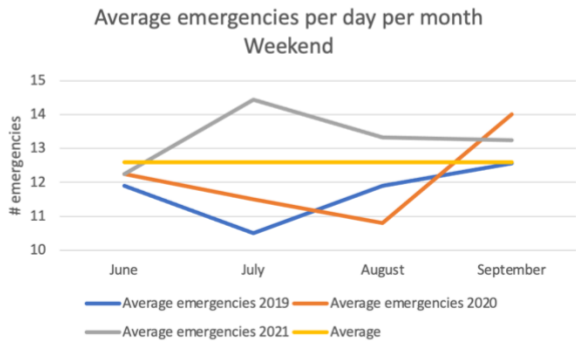

Figure 4.2: Arrival rates weekends

For the service time distribution, the service times for the weekdays and weekends differ. For each month, the service times will be the same since the service times are not consequently higher or lower in certain periods. The value of the service time for the weekdays is 48 minutes and 3 seconds per consultation. The service time for the weekend is 54 minutes and 35 seconds per consultation. The type of consultation can be a physical consultation at the observatory or a consultation on the phone. In Figure 4.3, the service time distribution can be found for the weekdays. In Figure 4.4, the service time distribution can be found for the weekends.

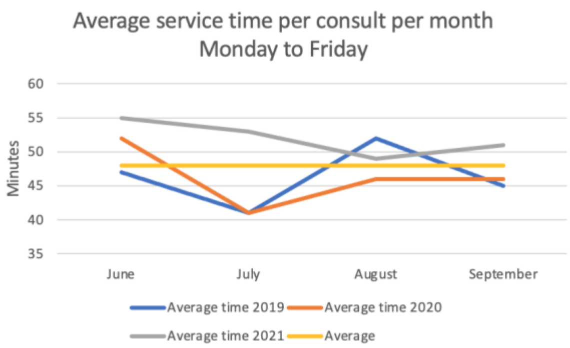

Figure 4.3: Service time distribution weekdays

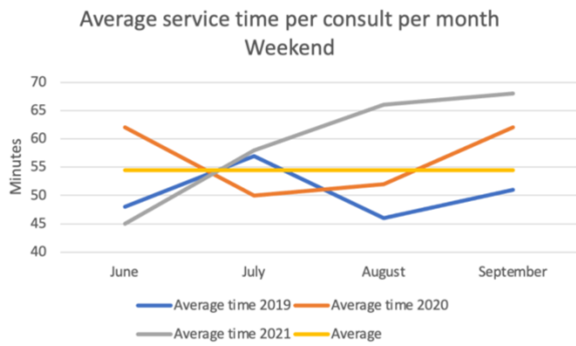

Figure 4.4: Service time distribution weekend

Besides determining the arrival rate and the service time distribution at the observatory, the probability of arrival at a certain timeslot is also determined. With this information, the number of midwives to allocate to a shift might differ during the day on the weekend or the evenings and nights on weekdays. In this way, an efficient allocation of midwives can be made for each part of the day. The probability distribution of arrival is determined by calculating the number of arrivals per hour. For each hour, the number of arrivals is divided by the total number of arrivals, this gives the probability of arrival in a certain hour. In Figure 4.5, the probability distribution of arrival for the weekdays is given. In Figure 4.6, the probability distribution of arrival for the days on the weekend can be found. From the figures can be concluded that there are peak moments during the evenings and nights on weekdays and during the day on the weekend. At night, fewer midwives could be working at the Emergency Medical Center to still cover all the consultations for an efficient allocation.

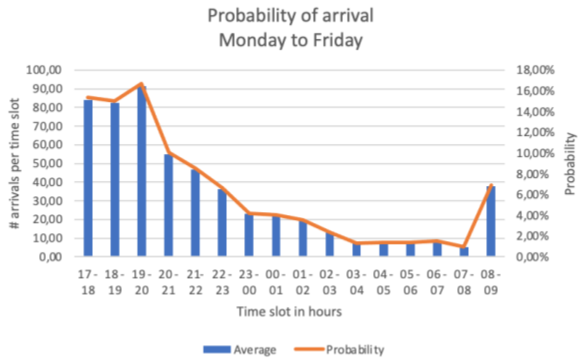

Figure 4.5: Probability of arrival on weekdays

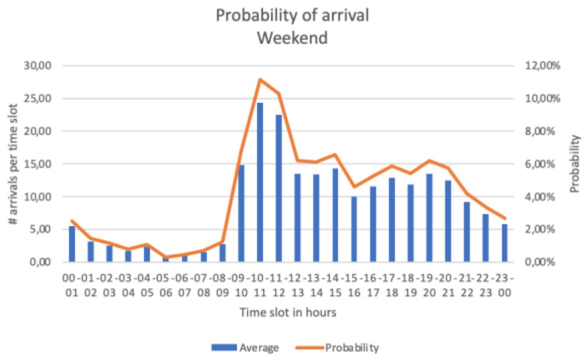

Figure 4.6: Probability of arrival on weekends

Data analysis primary care midwife practices

For the primary care midwife practices, the arrival rates per practice are estimated based on the number of midwives at the practice and the existing datasets of the three practices given. The arrival rate per day, for the weekdays and the weekend, can be found in Table 4.2.

		Physical consultations		Phone consultations	
Practices	# midwives	Weekdays	Weekend	Weekdays	Weekend
Practice 1	4	1	2	1	5
Practice 2	5	1	2	2	7
Practice 3	2	1	1	1	3
Practice 4	5	1	2	2	5
Practice 5	2	1	1	1	3
Practice 6	3	1	2	1	4
Practice 7	4	1	2	1	5
Practice 8	3	1	2	1	4
Practice 9	6	1	3	2	8
Practice 10	4	1	2	1	5
Practice 11	4	1	2	1	5

Table 4.2: Number of midwives and consultations for each of the practices

Based on the service time distribution of the phone consultations at the observatory, the estimation of the service time of the calls at the primary care midwife practices is ten minutes.

4.3 Queuing model

After the data is analyzed, the determined parameters are implemented in the queuing system. Queuing equations will be used to determine an efficient allocation of midwives at the new setup of the Emergency Medical Center. This efficient allocation will be based on the outcome of the data analysis in which the arrival rate at the observatory, the arrival rate at the primary care midwife practices, and the service time distribution of the observatory are determined.

4.3.1 M/M/s equations

The equations in this section are used to determine an efficient allocation of midwives at the new setup of the Emergency Medical Center. To calculate the workload of the employees of the observatory and of the primary care midwives, different queuing equations should be used that apply to the M/M/s queue. These equations are based on the following notation for characteristics of queuing systems (Winston and Goldberg (2004)):

- λ = arrival rate
- μ = service rate

- ρ = fraction of time an individual server is busy
- π_j = long-run fraction of the time that j patients are present
- L = average number of patients in the system
- L_q = average number of patients in the queue
- L_s = average number of patients in the service
- W = average sojourn time per patient
- W_q = average queuing or waiting time per patient
- W_s = average time a patient spends in service

The following equations are used to calculate the workload of the employees of the observatory and the workload of the primary care midwives. "For any queuing system in which a steady-state distribution exists, the following relations hold" (Winston and Goldberg (2004)):

$$L = \lambda W \tag{1}$$

$$L_q = \lambda W_q \tag{2}$$

$$L_s = \lambda W_s \tag{3}$$

Equations (1) to (3) are Little's queuing equations. With these equations, the number of patients can be determined based on the arrival rate and on the average time a patient spends in a part or the whole system. An average arrival rate of 6.27 is used to calculate the average number of patients in the system, in the queue, or service during the evening and night for weekdays. The value of the arrival rate is 12.60 for Saturday and Sunday.

With the use of Little's Law, other equations can be derived. These equations can be used for this thesis for an M/M/s queuing system:

$$L = L_q + L_s \tag{4}$$

$$L_s = \lambda/\mu \tag{5}$$

$$W_s = 1/\mu \tag{6}$$

$$\rho = \lambda/(s\mu) \tag{7}$$

For equations (5) to (7), the service time distribution should be known. Two different service time distributions are determined for the weekdays and the weekend. For the weekdays, the service time is 48 minutes and 3 seconds per consultation. For the weekend, the service time is 54 minutes and 35 seconds per consultation. This means that the service rate (μ) for the weekdays is 1.25; 1.25 women can be served per hour. The service rate (μ) for the weekend is 1.10; 1.10 women can be served per hour on Saturday and Sunday. With equation (7), the fraction of time an individual server is busy is calculated. The arrival rate and the service rate are used together with the number of servers (s). For this case, s is the minimum of the number of care providers available and the rooms available.

To model M/M/s queuing systems as birth-death processes, the following parameters are used:

$$\lambda_j = \lambda \quad (j = 0, 1, \ldots) \tag{8}$$

$$\mu_j = j\mu \quad (j = 0, 1, \ldots, s) \tag{9}$$

$$\mu_j = s\mu \quad (j = s + 1, s + 2, \ldots) \tag{10}$$

Equation (8) captures the arrival rate whenever there are j women present in the system. The arrivals can continue infinitely since there is an infinite waiting room. Equations (9) and (10) capture the service rate whenever there are j women present in the system. Equation (9) considers the services in which the number of women in the system is lower or equal to the number of servers. In this case, each of the women present in the system can be served since there is a server available. Equation (10) considers the services whenever there are more women in the system than servers. In this case, the value of servers (s), will stay the same while the number of women increases.

The steady-state probabilities give insight into the fraction of time a server is busy. The following steady-states probabilities can be formulated for $\rho < 1$:

$$\pi_0 = \frac{1}{\sum_{i=0}^{i=(s-1)} \frac{(s\rho)^i}{i!} + \frac{(s\rho)^s}{s!(1-\rho)}} \tag{11}$$

$$\pi_j = \frac{(s\rho)^j \pi_0}{j!} \qquad (j = 1, 2, \ldots, s) \tag{12}$$

$$\pi_j = \frac{(s\rho)^j \pi_0}{s! s^{j-s}} \qquad (j = s, s+1, s+2, \ldots) \tag{13}$$

The fraction of time an individual server is busy needs to be lower than one, otherwise, the system will 'blow up'. So, the arrival rate must be lower than the number of servers times the service rate. In this case, all the women can be helped within a certain time frame, and so, the system functions. Equation (11) considers the fraction of time there are no women in the system. Equation (12) and (13) consider the fraction of time there are j women present in the system. Equation (12) includes the patients in the system whenever the number of patients is lower or equal to the number of servers. Equation (13) captures the fraction of time that there are more women in the system than servers.

From the equations (7) and (11), the following equation can be derived. This equation shows the steady-state probability that all the servers are busy:

$$P(j \geq s) = \frac{(s\rho)^s \pi_0}{s!(1-\rho)} \tag{14}$$

In this case, all the servers are busy whenever the number of women at the Emergency Medical Center is equal to or larger than the number of servers available.

Equations (1) to (14) can be combined to calculate the number of patients in the system and the queue. Also, the average sojourn time of the patients in the system and the patients in the queue can be calculated:

$$L_q = \frac{P(j \geq s)\rho}{1-\rho} \tag{15}$$

$$W_q = \frac{L_q}{\lambda} = \frac{P(j \geq s)}{s\mu - \lambda} \tag{16}$$

$$L = L_q + \frac{\lambda}{\mu} \tag{17}$$

$$W = \frac{L}{\lambda} = \frac{L_q}{\lambda} + \frac{1}{\mu} = W_q + \frac{1}{\mu} = \frac{P(j \geq s)}{s\mu - \lambda} + \frac{1}{\mu} \tag{18}$$

4.4 Conclusion

Data is collected at MST and the primary care midwife practices. Existing datasets of MST and interviews with employees of the hospital are collected for this thesis together with the data of three practices. The data for the other eight practices are based on the data of the three practices and the number of midwives working at the practices. The data is analyzed in Microsoft Excel. The years 2019, 2020, and 2021 and the months June, July, August, and September are selected for the data analysis. Based on the data analysis, the arrival rates and the service time distributions are determined. These rates are the input values for the mathematical model. The arrival rate at the observatory on weekdays is 6.27 women per day during the evening and night. The arrival rate on the weekend at the observatory is 12.60 women per day. The service time distribution on weekdays is 48 minutes and 3 seconds per consultation. On the weekend the service time is 54 minutes and 35 seconds per consultation. At primary care midwife practices, the average service time for a call is ten minutes. The arrival rate differs for the practices, the arrival rate is based on the number of midwives working at the practice. For the practices, the arrival rates for the phone consultations are separated from the arrival rates for the physical consultations. After analyzing the data, the data can be implemented in the queuing system. The equations for a M/M/s queuing system will be used to determine eventually an efficient allocation of midwives at the new setup of the Emergency Medical Center.

5 Calculating current workload

The workload at both the observatory and primary care midwife practices is determined based on the current schedule. The current workload at the observatory and the primary care midwife practices must be determined to observe the difference in workload with and without the use of an Emergency Medical Center. In this chapter, one sub-research question will be answered:

"What is the current workload of the employees of the observatory and the primary care midwives?"

5.1 The current workload at the observatory

The current workload at the observatory is based on the number of employees working per shift in the evening and in the night on weekdays and during the weekend the whole day. The employees of the observatory are 24/7 available to answer the phone and to examine and observe women in the center. With the use of the following equations, the current workload per week at the observatory can be calculated:

$$Total\ workload\ per\ week\ observatory = weekly\ workload\ weekdays + weekly\ workload\ weekend$$

$$Total\ workload\ per\ week\ weekdays = 5 * \sum_{s=1}^{S} number\ of\ care\ providers\ at\ shift\ s * length\ of\ shift\ s$$

$$Total\ workload\ per\ week\ weekend = 2 * \sum_{s=1}^{S} number\ of\ care\ providers\ at\ shift\ s * length\ of\ shift\ s$$

Until 11 PM during the weekdays, two care providers are working at the observatory. For the rest of the night, one care provider is working at the observatory. Since the idea for the new setup of the Emergency Medical Center is to operate between 5 PM and 9 AM on weekdays and during the weekend, these hours will be considered for the current workload. So, per week, two care providers are working between 5 PM and 11 PM, which is 12 hours in total for the two care providers per day. Between 11 PM and 9 AM one care provider is on duty; this is ten hours per day. So, in total during the weekdays, 110 hours per week care providers are available for the observatory. For the weekend, the shifts of the whole day are covered by an employee of the observatory. One employee is on duty at the observatory during a shift on the weekend. This means that 48 hours are worked in total at the observatory during the weekend. So, in total per week, care providers work 158 hours at the observatory.

5.2 The current workload at primary care midwife practices

In the current situation, at each of the practices, a primary care midwife is 24/7 on duty. This means that during the evening and night on weekdays and on the weekend, at every practice, one midwife is working. This midwife answers the phone, visits women when needed, and refers women to the observatory at MST in case of urgency. This is the case with all the eleven practices focused on in this research. The current workload can be expressed in hours worked per week. The following equations are used to calculate the current workload at the primary care midwife practices:

$$Total\ workload\ per\ week\ primary\ care\ midwife\ practices = weekly\ workload\ weekdays + weekly\ workload\ weekend$$

$$Total\ weekly\ workload\ weekdays = 11 * 5 * length\ of\ shift$$

$$Total\ weekly\ workload\ weekend = 11 * 2 * length\ of\ shift$$

Since the idea for the new setup of the Emergency Medical Center is to operate between 5 PM and 9 AM on weekdays and during the weekend, these hours will be considered for the current workload. For both days in the weekend, a midwife is 24 hours on duty. For the weekdays, a midwife is 16 hours per day on duty. This means that weekly 128 hours a primary care midwife of a practice must be on duty besides the regular opening hours of the practice for appointments. This applies to all eleven practices. So, in total, the weekly workload of all the practices together is 1408 hours covered by 11 midwives.

5.3 Conclusion

The weekly workload at the observatory is 158 hours. 48 hours are worked on the weekend, 16 hours per day are worked from 5 PM to 11 PM, and ten hours are worked from 11 PM to 9 AM per day. The weekly workload at the primary care midwife practices is the sum of the workload of all eleven practices. For each of the practices, one midwife is on duty from 5 PM to 9 AM, and on the weekend one midwife is on duty the whole day. In total, the weekly workload for all the practices is 1408 hours.

6 Determining workload with Emergency Medical Center

In this chapter, the workload is determined whenever an Emergency Medical Center would be used by MST and the eleven practices. First, the data from the observatory and the practices will be combined. Based on this combination, the arrival rates and the service rates are determined. After this, the arrival rates and the service rates are implemented in the M/M/s queuing system for different server values (s) in different ways. With the output of these implementations, the optimal allocation of midwives is determined together with the total workload of this allocation. The last part of this chapter considers the priority queuing model and whether the outcome of this model results in the same conclusion. In this chapter, two sub-research questions will be answered:

"How does the new setup impact the workload of the observatory employees?"

"How does the new setup impact the workload of the primary care midwives?"

6.1 Combining observatory and primary care midwife practices

The first step to calculating the workload of the care providers with the use of an Emergency Medical Center is to combine the data of the observatory and the data of the eleven practices. Also, the capacity of the servers at the Emergency Medical Center is determined.

6.1.1 Arrival rate and service rate

Based on the outcome of the data analysis, the average arrival rate on weekdays at the observatory is 6.27 women per day and the average arrival rate on the weekend at the observatory is 12.60 women per day. The arrival rate consists of both phone consultations and physical consultations. For primary care midwife practices, the number of phone consultations and physical consultations can be combined and added to the arrival rate of the observatory. The phone and physical consultations can be combined since both types of consultations will take place in the same center. The average arrival rate for the Emergency Medical Center is calculated in the following way:

$$\begin{aligned} &Average\ arrival\ rate\ for\ the\ Emergency\ Medical\ Center \\ &\qquad = average\ arrival\ rate\ at\ observatory \\ &\qquad + \sum_{p=1}^{11} average\ arrival\ rate\ at\ primary\ care\ midwife\ practice\ p \end{aligned}$$

The average arrival rate for the weekdays at the Emergency Medical Center is 6.27 + 25 = 31.27 women per day. The service time distribution at the new setup of the Emergency Medical Center is 48 minutes and 3 seconds per consultation on weekdays. This is the same value as the service time at the observatory. The same value can be taken since the same medical operations will be executed at the Emergency Medical Center as currently at the observatory. For the weekend, the average arrival rate and the service time distribution are determined in the same way. The average arrival rate for the weekend at the Emergency Medical Center is 12.60 + 75 = 87.60 women per day. The service time distribution for the weekend for the Emergency Medical Center is 54 minutes and 35 seconds.

To implement the arrival rate and the service time distribution in the system, the arrival rates are expressed in the number of arrivals per hour, and the service rates are expressed in the number of services completed per hour. The arrival rate for the weekdays ($\lambda_{weekdays}$) is 1.95 arrivals per hour. For the weekend, the arrival rate ($\lambda_{weekend}$) is 3.65 arrivals per hour. The service rate for the weekdays ($\mu_{weekdays}$) is 1.25 completed services per hour. For the weekend, the service rate ($\mu_{weekend}$) is 1.10 completed services per hour. The reasoning and the overview for these values can be found in Table 6.1.

	Weekdays	Weekend
Arrival rate per day	31.27	87.60
Hours per shift	16	24
Arrival rate per hour (λ)	1.95	3.65
Average service time	48 minutes and 3 seconds	54 minutes and 35 seconds
Service rate per hour (μ)	1.25	1.10

Table 6.1: Arrival rates and service rates for the weekdays and weekend

6.1.2 Server capacity

To use the queuing equations from Section 4.3.1, the capacity of the servers at the Emergency Medical Center needs to be identified. The capacity of the Emergency Medical Center is infinite since the women will wait in the waiting room when all the servers are busy. The server capacity of the Emergency Medical Center represents the maximum number of women that can be served at the same time, so, the maximum number of servers. This maximum number of servers is the minimum between the rooms available and the care providers present in the center. The observatory contains five rooms. In two of the five rooms, there are two beds available. So, in total, the bed capacity at the observatory, and thus at the Emergency Medical Center is seven. The optimal number of care providers that should be present in the center is determined later in this chapter. For now, the conclusion can be drawn that the maximum number of servers in the center is seven.

6.2 M/M/s queuing system

The minimum number of servers for the weekdays is two and for the weekends four because the arrival rate cannot be larger than the service rate (Winston and Goldberg, 2004). For both the weekdays and the days on the weekend, the maximum number of servers is seven since the observatory has a maximum bed capacity of seven beds. The number of care providers for the weekdays could be any value between two and seven. The number of care providers for the weekend could be any value between four and seven. The average arrival rates and the service rates are constant values, the rates are per hour. In Table 9.1 and Table 9.2, the outcomes of the implementation of the arrival rates and the service rates can be found for different numbers of servers. Table 9.1 gives the outcomes for the weekdays and Table 9.2 gives the outcomes for Saturday and Sunday.

To determine the optimal number of midwives, the average waiting time per patient (W_q) is an important parameter to consider. The Emergency Medical Center should have a minimum number of care providers together with a minimum average waiting time per patient. The decrease in the average waiting in combination with adding an extra care provider should be considered when selecting the optimal number of care providers.

Because the average waiting time is an important parameter to focus on to determine the number of servers, a graph is made to observe the decrease in the average waiting time per patient when adding an extra server. In Figure 6.1, the average waiting time per patient for the possible number of midwives can be found. Based on the decrease in the average waiting time per patient and the difference in waiting time for adding an extra midwife, the optimal number of midwives is determined. For the weekdays, the optimal number of care providers is four, and for the weekend six. With these numbers of care providers, the average waiting time per patient is for the weekdays 1 minute and 41 seconds. For the weekend, a patient should on average wait 2 minutes and 56 seconds. With four care providers for the weekdays and six care providers for the weekend per day, the total weekly workload is 608 hours. The difference in weekly workload can be found in Figure 6.2. With this allocation, 958 hours are saved weekly.

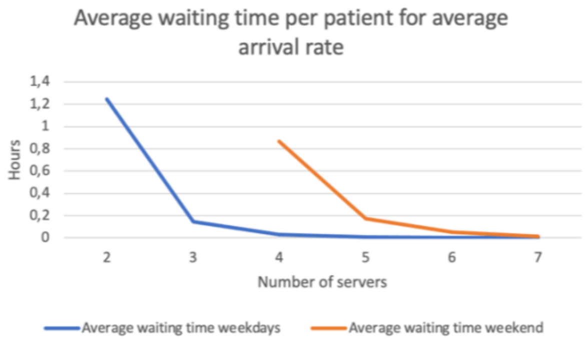

Figure 6.1: Average waiting time for different number of servers for average arrival rate

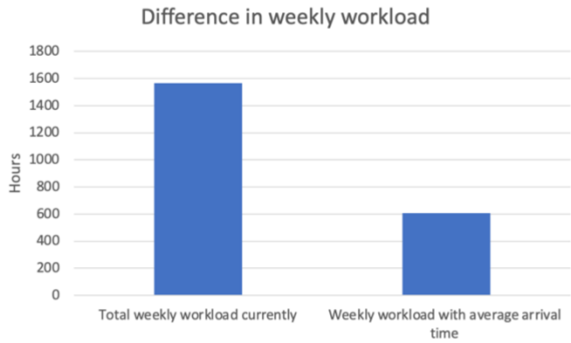

Figure 6.2: Difference in weekly workload

6.3 Analysis of higher arrival rates

Since during some periods the number of arrivals is far above the average and care of good quality should be provided at the Emergency Medical Center, enough care providers need to be always present. To make sure all the women arriving at the center are served as soon as possible, a higher arrival rate is implemented in the queuing system. This is done to observe whether there are any large changes in the outcomes and recommendations of allocation. The arrival rate that is used to make sure there are always enough care providers is the average plus one-third of the difference between the average and the maximum number of arrivals per day. The allocation based on the higher arrival rate can be used when expecting more arrivals in a certain period.

For the weekdays, the maximum number of arrivals at the observatory in the evening and night is 14 women. Based on the data of the practices in Table 4.2 and the maximum number of arrivals at the observatory, the maximum number of arrivals per weekday is for all the practices twice the average number of arrivals. So, the arrival rate used for the weekdays is 14 + 50 = 64. For the weekend, the maximum number of arrivals at the observatory per day is 25 women. So, the arrival rate used for the days on the weekend is 25 + 150 = 175 women per day. Because the arrival rate is said to be the average plus one-third of the difference between the average and the maximum, the arrival rate for the weekdays is 42.18 women, and the arrival rate for the weekend is 116.73.

To implement the arrival rates in the queuing system, the arrival rates need to be expressed in the number of arrivals per hour instead of per day. The arrival rate for the weekdays is 2.64 consultations per hour and for the weekend the arrival rate is 4.86 consultations per hour. Since the service rate should be higher than the arrival rate, the minimum number of care providers for the weekdays is three, and the minimum number of care providers for the weekend is five. Table 6.2 gives a clear overview of the values used in Table 9.3 and Table 9.4. In these tables the outcomes of the implementation with the higher arrival rate can be found.

	Weekdays	Weekend
Average arrival rate observatory per day	6.27	12.60
Average arrival rate practices per day	25	75
Sum average arrival rate per day	31.27	87.60
Maximum arrival rate observatory per day	14	25
Maximum arrival rate practices per day	50	150
Sum maximum arrival rate per day	64	175
Average + 1/3 difference maximum and average	42.18	116.73
Arrival rate per hour	2.64	4.86

Table 6.2: Overview of values for implementation

Using Table 9.3 and Table 9.4, the optimal number of midwives can be determined. The average waiting times per patient for a higher arrival rate can be found in Figure 6.3. For the weekdays, the optimal number of midwives is four because the decrease in waiting time is not large for adding an extra midwife. For the weekend, seven care providers should be present at the Emergency Medical Center. With these numbers of care providers, the average waiting time per patient is for the weekdays 5 minutes and 10 seconds. For the weekend, a patient should on average wait 4 minutes and 16 seconds. With four care providers for the weekdays and seven care providers for the weekend per day, the total weekly workload is 656 hours. The difference in weekly workload for each of the situations can be found in Figure 6.4.

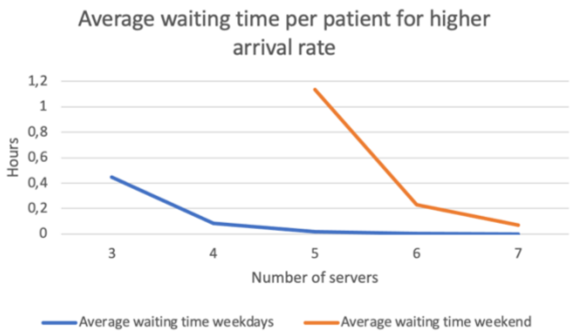

Figure 6.3: Average waiting time for different number of servers for a higher arrival rate

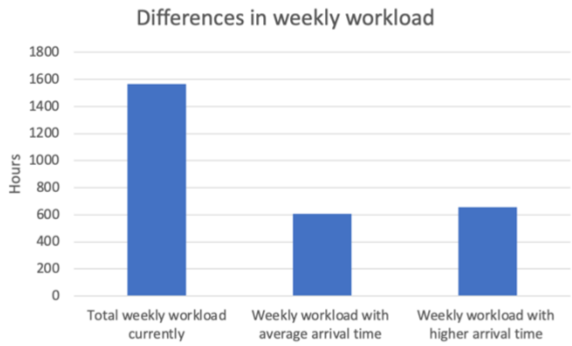

Figure 6.4: Differences in weekly workload

6.4 Shifts based on probability of arrival

In Section 4.2.2, the probability of arrival within a time slot is discussed. Based on these probabilities, different shifts can be made for the Emergency Medical Center in which care providers will be present. These shifts might improve the efficiency of the allocation of care providers. As can be seen in Figure 4.5 and Figure 4.6, there are fewer consultations during the night. This means that fewer care providers can be present at the center to cover all the consultations. Two shifts are made, one shift for the night and one shift for the rest of the day or evening. The night shift is for the time slots in which the probability of arrival is lower than 5%. The night shift is from 11 PM to 8 AM on the weekdays and from 9 PM to 9 AM on the weekends. So, the other shift for the weekdays is from 5 PM to 11 PM and from 8 AM and 9 AM. Since the timeslot from 8 AM to 9 AM is not connected to the other hours of this shift, 8 AM to 9 AM can also be part of the day shift for the weekdays.

Based on data visible in Figures 4.5 and 4.6, the arrival rates for the timeslots are determined. The arrival rate per hour for the night shift on the weekdays is 0.72 and for the weekend 1.45 arrivals per hour. For the shift during the evening/day, the arrival rate for the weekdays is 3.54 consultations per hour, and for the weekend 5.85 arrivals per hour. In Table 9.5, Table 9.6, Table 9.7, and Table 9.8, the outcome of the implementation of the queuing system for the different shifts can be found.

For each of the shifts for the weekdays, the optimal number of servers is selected. For the shift during the evening, the optimal number of care providers is five. With five care providers, the average waiting time per patient during the evening shift is 4 minutes and 23 seconds. For the weekday night shift, two care providers are the optimal choice. A patient should on average wait 4 minutes and 19 seconds. The average waiting times per patient for the shifts on weekdays can be found in Figure 6.5.

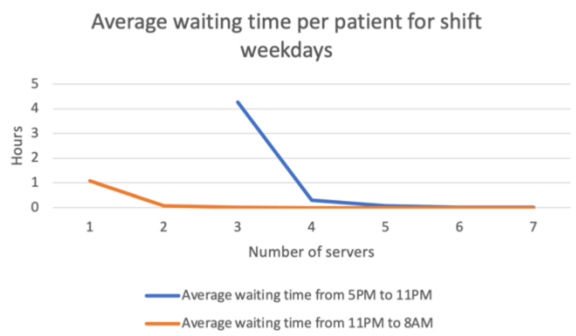

Figure 6.5: Average waiting time for weekday shifts

For the weekend, the optimal number of care providers is selected for the day shift, and for the night shift, the decrease in average waiting time per patient can be found in Figure 6.6. For the day shift, the optimal number of care providers is seven. With seven care providers, the average waiting time is 13 minutes and 8 seconds. The optimal number of care providers for the night shift is three. A patient waits on average 5 minutes and 42 seconds. With five care providers for the evening shift on weekdays, two care providers for the night shift on weekdays, seven care providers for the day shift on the weekend, and three care providers for the night shift on the weekend, the total weekly workload is 505 hours. The differences in weekly workload can be found in Figure 6.7.

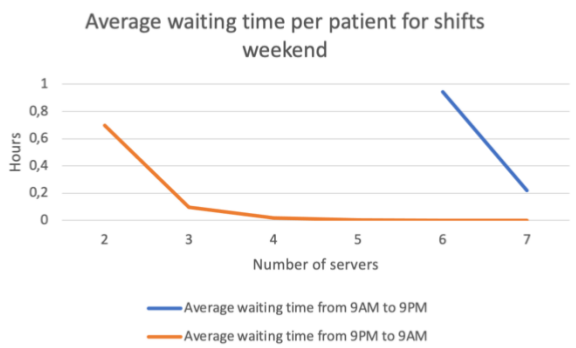

Figure 6.6: Average waiting time for weekend shifts

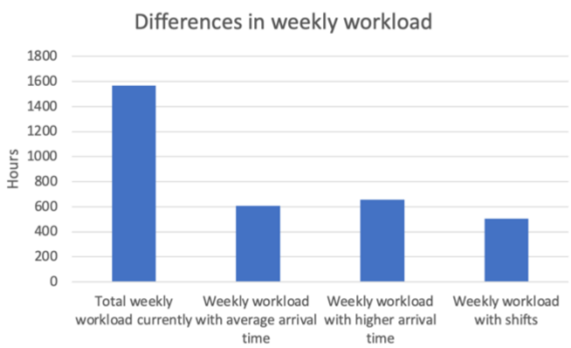

Figure 6.7: Differences in weekly workload

6.5 Priority queuing

Another queuing model to consider is the priority queuing model. The priorities are based on the urgency of the consultation; the level of urgency is determined during the triage. The patient with the highest urgency will be served first when there is a queue. At the observatory, there are five levels of urgency. In the priority queuing model used, level 1 is the highest urgency, and level 5 is the lowest urgency. There is no information available on the probability of the level of urgency, that is why the probabilities are based on an estimation in consultation with the supervisor of MST. With the use of these probabilities, for each of the urgency levels and the shifts, the arrival rate per hour is determined. These values can be found in Table 6.3.

Arrival rate per hour for each of the shifts based on the probability of urgency					
		Weekdays		Weekend	
Urgencies	Probability	17PM – 11PM	11 PM – 8AM	9AM – 9PM	9PM – 9AM
Urgency 1	0.10	0.345	0.072	0.585	0.145
Urgency 2	0.20	0.708	0.144	1.17	0.29
Urgency 3	0.25	0.885	0.18	1.4625	0.3625
Urgency 4	0.25	0.885	0.18	1.4625	0.3625
Urgency 5	0.20	0.708	0.144	1.17	0.29

Table 6.3: Arrival rates based on probability of urgency

Whenever a woman is served, the service will not be interrupted if a patient with a higher urgency is in the queue. So, a non-preemptive priority model is used (Winston and Goldberg, 2004). After the service is completed, the patient with the highest urgency is served first. The Kendall (1951) notation for this priority model is $M_i/M/s/NPRP/\infty/\infty$. The arrival rate and the service rate are both exponentially distributed, there are s servers, the queuing discipline is non-preemptive, the calling population is infinite, and the capacity is infinite since the women can take place in the infinite waiting room. With the use of the priority queuing model, the optimal allocation of care providers at the Emergency Medical Center can be determined. The optimal allocation will be based on the average waiting time of a patient. Equations (19) to (21) are used to calculate the average waiting time per patient for each of the urgencies.

$$W_{qk} = \frac{P(j \geq s)}{s\mu(1-a_{k-1})(1-a_k)} \tag{19}$$

$$a_k = \sum_{i=1}^{i=k} \frac{\lambda_i}{s\mu} \qquad (k \geq 1) \tag{20}$$

$$\rho = \frac{\lambda_1 + \lambda_2 + \cdots + \lambda_n}{s\mu} \tag{21}$$

Equation (19) is eventually used to calculate the average waiting time per patient for urgency level k. Equation (20) is used as input to calculate the average waiting time per patient per urgency level. This equation gives the sum of the fractions of time an individual server is busy. Equation (21) is used to determine the steady-state probability that all the servers are busy. This value is determined with the outcome of Equation (21), the number of servers, and the corresponding outcome in Figure A.1. For the service rates, the same rates are used as in Section 6.3. The average waiting times per patient per urgency are determined for the four shifts described in Section 6.3. The outcome of the implementation can be found in Tables 9.9 to 9.12. Based on the values of W_{qk} per number of servers, the optimal allocation of care providers per shift is selected. The rule of thumb for determining the number of servers with the average waiting time per patient is to observe the impact of adding an extra server. The impact of adding an extra server is observed in the decrease in the average waiting time. This rule of thumb is combined with the general rule that for urgency levels 1, 2, and 3, the maximum acceptable waiting time is set at six minutes, which corresponds to 0.1 W_{qk}. A visualization of the acceptable waiting time is shown in Figures 6.8 to 6.11.

A visualization of the average waiting times per patient for each of the urgencies for the evening shift on weekdays can be found in Figure 6.8. Based on the outcome of the implementation of the priority queuing model, the optimal number of care providers for the evening shift on weekdays is five. With five care providers, the average waiting time for a patient with urgency 1 is 2 minutes and 2 seconds.

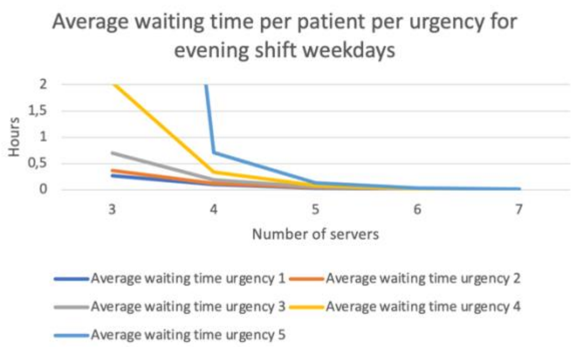

Figure 6.8: Average waiting time per patient for each urgency for the evening shift on weekdays

An overview of the average waiting times per patient per urgency for the different number of care providers for the night shift during the weekdays can be found in Figure 6.9. Based on the values, the optimal number of care providers for this shift is two. With two care providers, a patient with urgency 1 should wait on average 3 minutes and 14 seconds.

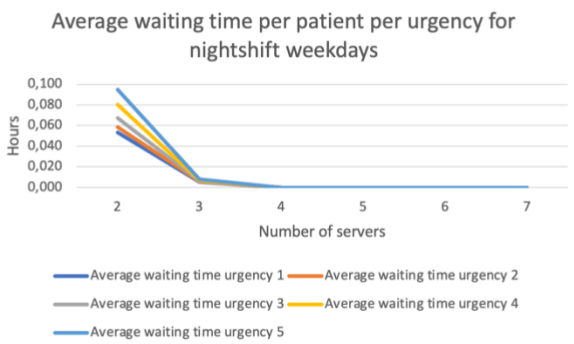

Figure 6.9: Average waiting time per patient for each urgency for the night shift on weekdays

In Figure 6.10, the average waiting times per patient per urgency can be found for each of the possible number of midwives. The optimal number of care providers for the day shift on the weekend is seven. With seven care providers, the average waiting time per patient for urgency 1 is 3 minutes and 29 seconds.

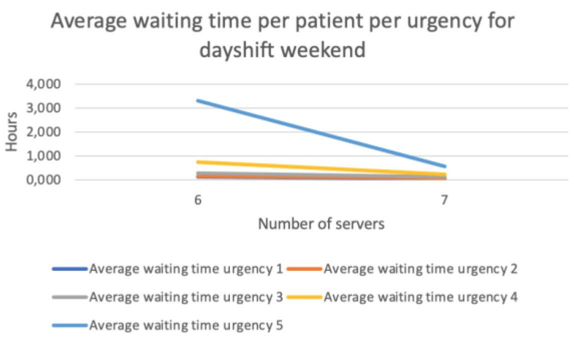

Figure 6.10: Average waiting time per patient for each urgency for the day shift on the weekend

Figure 6.11 visualizes the decrease in average waiting time per patient for each of the urgencies for different numbers of servers. The optimal number of servers for the night shift on the weekend is three. With three care providers, a patient with urgency 1 waits on average 3 minutes and 25 seconds.

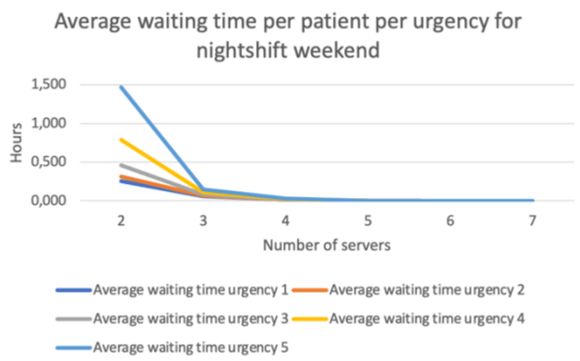

Figure 6.11: Average waiting time per patient for each urgency for the night shift on the weekend

For the priority queuing model, the same conclusion can be drawn as with the use of the queuing model with the probability of arrival per shift. So, from 5 PM to 11 PM and from 8 AM to 9 AM on the weekdays, the number of care providers present at the Emergency Medical Center should be five. From 11 PM to 8 AM on weekdays, the optimal number of midwives is two. For the weekend, the optimal number of care providers from 9 AM to 9 PM is seven, and from 9 PM to 9 AM there should be three midwives at the Emergency Medical Center. Since the optimal allocation is the same as with the queuing model with the probability of arrival per shift, the total weekly workload is 505 hours. Since the current weekly workload is 1566 hours, weekly 1061 hours will be saved with the use of an Emergency Medical Center. The differences in workload can be found in Figure 6.12.

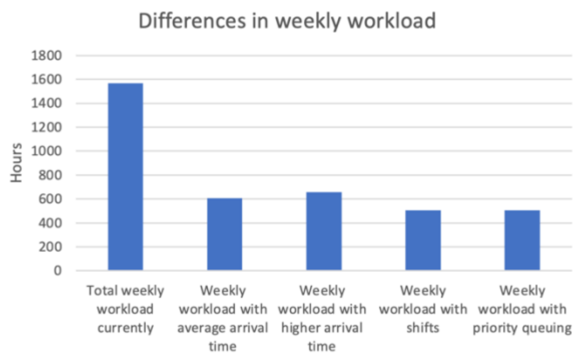

Figure 6.12: Differences in weekly workload

6.6 Allocation of shifts per week

The allocation for each of the shifts per week is based on the ratio between the current workload of the observatory and the primary care midwife practices. The current weekly workload of the observatory is 158 hours and of the eleven practices 1408 hours. So, a total workload of 1566 hours per week. When implementing the Emergency Medical Center, the total weekly workload will be 505 hours for the observatory and practices together. To allocate the care providers for the shifts, the same ratio between the current workload of the observatory and the practices is used. In this way, the hospital and the practices will benefit from the Emergency Medical Center with the same percentage of decrease in workload. According to this, the employees of the observatory will weekly cover 51 hours and the practices will weekly cover 454 hours at the Emergency Medical Center. Table 6.4 gives an overview of this reasoning.

	Current	Ratio	Total with EMC	Ratio * Total
Observatory	158 hours	0.100894		51 hours
Practices	1408 hours	0.899106		454 hours
Total	1566 hours	1	505 hours	505 hours

Table 6.4: Reasoning for division of hours for observatory and practices

Based on the division of hours for the Emergency Medical Center, the shifts can be divided between the observatory and the practices. Since the employees of the observatory need to cover 51 hours per week, a possible division could be that an employee of the observatory works three shifts in the evening on weekdays, two shifts during the night on weekdays, and one shift during the weekend per week. The other care providers working per shift will be primary care midwives. An overview of the hours per shift, the number of care providers weekly per shift, and the possible division is given in Table 6.5.

	Weekdays		Weekend	
	Shift evening	Shift night	Shift day	Shift night
Hours per shift	7	9	12	12
Care providers per shift	5	2	7	3
Care providers per shift weekly	25	10	14	6
Assigned to observatory weekly	3	2	0	1
Assigned to practices weekly	22	8	14	5

Table 6.5: Possible division of shifts for observatory and practices

In Table 6.6, the weekly schedule can be found. For each of the shifts per day, a possible allocation is given. The eleven practices will divide all the shifts for the practices. In total, 49 shifts for the primary care midwives need to be covered at the Emergency Medical Center. This means that every practice covers weekly four or five shifts in the center. The division of the shift between the practices can change weekly so every practice will work the same number of hours per year.

	Weekdays		Weekend	
	Shift evening	Shift night	Shift day	Shift night
Monday	1 observatory, 4 practices	0 observatory, 2 practices	-	-
Tuesday	0 observatory, 5 practices	1 observatory, 1 practices	-	-
Wednesday	1 observatory, 4 practices	0 observatory, 2 practices	-	-
Thursday	0 observatory, 5 practices	1 observatory, 1 practices	-	-
Friday	1 observatory, 4 practices	0 observatory, 2 practices	-	-
Saturday	-	-	0 observatory, 7 practices	1 observatory, 2 practices
Sunday	-	-	0 observatory, 7 practices	0 observatory, 3 practices

Table 6.6: Possible weekly schedule

6.7 Conclusion

To determine the most efficient allocation of midwives for the new setup of the Emergency Medical Center, the average waiting time (W_q) is an important parameter to consider. The Emergency Medical

Center should have a minimum number of care providers together with a minimum average waiting time per patient. Based on the differences in the probability of arrival, the most efficient option for the allocation of care providers is to work in shifts. During the night, the probability of arrival is less than during the evening or the day. Work hours will be saved when separating these time slots and determining an allocation of care providers for the evening or day and the night.

The number of midwives chosen to allocate to each shift is based on the average waiting time per patient. The value of the number of midwives is based on the decrease in the average waiting time for adding an extra midwife. Whenever the average waiting time per patient stagnates for an extra midwife, the optimal number of midwives can be determined. Based on the figures in this chapter which visualize the decrease in average waiting time for adding an extra midwife, the rule of thumb is determined for selecting the number of midwives. The rule of thumb is that the maximum average waiting time per patient is six minutes; this corresponds to a maximum W_q of 0.1.

Based on the same outcomes of the implementation of the queuing model with the probability of arrival per shift and of the priority queuing model, the optimal allocation can be determined for the Emergency Medical Center. For the weekdays from 5 PM to 11 PM and from 8 AM to 9 AM, five care providers should be present. From 11 PM to 8 AM on weekdays, the optimal number of care providers is two. For the weekend from 9 AM to 9 PM, seven care providers should be present, and three care providers should be present from 9 PM to 9 AM. For this allocation, the total weekly workload is 505 hours. Comparing this with the current workload of 1566 hours for both the practices and the observatory, 1061 hours of work will be saved in total per week with the use of the Emergency Medical Center.

Based on the current weekly workload ratio between the observatory and the practices, the division of the hours at the Emergency Medical Center is determined. The observatory needs to cover weekly 51 hours at the Emergency Medical Center and the eleven practices need to cover weekly 454 hours together. A possible division is that an employee of the observatory works three evening shifts on weekdays, two night shifts on weekdays, and one shift during the whole weekend. The other shifts are covered by primary care midwife practices. Each practice needs to cover weekly four or five shifts in the center. The observatory will save with the use of an Emergency Medical Center 107 hours per week. The eleven practices will save weekly 954 hours together. This means that for each of the practices weekly 86 hours and 44 minutes will be saved with the use of an Emergency Medical Center.

7 Conclusion

This chapter contains a short summary of this thesis together with a discussion of the limitations of this research, the contribution of this thesis to practice for MST, and the future research. One sub-research question is answered:

"What are the recommendations for the implementation of the solution?"

7.1 Conclusion

MST and the primary care midwife practices in the region experience a high workload. To lower the workload for the employees of the observatory and the primary care midwives, both should collaborate more. A new setup of an Emergency Medical Center is introduced and analyzed in this thesis to observe the impact on the workload of the employees of the observatory and the primary care midwives. For the Emergency Medical Center, the optimal allocation of midwives is determined in this thesis. The main research question answered in this thesis is:

"How many midwives should be available at the Emergency Medical Center at the observatory during the evenings, nights, and weekends for an efficient allocation?"

This research question is answered by collecting and analyzing the data of MST and the eleven practices. The data is analyzed by using the applicable mathematical model. Queuing theory is used to determine the optimal allocation of midwives. When analyzing the data, the arrival rates, and service rates are selected together with the possible number of midwives. These input values are used for the queuing model. The most important output value of the queuing model is the average waiting time per patient. The average waiting time should be as low as possible together with a minimum number of midwives. So, adding an extra midwife should have a significant impact on the waiting time.

The main findings of this research are that working with shifts at the Emergency Medical Center gives the most efficient allocation of midwives and that for each shift, a different number of midwives should be allocated. With the use of shifts, five midwives should be present during the evening shift on weekdays, two midwives need to be present during the night on weekdays, seven midwives should be present during the day on the weekend, and three midwives during the night on the weekend. With an operating Emergency Medical Center, weekly 1061 hours will be saved in total.

7.2 Discussion of limitations

In this section, the research is discussed together with the limitations of the research. The main research question is answered by answering the sub-research questions. To answer these questions, qualitative research is done, and quantitative data is used. At the beginning of the research, the qualitative research was important to get familiar with the hospital, birth care, emergency departments, and mathematical modeling. The qualitative part consists of interviews and literature research. The outcome of the interviews was valuable and applicable to this research. The literature research was more difficult since an emergency department for obstetric care is a new concept. There is little information available for an obstetric emergency department. That is why also the information about the regular emergency department is used for this thesis to get familiar with an emergency department. For the mathematical modeling part, a lot of information could be found about using models for an optimal allocation of care providers at an emergency department. This information was very valuable in selecting the right mathematical model for this thesis.

To implement data in the queuing model, accurate datasets are needed for both MST and the eleven practices. From MST, the existing datasets contained usable information for the research. The only limitation of the data of MST was that there was no data available for 2022 due to a transition to a new system. That is why 2019, 2020, and 2021 are used for this research. Next to this, the level of urgency for each consultation is not registered in the existing datasets of MST, so estimations are made in collaboration with the supervisor of MST for the priority queuing model. The data of the practices had more limitations. Based on conversations with the practices, data is not registered properly at some of the practices. So, it was hard for the practices to share accurate data. Three out of the eleven practices shared the data of the last year. The data of two of the three practices was precise, the other practice made some estimations. Combining the data of the three practices, the data of MST, and the number of midwives working at the practices, the data of the other practices was estimated. Because a lot of assumptions are made for the data of the practices, there might not correspond to the actual data. This might have an impact on the outcome of the queuing models. Next to the use of queuing models, other models or tools might be used to determine the optimal allocation of midwives.

Besides the limitation on data and information available about an obstetric emergency department, for this research, only one option is considered for a possible Emergency Medical Center. Within this research, the Emergency Medical Center will operate during the evenings, nights, and weekends. Additionally, the Emergency Medical Center considered in this research will only include phone and physical consultations, no childbirths. Other options for the Emergency Medical Center might be explored to discover an optimal process to lower the workload of the employees of the observatory and the primary care midwives.

7.3 Recommendations

Based on the conclusion and the limitations of the research, recommendations are made for MST and the practices.

1. Practices should record data in more detail

For an optimal outcome of the queuing models, the data used should be precise and accurate, no estimations should be made. That is why the practices should register data more precisely. The number of phone and physical consultations for each day should be registered together with the arrival and departure rate. With this information, the correct average arrival rate and service rate can be determined. This information should be available for all the practices to conduct proper research and to receive an optimal outcome.

2. More collaboration between MST and practices (in busy periods)

What can be concluded from the data and the outcome of the queuing models, is that work hours can be saved by collaborating more. A midwife at each of the practices is currently 24/7 available, this is unnecessary when looking at the number of consultations during the evenings, nights, and weekends. Practices can collaborate more with each other and/or with the hospital to save work hours and still cover all the consultations. Any form of collaboration will lower the workload. This collaboration can be implemented in busy periods, but also regularly.

3. Recommendations when using Emergency Medical Center

When implementing the Emergency Medical Center as discussed in this thesis, weekly 1061 hours can be saved. The optimal solution is to work in shifts: for the weekdays, one shift for the evening and one shift for the night, for the weekend, one shift for the day and one shift for the night. These shifts are based on the probability of arrival. The optimal allocation is to have five care providers during the evening on weekdays, two care providers during the night on weekdays, seven care providers during the day on the weekend, and three care providers during the night on the weekend. With this allocation, weekly 505 hours are worked in the center. A possible schedule is shown in Table 6.6.

7.4 Practical relevance and future research

7.4.2 Practical relevance

During this research, data is collected and used for a purpose that is not done before. With the outcome of this research, the workload for both the employees of the observatory and the primary care midwives can be lowered. Time and resources will be saved since the triage and the examination will take place in the center instead of at multiple locations. Besides the care providers, pregnant women might also benefit from the Emergency Medical Center. The women will be triaged and examined in the center instead of possibly by the primary care midwife and thereafter at the observatory in case of urgency or complications. In this way, the women will get the care needed in a shorter timeframe.

7.4.3 Future research

Within this thesis, only the optimal allocation of midwives at the Emergency Medical Center is considered. For an emergency department to operate, other aspects should be considered as well. An example of an aspect to consider is the financial part of implementing an Emergency Medical Center. A different price is paid at the practice compared to the hospital. When designing the Emergency Medical Center, the health insurance companies should agree on the plan for the center and should be willing to make an acceptable financial plan. Also, the accessibility of patient files and the hospital itself should be considered when implementing the center. To provide good care, all the care providers should be able to open the patient files, midwives should be able to open the files of the observatory, and employees of the observatory and midwives of other practices should be able to open the files of patients registered at a certain practice. But also, if the midwives need to cover shifts in the center, the midwives should be able to access the hospital and the systems the hospital is using. Privacy and accessibility are important factors to consider and investigate.

In Appendix 9.2 the requirements for an Emergency Medical Center are discussed. These requirements and constraints should be included in the model as well whenever the center will be implemented. Since these constraints are outside the scope of this research, the requirements and constraints should be included in the model. In any further research, the scheduling of other departments should be considered as well.

Besides the new setup of the Emergency Medical Center for the evenings, nights, and weekends, other options for collaboration between the practices and/or the hospital should be considered. For example, a plan for centralized childbirth, an emergency department during the whole day, or more joint departments in the region.

8 Bibliography

Ala, A., Yazdani, M., Ahmadi, M., Poorianasab, A., & Attari, M. Y. N. (2023). An efficient healthcare chain design for resolving the patient scheduling problem: queuing theory and MILP-ASA optimization approach. *Annals of Operations Research*. https://doi.org/10.1007/s10479-023-05287-5

Avasthi, A., Ghosh, A., Sarkar, S., & Grover, S. (2013). Ethics in medical research: General principles with special reference to psychiatry research. *Indian Journal of Psychiatry*. https://doi.org/10.4103/0019-5545.105525

Azaiez, M. N., & Sharif, S. S. A. (2005). A 0-1 goal programming model for nurse scheduling. *Computers & Operations Research*, *32*(3), 491–507. https://doi.org/10.1016/s0305-0548(03)00249-1

Bard, J. F., Binici, C., & deSilva, A. H. (2003). Staff scheduling at the United States Postal Service. *Computers & Operations Research*, *30*(5), 745–771. https://doi.org/10.1016/s0305-0548(02)00048-5

Basiseisen voor intramurale spoedzorg - Richtlijn - Richtlijnendatabase. (2019). https://richtlijnendatabase.nl/richtlijn/kwaliteitsstandaard_intramurale_spoedzorg/basiseisen.html

Beaumont, N. B. (1997). Using mixed integer programming to design employee rosters. *Journal of the Operational Research Society*, *48*(6), 585–590. https://doi.org/10.1057/palgrave.jors.2600415

Blöchliger, I. (2004). Modeling staff scheduling problems. A tutorial. *European Journal of Operational Research*, *158*(3), 533–542. https://doi.org/10.1016/s0377-2217(03)00387-4

Boucherie, R. J., Braaksma, A., & Tijms, H. C. (2021). *Operations Research: Introduction to Models and Methods*. World Scientific Publishing Company.

Brucker, P., Qu, R., & Burke, E. (2011). Personnel scheduling: Models and complexity. *European Journal of Operational Research*, *210*(3), 467–473. https://doi.org/10.1016/j.ejor.2010.11.017

Code of Ethics for Engineers, National Society of Professional Engineers. (2019) https://www.nspe.org/resources/ethics/code-ethics

Cooper, D. R., & Schindler, P. S. (2013). *Business Research Methods*. McGraw-Hill Education.

Ernst, A. T., Jiang, H., Krishnamoorthy, M., Owens, B., & Sier, D. (2004). An Annotated Bibliography of Personnel Scheduling and Rostering. *Annals of Operations Research*, *127*(1–4), 211-44. https://doi.org/10.1023/b:anor.0000019087.46656.e2

Ernst, A. T., Jiang, H., Krishnamoorthy, M., & Sier, D. (2004). Staff scheduling and rostering: A review of applications, methods, and models. *European Journal of Operational Research*, *153*(1), 3-27. https://doi.org/10.1016/s0377-2217(03)00095-x

Heerkens, H. (2015). *mpsm phase 01*. University of Twente.

https://vimeo.com/showcase/2938606/video/101271073

Heerkens, H. (2015). *validity*. University of Twente. https://vimeo.com/showcase/2938606/video/117885780

Heerkens, H., & van Winden, A. (2017). *Solving Managerial Problems Systematically*. Noordhoff Uitgevers.

Hidri, L., Gazdar, A., & Mabkhot, M. M. (2020). Optimized Procedure to Schedule Physicians in an Intensive Care Unit: A Case Study. *Mathematics*, *8*(11), 1976. https://doi.org/10.3390/math8111976

Joseph, J. J. (2020). Queuing Theory and Modeling Emergency Department Resource Utilization. *Emergency Medicine Clinics of North America*, *38*(3), 563-572. https://doi.org/10.1016/j.emc.2020.04.006

Kendall, D. (1951). "Some Problems in the Theory of Queues," *Journal of the Royal Statistical Society,* Series B, 13:151–185.

KNAW; NFU; NWO; TO2-federatie; Vereniging Hogescholen; VSNU (2018): *Nederlandse gedragscode wetenschappelijke integriteit*. DANS. https://doi.org/10.17026/dans-2cj-nvwu

Kulasiri, D., & Verwoerd, W. S. (2002). Modeling Solute Transport in Porous Media. *Elsevier EBooks*, 1-25. https://doi.org/10.1016/s0167-5931(02)80002-x

Middenin Geboortezorg (2018). Parallelle acties bij obstetrische spoedsituaties in de 1e en 2e lijn. https://middeningeboortezorg.nl/wp-content/uploads/2019/02/Transmuraal-protocolparallelle-acties.pdf

Over MST - Medisch Spectrum Twente. (2022, December 15). Medisch Spectrum Twente. https://www.mst.nl/over-mst/

Ozair, F. F., Jamshed, N., Sharma, A., & Aggarwal, P. (2015). Ethical issues in electronic health records: A general overview. *Perspectives in Clinical Research*, *6*(2), 73. https://doi.org/10.4103/2229-3485.153997

Saunders, M. N. K., Thornhill, A., & Lewis, P. (2019). *Research Methods for Business Students*.

Vass, H., & Szabo, Z. (2015). Application of Queuing Model to Patient Flow in Emergency Department. Case Study. *Procedia. Economics and Finance*, *32*, 479–487. https://doi.org/10.1016/s2212-5671(15)01421-5

Winston, W. L., & Goldberg, J. B. (2004). *Operations Research: Applications and Algorithms*. Brooks/Cole.

Zorginstituut Nederland (2020). Kwaliteitskader Spoedzorgketen: *Landelijke afspraken over de organisatie van en eisen aan de Spoedzorgketen.* https://www.zorginzicht.nl/binaries/content/assets/zorginzicht/kwaliteitsinstrumenten/Kwaliteitskader+Spoedzorgketen.pdf

9 Appendices

9.1 Validity and reliability

According to Cooper and Schindler (2013), validity is the extent to which a test measures what is being wished to be measured and reliability focuses on the accuracy and the precision of a measurement procedure. According to Heerkens (2015), reliability is a part of validity. Reliability focuses on the fact that repeated measurements produce identical results and validity focuses on whether the right thing is measured.

There are three types of validity according to the microlecture about validity of Heerkens (2015): internal validity, construct validity, and external validity. Internal validity is the soundness of the research design, the question that arises within this type of validity is: “Is the research set up in a way that is measured what is intended to be measured?” (Heerkens (2015)). To achieve this type of validity in this thesis, there will be regular meetings with supervisors and other specialists to discuss the progress of the research design. During these meetings, the completeness of the design is discussed to make sure that is measured what is intended to be measured. By making a research design before executing the research, no data will be forgotten during the research. This design should be discussed with supervisors from UT and MST and specialists from MST to make sure everything is included and that is measured what is intended to be measured.

Construct validity concerns the question: “Are the right indicators with the right variables used and are the indicators and variables based on the scientific body of knowledge?” (Heerkens (2015)). To assure this type of validity in this thesis, the indicators and variables should be chosen with care. The indicators and variables should be selected with the use of and based on the scientific body of knowledge. When selecting the indicators and variables, the reason should be underpinned, and these reasons should be discussed with the supervisors to make sure the right indicators and right variables are used. When making use of the scientific body of knowledge, sources should be used that are trustworthy.

External validity is also called generalizability. The question that arises within this type of validity is: “Are the results also valid outside the research population and the particular situation?” (Heerkens (2015)). This type of validity needs to be considered when the mathematical modeling process is executed. Mathematical models are used in various situations and with the use of various populations. The same models can be used in other circumstances, but also for other hospitals and primary care midwife practices the results should be valid. This will be done by generalizing the population and the situation to make the research applicable to other cases. This will be done by making the case applicable to other situations and not only to this specific case by using mathematical models applicable to other situations.

9.2 Requirements Emergency Medical Center

When designing an Emergency Medical Center, there might be some guidelines and requirements. These guidelines and requirements are determined by all the involved parties. All these guidelines and requirements for emergency care are documented in the quality framework for emergency care. This framework is a national quality framework and describes how all healthcare parties must collaborate to always deliver excellent care for the patient. Next to this quality framework, there are also specific procedures for emergency midwifery care. These procedures are for the primary care midwives and the midwives at the hospital. The requirements for the Emergency Medical Center can be translated into constraints for the queuing model when taking the whole hospital into account.

9.2.2 Quality framework

According to Zorginstituut Nederland (2020), there are national agreements about the organization and the requirements for an emergency department. The provided care must be 24/7 of good quality during each of the stages of the process. The stages in the process are the notification of a patient that needs help, triage, care coordination, diagnosis and treatment, and coordination of outflow. The provided care must be patient-focused, safe, effective, timely, efficient, and accessible.

To provide care of good quality, the care should be patient focused. Up-to-date information about the patient should be available, the wishes of the patient should be known, and information during the care needs to be shared with the patient and relatives. The information should be accessible to inform the patient and relatives about the situation. The care needs to be safe as well, the patient should be carefully transferred to other care providers and the patient records should be safely used. To make sure the care is effective, the wishes of the patient should be clear and other care providers should be up to date about the patient. Since the up-to-date information of the patient should be available, the care must be timely and efficient as well.

Good care must be 24/7 provided and during every stage of the process. During the notification that the patient needs help, the patient and the relatives should have 24/7 the possibility to receive support by determining the urgency of the case. The primary care midwife practices and the hospital should collaborate intensively to provide the best possible care as soon as possible after the notification. When the notification is made, the Emergency Medical Center should be 24/7 contactable and available for treatment. While the triage is done, the care providers make 24/7 use of recorded triage systematic, and the care providers are authorized and competent to triage a patient. During care coordination, there should be a possibility to consult a specialist. Also, based on the triage, there should be clarity about what needs to be done and who is needed for this. For the diagnosis and the treatment, 24/7 the right and timely care providers are needed together with the right facilities. The care providers will make use of protocols that serve as guides. During the coordination of the outflow, the patient should be able to go 24/7 home with good care and follow-up care or to go to a (temporarily) stay with good follow-up care.

Because the hospital will be cooperating with the primary care midwives at the Emergency Medical Center, both should use the same way of triaging patients. The care providers that are present at the Emergency Medical Center should have experience and specialists should be available. According to the Richtlijnendatabase (2019), there are some additional guidelines for an Emergency Medical Center. The care providers should be immediately available for triaging a patient. This care provider must have minimal competencies. The time that a patient is in the system should be monitored to give insights into the activities at the Emergency Medical Center. The urgency and the waiting time should be shared with the patient, together with the reason for the urgency and the waiting time. When transmitting the care of a patient to another care provider, this should be done structurally and the tasks that need to be done should be clear.

With the use of the quality framework, some constraints can be determined for the queuing model. Since there should always be a care provider available to give support to the patient and relatives. Also, always a care provider should be available to conduct the triage, and someone should be available for treatment. Next to this, a specialist needs to be available for a care provider to consult. These requirements can serve as constraints within the model for MST, for each of these functions, a care provider must be available.

9.2.3 Procedures acute situations

Next to the general guidelines and requirements for an Emergency Medical Center, there are also guidelines and requirements specifically for midwifery emergency care. According to Middenin Geboortezorg (2018), there are procedures in emergency situations in primary care as well as procedures in emergency situations at the hospital. These are situations in which the level of urgency is very high, sometimes life-threatening. Whenever there is an emergency at a primary care midwife practice, the primary care midwife communicates the Situation, Background, Assessment, and Recommendation (SBAR) to the on-duty gynecologist. The gynecologist informs, based on insight into the situation, the obstetrician, anesthetist, the operating room team, and the pediatrician. The primary care midwife organizes the ride to the hospital, after this, the patient is transferred to the operating room or the delivery room. This process only happens in very acute situations in which the baby or the woman is in danger. This process can be found in Figure 3.2.

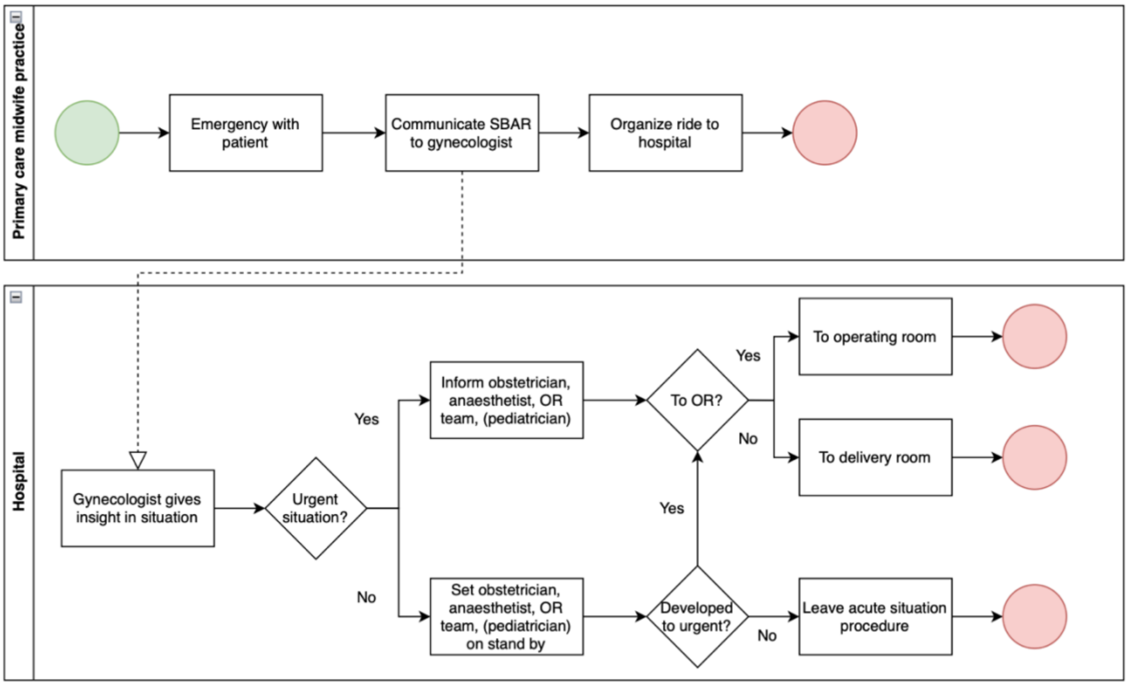

Figure 9.1: Procedure acute situation at primary care midwife practice and hospital

These acute situations also happen at the hospital. This procedure is visualized in Figure 3.3. In this case, the obstetrician informs the gynecologist, and the gynecologist informs the anesthetist, the operating room team, and the pediatrician (whenever the patient has not given birth yet). In which the situation is not very acute yet but there is a high risk, the gynecologist might inform the other care providers to be ready when the situation develops into an acute situation.

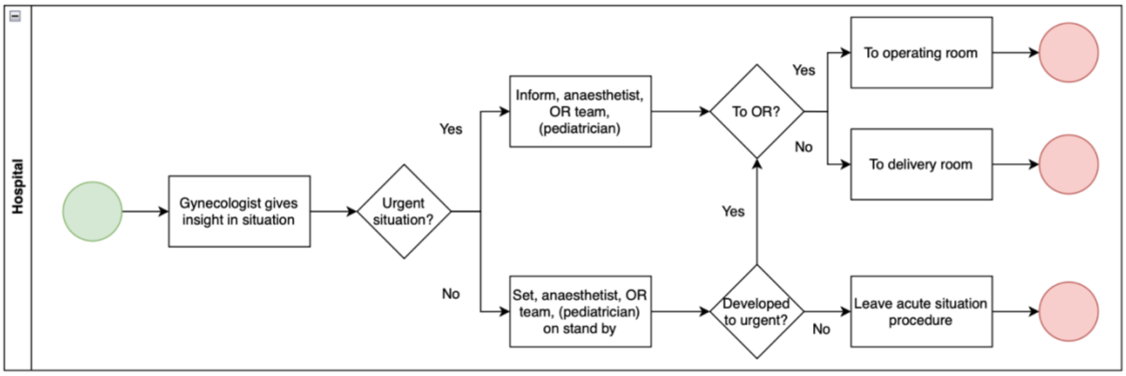

Figure 9.2: Procedure acute situation at the hospital

The procedure in acute situations can be used for the setup of the new Emergency Medical Center when also taking the optimal allocation of care providers of other departments into account. Based on the requirements for an emergency center and the specialists available, the minimum number of available care providers should be used as constraints.

9.3 Output queuing models

Weekdays at the Emergency Medical Center for average arrival rate (per hour)						
	s = 2	s = 3	s = 4	s = 5	s = 6	s = 7
Arrival rate (λ)	1.95	1.95	1.95	1.95	1.95	1.95
Service rate (μ)	1.25	1.25	1.25	1.25	1.25	1.25
Fraction of time a server is busy (ρ)	0.780	0.520	0.390	0.312	0.260	0.223
Fraction of time no patients (π_0)	0.124	0.196	0.208	0.210	0.210	0.210
All servers busy (P(j ≥ s))	0.684	0.259	0.084	0.023	0.006	0.001
Average number of patients in queue (L_q)	2.424	0.280	0.054	0.011	0.002	0.000
Average waiting time per patient (W_q)	1.243	0.144	0.028	0.005	0.001	0.000
Average number of patients in system (L)	3.984	1.840	1.614	1.571	1.562	1.560
Average sojourn time per patient (W)	2.043	0.944	0.828	0.805	0.801	0.800
Average number of patients in service (L_s)	1.560	1.560	1.560	1.560	1.560	1.560
Average time patients in service (W_s)	0.800	0.800	0.800	0.800	0.800	0.800

Table 9.1: Outcome of implementation in queuing system for the weekdays for average arrival rate

Weekend at the Emergency Medical Center for average arrival rate (per hour)				
	s = 4	s = 5	s = 6	s = 7
Arrival rate (λ)	3.65	3.65	3.65	3.65
Service rate (μ)	1.10	1.10	1.10	1.10
Fraction of time a server is busy (ρ)	0.830	0.664	0.553	0.474
Fraction of time no patients (π_0)	0.022	0.032	0.035	0.036
All servers busy (P(j ≥ s))	0.651	0.322	0.146	0.060
Average number of patients in queue (L_q)	3.166	0.636	0.180	0.054
Average waiting time per patient (W_q)	0.868	0.174	0.049	0.015
Average number of patients in system (L)	6.485	3.954	3.498	3.372
Average sojourn time per patient (W)	1.777	1.083	0.958	0.924
Average number of patients in service (L_s)	3.318	3.318	3.318	3.318
Average time patients in service (W_s)	0.909	0.909	0.909	0.909

Table 9.2: Outcome of implementation in queuing system for the weekend for average arrival rate

Weekdays at the Emergency Medical Center for higher arrival rate (per hour)					
	s = 3	s = 4	s = 5	s = 6	s = 7
Arrival rate (λ)	2.64	2.64	2.64	2.64	2.64
Service rate (μ)	1.25	1.25	1.25	1.25	1.25
Fraction of time a server is busy (ρ)	0.704	0.528	0.422	0.352	0.302
Fraction of time no patients (π_0)	0.094	0.115	0.120	0.121	0.121
All servers busy (P(j ≥ s))	0.498	0.203	0.073	0.023	0.006
Average number of patients in queue (L_q)	1.185	0.227	0.053	0.012	0.003
Average waiting time per patient (W_q)	0.449	0.086	0.020	0.005	0.001
Average number of patients in system (L)	3.297	2.339	2.165	2.124	2.115
Average sojourn time per patient (W)	1.249	0.886	0.820	0.805	0.801
Average number of patients in service (L_s)	2.112	2.112	2.112	2.112	2.112
Average time patients in service (W_s)	0.800	0.800	0.800	0.800	0.800

Table 9.3: Outcome of implementation in queuing system for the weekend for higher arrival rate

Weekend at the Emergency Medical Center for higher arrival rate (per hour)			
	s = 5	s = 6	s = 7
Arrival rate (λ)	4.86	4.86	4.86
Service rate (μ)	1.10	1.10	1.10
Fraction of time a server is busy (ρ)	0.884	0.736	0.631
Fraction of time no patients (π_0)	0.006	0.010	0.011
All servers busy (P(j ≥ s))	0.726	0.397	0.202
Average number of patients in queue (L_q)	5.515	1.110	0.346
Average waiting time per patient (W_q)	1.135	0.228	0.071
Average number of patients in system (L)	9.934	5.528	4.764
Average sojourn time per patient (W)	2.044	1.137	0.980
Average number of patients in service (L_s)	4.418	4.418	4.418
Average time patients in service (W_s)	0.909	0.909	0.909

Table 9.4: Outcome of implementation in queuing system for the weekend for higher arrival rate

Shift from 5 PM to 11 PM and from 8 AM to 9 AM for weekdays at the Emergency Medical Center (per hour)					
	s = 3	s = 4	s = 5	s = 6	s = 7
Arrival rate (λ)	3.54	3.54	3.54	3.54	3.54
Service rate (μ)	1.25	1.25	1.25	1.25	1.25
Fraction of time a server is busy (ρ)	0.944	0.708	0.566	0.472	0.405
Fraction of time no patients (π_0)	0.013	0.048	0.056	0.058	0.059
Probability all servers busy (P(j ≥ s))	0.896	0.441	0.197	0.079	0.029
Average number of patients in queue (L_q)	15.105	1.070	0.257	0.071	0.019
Average waiting time per patient (W_q)	4.267	0.302	0.073	0.020	0.005
Average number of patients in system (L)	17.937	3.902	3.089	2.903	2.851
Average sojourn time per patient (W)	5.067	1.102	0.873	0.820	0.805
Average number of patients in service (L_s)	2.832	2.832	2.832	2.832	2.832
Average time patients in service (W_s)	0.800	0.800	0.800	0.800	0.800

Table 9.5: Outcome of implementation in queuing system for the weekdays for shift from 5 PM to 11 PM and from 8 AM to 9 AM

Shift from 11 PM to 8 AM for weekdays at the Emergency Medical Center (per hour)							
	s = 1	s = 2	s = 3	s = 4	s = 5	s = 6	s = 7
Arrival rate (λ)	0.72	0.72	0.72	0.72	0.72	0.72	0.72
Service rate (μ)	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Fraction of time a server is busy (ρ)	0.576	0.288	0.192	0.144	0.115	0.096	0.082
Fraction of time no patients (π_0)	0.424	0.553	0.561	0.562	0.562	0.562	0.562
Probability all servers busy (P(j ≥ s))	0.576	0.129	0.022	0.003	0.000	0.000	0.000
Average number of patients in queue (L_q)	0.782	0.052	0.005	0.001	0.000	0.000	0.000
Average waiting time per patient (W_q)	1.087	0.072	0.007	0.001	0.000	0.000	0.000
Average number of patients in system (L)	1.358	0.628	0.581	0.577	0.576	0.576	0.576
Average sojourn time per patient (W)	1.887	0.872	0.807	0.801	0.800	0.800	0.800
Average number patients in service (L_s)	0.576	0.576	0.576	0.576	0.576	0.576	0.576
Average time patients in service (W_s)	0.800	0.800	0.800	0.800	0.800	0.800	0.800

Table 9.6: Outcome of implementation in queuing system for the weekdays for the shift from 11 PM to 8 AM

Shift from 9 AM to 9 PM for weekend at the Emergency Medical Center (per hour)		
	s = 6	s = 7
Arrival rate (λ)	5.85	5.85
Service rate (μ)	1.10	1.10
Fraction of time a server is busy (ρ)	0.886	0.760
Fraction of time no patients (π_0)	0.003	0.004
Probability all servers busy (P(j ≥ s))	0.708	0.405
Average number of patients in queue (L_q)	5.519	1.282
Average waiting time per patient (W_q)	0.943	0.219
Average number of patients in system (L)	10.837	6.600
Average sojourn time per patient (W)	1.852	1.128
Average number of patients in service (L_s)	5.318	5.318
Average time patients in service (W_s)	0.909	0.909

Table 9.7: Outcome of implementation in queuing system for the weekend for the shift from 9 AM to 9 PM

Shift from 9 PM to 9 AM for weekend at the Emergency Medical Center (per hour)						
	s = 2	s = 3	s = 4	s = 5	s = 6	s = 7
Arrival rate (λ)	1.45	1.45	1.45	1.45	1.45	1.45
Service rate (μ)	1.10	1.10	1.10	1.10	1.10	1.10
Fraction of time a server is busy (ρ)	0.659	0.439	0.330	0.264	0.220	0.188
Fraction of time no patients (π_0)	0.205	0.259	0.266	0.267	0.268	0.268
Probability all servers busy (P(j ≥ s))	0.524	0.176	0.050	0.012	0.002	0.000
Average number of patients in queue (L_q)	1.012	0.138	0.025	0.004	0.001	0.000
Average waiting time per patient (W_q)	0.698	0.095	0.017	0.003	0.000	0.000
Average number of patients in system (L)	2.331	1.456	1.343	1.322	1.319	1.318
Average sojourn time per patient (W)	1.607	1.004	0.926	0.912	0.910	0.909
Average number patients in service (L_s)	1.318	1.318	1.318	1.318	1.318	1.318
Average time patients in service (W_s)	0.909	0.909	0.909	0.909	0.909	0.909

Table 9.8: Outcome of implementation in queuing system for the weekend for the shift from 9 PM to 9 AM

Average waiting time per patient for the shift from 5 PM to 11 PM and from 8 AM to 9 AM for weekdays at the Emergency Medical Center (per hour)					
	s = 3	s = 4	s = 5	s = 6	s = 7
Average waiting time per patient with urgency 1 (W_{q1})	0.265	0.097	0.034	0.011	0.004
Average waiting time per patient with urgency 2 (W_{q2})	0.370	0.123	0.041	0.013	0.004
Average waiting time per patient with urgency 3 (W_{q3})	0.696	0.187	0.056	0.017	0.005
Average waiting time per patient with urgency 4 (W_{q4})	2.039	0.340	0.085	0.023	0.007
Average waiting time per patient with urgency 5 (W_{q5})	17.507	0.711	0.135	0.032	0.009

Table 9.9: Average waiting time per patient for the different urgencies for the weekdays for the shift from 5 PM to 11 PM and from 8 AM to 9 AM

Average waiting time per patient for the shift from 11 PM to 8 AM for weekdays at the Emergency Medical Center (per hour)						
	s = 2	s = 3	s = 4	s = 5	s = 6	s = 7
Average waiting time per patient with urgency 1 (W_{q1})	0.054	0.005	0.000	0.000	0.000	0.000
Average waiting time per patient with urgency 2 (W_{q2})	0.059	0.006	0.000	0.000	0.000	0.000
Average waiting time per patient with urgency 3 (W_{q3})	0.068	0.006	0.000	0.000	0.000	0.000
Average waiting time per patient with urgency 4 (W_{q4})	0.080	0.007	0.000	0.000	0.000	0.000
Average waiting time per patient with urgency 5 (W_{q5})	0.095	0.008	0.000	0.000	0.000	0.000

Table 9.10: Average waiting time per patient for the different urgencies for the weekdays for the shift from 11 PM to 8 AM

Average waiting time per patient for the shift from 9 AM to 9 PM for weekend at the Emergency Medical Center (per hour)		
	s = 6	s = 7
Average waiting time per patient with urgency 1 (W_{q1})	0.120	0.058
Average waiting time per patient with urgency 2 (W_{q2})	0.163	0.075
Average waiting time per patient with urgency 3 (W_{q3})	0.290	0.118
Average waiting time per patient with urgency 4 (W_{q4})	0.732	0.233
Average waiting time per patient with urgency 5 (W_{q5})	3.300	0.565

Table 9.11: Average waiting time per patient for the different urgencies for the weekend for the shift from 9 AM to 9 PM

Average waiting time per patient for the shift from 9 PM to 9 AM for the weekend at the Emergency Medical Center (per hour)						
	s = 2	s = 3	s = 4	s = 5	s = 6	s = 7
Average waiting time per patient with urgency 1 (W_{q1})	0.253	0.057	0.014	0.002	0.000	0.000
Average waiting time per patient with urgency 2 (W_{q2})	0.315	0.066	0.016	0.002	0.000	0.000
Average waiting time per patient with urgency 3 (W_{q3})	0.462	0.083	0.018	0.002	0.000	0.000
Average waiting time per patient with urgency 4 (W_{q4})	0.784	0.111	0.023	0.003	0.000	0.000
Average waiting time per patient with urgency 5 (W_{q5})	1.467	0.150	0.028	0.003	0.000	0.000

Table 9.12: Average waiting time per patient for the different urgencies for the weekend for the shift from 9 PM to 9 AM

9.4 Value of $P(j \geq s)$

ρ	$s = 2$	$s = 3$	$s = 4$	$s = 5$	$s = 6$	$s = 7$
.10	.02	.00	.00	.00	.00	.00
.20	.07	.02	.00	.00	.00	.00
.30	.14	.07	.04	.02	.01	.00
.40	.23	.14	.09	.06	.04	.03
.50	.33	.24	.17	.13	.10	.08
.55	.39	.29	.23	.18	.14	.11
.60	.45	.35	.29	.24	.20	.17
.65	.51	.42	.35	.30	.26	.21
.70	.57	.51	.43	.38	.34	.30
.75	.64	.57	.51	.46	.42	.39
.80	.71	.65	.60	.55	.52	.49
.85	.78	.73	.69	.65	.62	.60
.90	.85	.83	.79	.76	.74	.72
.95	.92	.91	.89	.88	.87	.85

Figure 9.3: Value of $P(j \geq s)$ for the $M_i/M/NPRP/\infty/\infty$queuing model (Winston and Goldberg (2004))